Costo de la Tecnología para el Control de Emisiones en Vehículos Ligeros y OBD

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Mexico, DF
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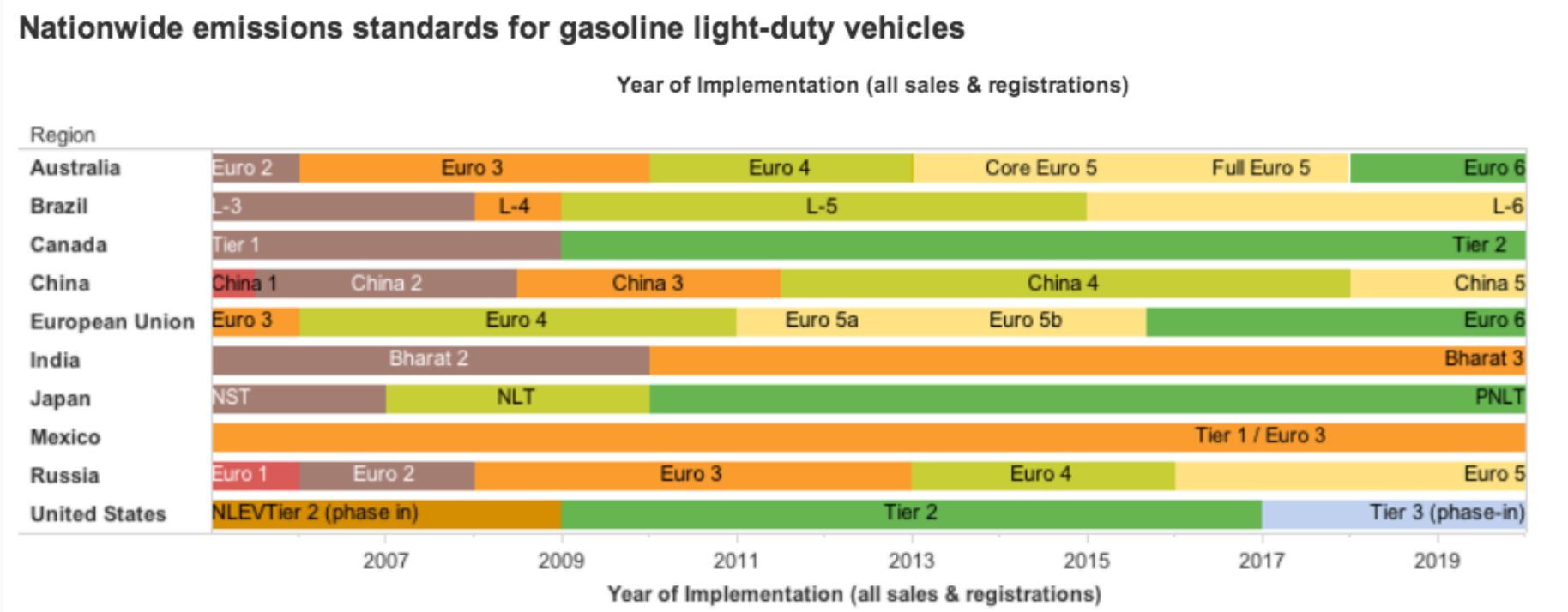
Por que hablamos de costos:



- Es un elemento muy importante durante los procesos de negociación de nuevos estándares de emisiones
  - **Requerida para hacer análisis de costo/beneficio**
- Los estándares son adoptados inicialmente en Europa, Japón y los EUA, para luego migrar a otros países.
- Los costos se reducen con el tiempo: las estimaciones que se hicieron en EUA y Europa muy probablemente son mas bajas hoy

Las estimaciones originales requieren actualización dado que la tecnología evoluciona

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Baseline Data

- Baseline technology: RIAs
- Baseline costs: RIAs

Updated Data

- Corrected baseline technology application and evolution (e.g. PGM content)
- Corrected baseline costs: CPI and technology changes (e.g. PGM prices)

New Data

- SAE and other technical papers
- FE/GHG rules 2012-16 and 2017-25
- Adjsuted price tag from Autopart retailers

Review and Consolidation

- Expert review
- Cost comparisons

Final Technology by regulatory level and costs

PAPER # 2013-01-0534/0539

Emission Control Technologies

- Gasoline and Diesel combustion is different

Gasoline	Diesel
Fuel is injected either outside the cylinder (PFI) or inside (GDI)*	Fuel in injected inside the cylinder (high pressure0
Gasoline evaporates and mix easily with air	Diesel evaporation and mixing demands special T, P conditions
Air/Fuel ratio close to stoichiometric conditions (for TWC operation)	Air/Fuel ratio is mostly lean (excess air; impacts NOx control
Ignition occurs due to spark	Ignition occurs due to high temperature during compression

Tecnologías para vehículos a gasolina

En el Cilindro	Post-tratamiento

• Control de la relacion Aire-Combustible
  • Fuel injection (MPFI, GDI)
  • O_2 sensor (O2S, HO2S, UEGO)
• Geometria (I&D)
  • Reduce crevices
  • Intake ports
  • Posicionamiento de la bujia
• EGR
	• **Catalizador de tres vías (Three-Way Catalyst - TWC)**
	  • NOx, HC, CO
	• **Filtros de partículas**
	  • PM/PN no es un problema en motores PFI
	  • PN es un tema importante para vehículos **GDI** y puede que requiera de un GPF para estandard Euro 6

