

Mobile Source Climate Change Emission Reduction Technologies

Sacramento, California
April 20, 2004

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International Vehicle Technology Symposium

- International experts on vehicle climate change emission reduction technologies participated
- Numerous technology areas were covered
 - engine and drivetrain modifications
 - alternatives to reduce methane and nitrous oxide emissions
 - modifications to air conditioning systems
 - alternative fuel vehicles

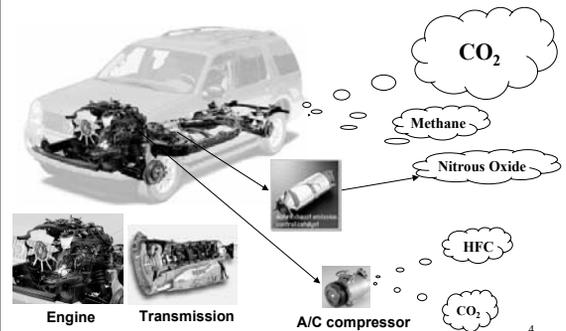
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ARB Technical Review

- Staff investigated technologies that can reduce greenhouse gas emissions from motor vehicles in 2009 and beyond
- Greenhouse gases include:
 - carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and hydroflouorocarbons (HFC143a)
- Relied primarily on comprehensive technical study initiated by the Northeast States Center for a Clean Air Future (NESCCAF)

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Technology Evaluation

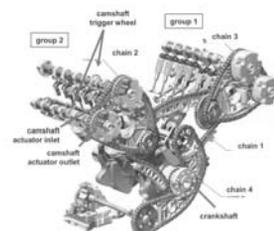


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Near Term Technologies 2009-2012

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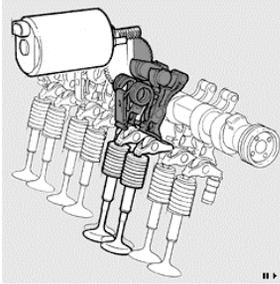
Gasoline Direct Injection Engine w/ Dual Cam Phasers



Audi

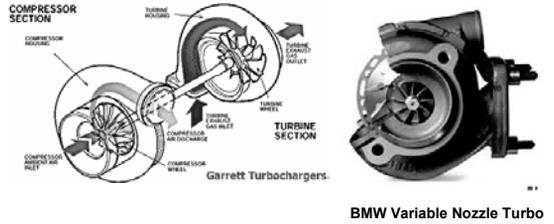
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BMW Valvetronic (continuous variable valve lift)



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Turbocharger



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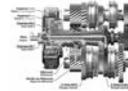
Cylinder Deactivation



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Transmissions

6-speed automatic transmission
Lighter, smaller, better performance than
5-speed transmissions.



Automated manual transmission



Continuously variable transmission



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Small Car (Near Term - 2009)

Small Car	Combined Technology Packages	CO ₂ (gpm)	Potential CO ₂ reduction from 2002 baseline	Retail Price Equivalent 2002	Potential CO ₂ reduction from 2009 baseline	Retail Price Equivalent 2009
Near Term 2009-2012	DVVL, DCP, AS (2009 baseline)	284	-2.6%	\$308	0%	\$0
	DCP, CVT, EPS, ImpAlt	270	-7.6%	\$270	-5.1%	\$252
	DCP, AA, EPS, ImpAlt	269	-7.6%	\$360	-5.2%	\$52
	DCP, AA, EPS, ImpAlt	260	-10.7%	\$392	-4.4%	\$186
	DCP, AA	260	-10.8%	\$346	-8.4%	\$59
Mid Term 2013-2015	DVVL, DCP, AMT, EPS, ImpAlt	233	-19.9%	\$465	-17.8%	\$157
	GDI, S, DCP, Turbo, AMT, EPS, ImpAlt	215	-26.4%	\$1128	-24.4%	\$820
	2009 Baseline, DCP, AMT, EPS, ImpAlt	229	-21.6%	\$673	-24.1%	\$355
Long Term 2015+	ModHEV	213	-26.9%	\$1937	-25.0%	\$1629
	HydHEV	147	-49.5%	\$5117	-48.2%	\$4809
	AdvHEV	138	-52.6%	\$3017	-51.4%	\$2709

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Near Term Technologies Small Car

- **Small Car - top two packages**
 - Gasoline direct injection-stoichiometric, dual cam phasers, turbo, 6-speed automated manual transmission, electric power steering, improved alternator
 - 24.4% CO₂ reduction - \$820 retail price increase
 - Discrete variable valve lift, dual cam phasers, 6-speed automated manual transmission, electric power steering, improved alternator
 - 17.8% CO₂ reduction - \$157 retail price increase

Note: Reductions relative to 2009 baseline 12

Large Car (Near term - 2009)

Large Car	Combined Technology Packages	CO ₂ (gmi)	Potential CO ₂ reduction from 2002 baseline	Retail Price Equivalent 2002	Potential CO ₂ reduction from 2009 baseline	Retail Price Equivalent 2009
Near Term 2009-2012	DVWL,DCP,A6 (2009 baseline)	322	-6.6%	\$427	0%	\$0
	DCP,A6	304	-11.5%	\$476	5.0%	\$50
	DCP,DV,EP,ImpAlt	303	-12.1%	\$378	-5.0%	-\$25
	DVWL,DCP,A6	298	-15.8%	\$554	-10.0%	-\$43
	DCP,DeAct,A6	279	-19.2%	\$320	-13.5%	-\$74
	DVWL,DCP,A6,EP,ImpAlt	285	-23.2%	\$873	-17.8%	-\$446
	GDI-S,DeAct,DCP,AMT,EP,ImpAlt	265	-23.2%	\$931	-17.8%	-\$554
	GDI-S,DCP,Turbo,AMT,EP,ImpAlt	291	27.2%	\$369	22.1%	-\$58
	DVWL,DCP,AMT,EP,ImpAlt	272	-27.0%	\$350	-15.8%	-\$44
	DVWL,DCP,AMT,EP,ImpAlt	262	-30.6%	\$776	-19.4%	-\$124
Mid Term 2013-2015	dVWL,AMT,EP,ImpAlt	230	-27.4%	\$920	-22.2%	-\$552
	dVWL,GDI-S,AMT,EP,ImpAlt	242	-29.0%	\$1188	-24.9%	-\$751
	dVWL,DVWL,DCP,AMT,EP,ImpAlt	231	-32.9%	\$1796	-28.2%	-\$1369
	EP,ImpAlt	224	-35.1%	\$1196	-30.5%	-\$789
Long Term 2015+	dVWL,AMT,EP,ImpAlt	277	-18.7%	\$1978	-14.0%	-\$1551
	AMT,EP,ImpAlt	236	-27.0%	\$218	-21.3%	-\$168
	AMT,EP,ImpAlt	183	-50.6%	\$3503	-48.3%	-\$3075
	HSD,AMT,EP,ImpAlt	197	-54.4%	\$4728	-51.1%	-\$4301

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Near Term Technologies Large Car

- Top three packages
 - Gasoline direct injection-stoichiometric, dual cam phasers, turbo, 6-speed automated manual transmission, electric power steering, improved alternator
 - 22.1% CO₂ reduction - \$58 retail price savings
 - Gasoline direct injection stoichiometric, cylinder deactivation, dual cam phasers, 6-speed automated manual transmission, electric power steering, improved alternator
 - 17.8% CO₂ reduction - \$504 retail price increase
 - Continuous variable valve lift, dual cam phasers, 6-speed automated manual transmission, electric power steering, improved alternator
 - 17.8% CO₂ reduction - \$446 retail price increase

Note: Reductions relative to 2009 baseline 14

Large Truck/SUV (Near Term - 2009)

Large Truck	Combined Technology Packages	CO ₂ (gmi)	Potential CO ₂ reduction from 2002 baseline	Retail Price Equivalent 2002	Potential CO ₂ reduction from 2009 baseline	Retail Price Equivalent 2009
Near Term 2009-2012	CCP,A6 (2009 baseline)	484	-5.5%	\$128	0%	\$0
	DVWL,DCP,A6	442	-10.8%	\$349	-8.0%	-\$42
	CCP,DeAct,A6	433	-15.4%	\$550	-7.0%	-\$42
	DCP,DeAct,A6	430	-15.9%	\$916	-11.0%	-\$790
	DeAct,DVWL,CCP,A6,EHP S,ImpAlt	418	-18.4%	\$779	-13.6%	-\$653
	DeAct,DVWL,CCP,AMT,EHP S,ImpAlt	396	-22.6%	\$667	-18.1%	-\$541
Mid Term 2013-2015	CCP,DeAct,IMP,S,AMT,EP,ImpAlt	316	-18.9%	\$872	-13.9%	-\$740
	DeAct,DVWL,CCP,A6,ISG,EP,ImpAlt	378	-26.2%	\$1710	-21.9%	-\$1584
	dVWL,GDI-S,AMT,EHP S,ImpAlt	381	-25.5%	\$1684	-21.2%	-\$1558
Long Term 2015+	GDI-L,AMT,EHP S,ImpAlt	354	-30.7%	\$1901	-26.7%	-\$1775
	Mod HEV	372	-27.3%	\$2340	-23.1%	-\$2214
	dVWL,AMT,ISG,EP,ImpAlt	362	-29.3%	\$2031	-25.2%	-\$2005
	GDI-L,AMT,ISG,EP,ImpAlt	354	-30.7%	\$2800	-26.7%	-\$2674
	HSD,AMT,EP,ImpAlt	244	-52.2%	\$4821	-49.0%	-\$4695
	AMT,EP,ImpAlt	241	-52.9%	\$4091	-50.2%	-\$3965

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Near Term Technologies Large Truck/SUV

- Top two packages
 - Cylinder deactivation, discrete variable valve lift, coupled cam phasers, 6-speed automated manual transmission, electro-hydraulic power steering, improved alternator
 - 18.1% CO₂ reduction - \$541 retail price increase
 - Cylinder deactivation, discrete variable valve lift, coupled cam phasers, 6-speed automatic transmission, electro-hydraulic power steering, improved alternator
 - 13.6% CO₂ reduction - \$653 retail price increase

Note: Reductions relative to 2009 baseline 16

Key Findings--Near Term

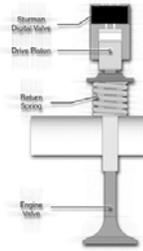
- At least one off-the-shelf or near term package in each vehicle class gives
 - CO₂ reductions of 14-24 percent compared to 2009 baseline
 - Savings of ~\$60 to retail price increase of \$800
 - Payback 0-5 years
- Best packages generally include
 - Turbochargers w/ engine downsize
 - Variable valve timing
 - Improved transmissions
 - Improved electric accessories
 - Cylinder deactivation

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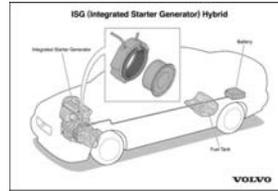
Mid Term Technologies 2013-2015

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Electro-hydraulic Camless Valve Actuation



42v Integrated Starter/Generator



Provides stop/start capability and some motor assist



Substantial CO₂ reductions at modest cost

Diesel Engine



Small Car (Mid Term - 2013)

Small Car	Combined Technology Packages	CO ₂ (g/mi)	Potential CO ₂ reduction from 2002 baseline	Retail Price Equivalent 2002	Potential CO ₂ reduction from 2009 baseline	Retail Price Equivalent 2009
Near Term 2009-2012	DVVL,DCP,AS (2009 baseline)	284	-2.6%	\$308	0%	\$0
	DCP,CVT,EP5,ImpAlt	270	-7.6%	\$376	-8.1%	\$262
	DCP,AS,EP5,ImpAlt	269	-7.6%	\$360	-5.2%	\$52
	DCP,AS,EP5,ImpAlt	260	-10.7%	\$454	-8.3%	\$186
	DCP,AS	260	-10.8%	\$346	-8.4%	\$38
	DVVL,DCP,AMT,EP5,ImpAlt	253	-19.9%	\$465	-17.8%	\$157
	GDI,S,DCP,Turbo,AMT,EP5,ImpAlt	215	-28.4%	\$1726	-24.4%	\$820
	gHCi, DVVL, ICP, AMT, EP5, ImpAlt	229	-21.6%	\$673	-19.5%	\$365
	CVVL,DCP,AMT,ISG-SS,EP5, ImpAlt	216	-25.7%	\$1387	-23.8%	\$1079
	gHCi, DVVL, ICP, AMT, ISG, EP5, aACC	204	-29.9%	\$1570	-28.1%	\$1262
Mid Term 2013-2015	gHCi, DVVL, ICP, AMT, EP5, aACC	217	-25.5%	\$2536	-23.8%	\$2228
	ModHyV	244	-26.6%	\$1997	-25.0%	\$1629
	HSD,AdmHyV	147	-49.5%	\$5117	-48.2%	\$4809
Long Term 2015	AdmHyV	138	-52.6%	\$3017	-51.4%	\$2709

Mid Term Technologies Small Car

- **Small Car - top three packages**
 - Gasoline homogeneous charge compression ignition, discrete variable valve lift, intake cam phaser, 6-speed automated manual transmission, integrated starter generator, electric power steering, electric accessories
 - 28.1% CO₂ reduction - \$1262 retail price increase
 - Continuous variable valve lift, dual cam phasers, 6-speed automated manual transmission, integrated starter generator - start/stop, electric power steering, improved alternator
 - 23.8% CO₂ reduction - \$1079 retail price increase
 - Gasoline homogeneous charge compression ignition, discrete variable valve lift, intake cam phaser, 6-speed automated manual transmission, electric power steering, improved alternator
 - 19.5% CO₂ reduction - \$365 retail price increase

Note: Reductions relative to 2009 baseline 23

Large Car (Mid Term - 2013)

Large Car	Combined Technology Packages	CO ₂ (g/mi)	Potential CO ₂ reduction from 2002 baseline	Retail Price Equivalent 2002	Potential CO ₂ reduction from 2009 baseline	Retail Price Equivalent 2009
Near Term 2009-2012	DVVL,DCP,AS (2009 baseline)	322	-8.6%	\$427	0%	\$0
	DCP,AS	304	-11.5%	\$478	-6.6%	\$52
	DCP,CVT,EP5,ImpAlt	303	-12.1%	\$708	-6.0%	\$281
	CVVL,DCP,AS	290	-15.0%	\$684	-10.0%	\$437
	DCP,Turbo,AS	289	-16.0%	\$662	-11.0%	\$235
	DCP,Turbo,AS,EP5,ImpAlt	279	-19.2%	\$266	-13.5%	\$161
	CVVL,DCP,AMT,EP5,ImpAlt	265	-23.2%	\$673	-17.8%	\$446
	GDI,S,DCP,DCP,AMT,EP5,ImpAlt	265	-23.2%	\$691	-17.8%	\$564
	GDI,S,DCP,Turbo,AMT,EP5,ImpAlt	251	-27.2%	\$390	-22.1%	\$55
	gHCi, DVVL, ICP, AMT, EP5, ImpAlt	272	-21.0%	\$880	-15.2%	\$451
gHCi, DVVL, ICP, AMT, EP5, aACC	266	-24.2%	\$1220	-19.4%	\$1094	
Mid Term 2013-2015	gHCi, DVVL, ICP, AMT, EP5, ImpAlt	250	-27.4%	\$698	-22.2%	\$502
	gHCi, DVVL, ICP, AMT, ISG, EP5, aACC	242	-29.9%	\$1188	-24.9%	\$781
	gHCi, DVVL, ICP, AMT, ISG, EP5, aACC	231	-32.9%	\$1796	-28.2%	\$1369
Long Term 2015	gHCi, DVVL, ICP, AMT, ISG, EP5, aACC	224	-35.1%	\$1196	-30.5%	\$789
	ModHyV	277	-19.1%	\$1970	-14.0%	\$1447
	AdmHyV	163	-52.6%	\$3503	-49.3%	\$3076
HSD,AdmHyV	127	-54.4%	\$4228	-51.1%	\$4831	

Mid Term Technologies Large Car

- Top three packages
 - Gasoline direct injection-stoichiometric, dual cam phasers, turbo, 6-speed automatic transmission, integrated starter generator, electric power steering, electric accessories
 - 30.5% CO₂ reduction - \$769 retail price increase
 - Gasoline homogeneous charge compression ignition, discrete variable valve lift, intake cam phasers, 6-speed automated manual transmission, integrated starter generator, electric power steering, electric accessories
 - 28.2% CO₂ reduction - \$1369 retail price increase
 - Electro-hydraulic camless valve actuation, gasoline direct injection-stoichiometric, 6-speed automated manual transmission, electric power steering, improved alternator
 - 24.9% CO₂ reduction - \$761 retail price increase

Note: Reductions relative to 2009 baseline 25

Small Truck/SUV (Mid Term - 2013)

Small Truck	Combined Technology Packages	CO ₂ (g/mi)	Potential CO ₂ reduction from 2002 baseline	Retail Price Equivalent 2002	Potential CO ₂ reduction from 2009 baseline	Retail Price Equivalent 2009
Near Term 2009-2012	DVWL,DCP,AB (2009 baseline)	404	-9.0%	\$427	0%	\$0
	DCP,AB	379	-14.7%	\$479	-6.3%	\$52
	DCP,AB,Turbo,ImpAlt	371	-16.7%	\$283	-8.4%	\$144
	DCP,AB,DeAct	366	-17.7%	\$656	-9.5%	\$229
	GDI,S,DCP,DeAct,AMT,EPS,ImpAlt	334	-24.9%	\$928	-17.5%	\$501
Mid Term 2013-2015	DhCCL,AMT,EPS,ImpAlt	330	-28.2%	\$736	-18.9%	\$309
	GDI,S,DCP,Turbo,AMT,EPS,ImpAlt,DCP,OS	318	-30.4%	\$367	-21.3%	\$60
Long Term 2015+	DeAct,DVWL,CCP,AB,ISG,EPS,eACC	316	-29.0%	\$1757	-22.0%	\$1330
	ehCVA,GDI,S,AMT,EPS,ImpAlt	309	-30.5%	\$1186	-23.6%	\$759
	ISD,AMT,EPS,ImpAlt	307	-31.0%	\$1565	-24.2%	\$1158
Long Term 2015+	dhCCL,AMT,EPS,ImpAlt	295	-33.9%	\$912	-18.3%	\$485
	Mid HEV	225	-47.0%	\$2071	-19.7%	\$1644
	Adv HEV	210	-52.7%	\$3375	-48.0%	\$2948

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Mid Term Technologies Small Truck/SUV

- Top three packages
 - Diesel high speed direct injection, automated manual transmission, electric power steering, improved alternator
 - 24.2% CO₂ reduction - \$1158 retail price increase
 - Electro-hydraulic camless valve actuation, gasoline direct injection - stoichiometric, automated manual transmission, electric power steering, improved alternator
 - 23.6% CO₂ reduction - \$759 retail price increase
 - Cylinder deactivation, discrete variable valve lift, coupled cam phaser, 6-speed automatic transmission, integrated starter generator, electric power steering, electric accessories
 - 22.0% CO₂ reduction - \$1330 retail price increase

Note: Reductions relative to 2009 baseline 27

Large Truck/SUV (Mid Term - 2013)

Large Truck	Combined Technology Packages	CO ₂ (g/mi)	Potential CO ₂ reduction from 2002 baseline	Retail Price Equivalent 2002	Potential CO ₂ reduction from 2009 baseline	Retail Price Equivalent 2009
Near Term 2009-2012	CCP,AB (2009 baseline)	484	-5.5%	\$126	0%	\$0
	DVWL,DCP,AB	442	-13.6%	\$549	-8.6%	\$423
	CCP,DeAct,AB	433	-15.4%	\$550	-10.5%	\$424
	DCP,DeAct,AB	430	-15.9%	\$516	-11.0%	\$790
	DeAct,DVWL,CCP,AB,EHPS,ImpAlt	418	-18.4%	\$779	-13.0%	\$653
Mid Term 2013-2015	DeAct,DVWL,CCP,AMT,EHPS,ImpAlt	396	-22.6%	\$697	-16.1%	\$541
	CCP,DeAct,ISG,S,AMT,EHPS,ImpAlt	410	-18.6%	\$972	-14.0%	\$246
Long Term 2015+	DeAct,DVWL,CCP,AB,ISG,EHPS,eACC	378	-26.2%	\$1710	-21.9%	\$1584
	ehCVA,GDI,S,AMT,EHPS,ImpAlt	381	-25.5%	\$1684	-21.2%	\$1558
	GDH,AMT,EHPS,ImpAlt	354	-30.7%	\$1901	-26.7%	\$1775
Long Term 2015+	Mid HEV	372	-27.3%	\$2349	-23.1%	\$2214
	dhCCL,AMT,ISG,EPS,eACC	362	-29.3%	\$2031	-25.2%	\$2205
	GDH,AMT,ISG,EPS,ImpAlt	354	-30.7%	\$2800	-26.7%	\$2674
	HSD,AdvHEV	244	-52.2%	\$6821	-49.8%	\$6695
Adv HEV	241	-53.9%	\$4991	-50.2%	\$3995	

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Mid Term Technologies Large Truck/SUV

- Top two packages
 - Cylinder deactivation, discrete variable valve lift, coupled cam phasers, 6-speed automatic transmission, integrated starter generator, electro-hydraulic power steering, electric accessories
 - 21.9% CO₂ reduction - \$1584 retail price increase
 - Electro-hydraulic camless valve actuation, gasoline direct injection stoichiometric, 6-speed automated manual transmission, electro-hydraulic power steering, improved alternator
 - 21.2% CO₂ reduction - \$1558 retail price increase

Note: Reductions relative to 2009 baseline 29

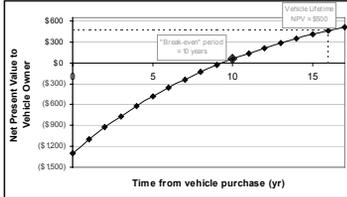
Key Findings--Mid Term

- Substantially larger CO₂ reductions possible
 - Up to 30 percent reduction from 2009 baseline
 - Retail price increase: Typically \$400 to <\$1600
 - Payback 3-7 years
- Promising technologies
 - Gasoline direct injection
 - Camless valve actuation
 - 42 volt ISG
 - Improved transmissions

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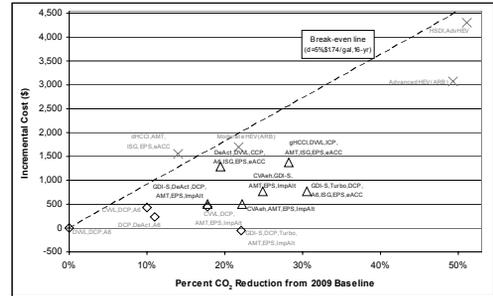
Lifetime Cost to Consumer (Example for Large Car)

- Technology package: Cylinder deactivation, discrete variable valve lift, coupled cam phasing, 6-speed automatic transmission, integrated starter-generator, electric power steering, electric power steering
- Initial cost from 2009 baseline: \$1294
- CO₂ emission reduction from 2009 baseline: 19.4%



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Break-even to Consumer (Large Car)



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Cost Assessment

Selected Near-term Results for Cars and Large Trucks

Vehicle Class	Technology Packages	CO ₂ emissions (g/mi)	CO ₂ change from 2009 baseline	Lifetime CO ₂ reduced from 2009 baseline (ton)	Lifetime Net Present Value to Consumer (2004\$)	Payback period (yr)	Cost Effectiveness (\$/ton)
Small Car	GDI-S, DCP, Turbo, AMT, EPS, ImpAlt	215	-24.4%	15.4	1,133	5	53
	DVVL, DCP, AMT, EPS, ImpAlt	233	-17.8%	11.3	1,267	2	14
Large Car	GDI-S, DCP, Turbo, AMT, EPS, ImpAlt	251	-22.1%	15.8	2,060	0	0
	GDI-S, DeAct, DCP, AMT, EPS, ImpAlt	265	-17.8%	12.8	1,111	4	39
	DVVL, DCP, AMT, EPS, ImpAlt	265	-17.8%	12.7	1,166	3	35
Large Truck	DeAct, DVVL, CCP, AMT, EHPS, ImpAlt	396	-18.1%	21.6	2,106	3	25
	DeAct, DVVL, CCP, A6, EHPS, ImpAlt	418	-13.6%	16.2	1,340	4	40

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Summary

- Multiple technology packages to reduce vehicle greenhouse gases have been identified
- These packages have been modeled to determine their potential to reduce greenhouse gases
- Modeling properly accounted for the impact of combining technologies on a vehicle
- The majority of technologies modeled are cost-effective - some provide consumer savings
- Manufacturers have a menu of technologies to choose from
- Significant cost-effective climate change emission reductions are possible in 2009
 - greater reductions possible later

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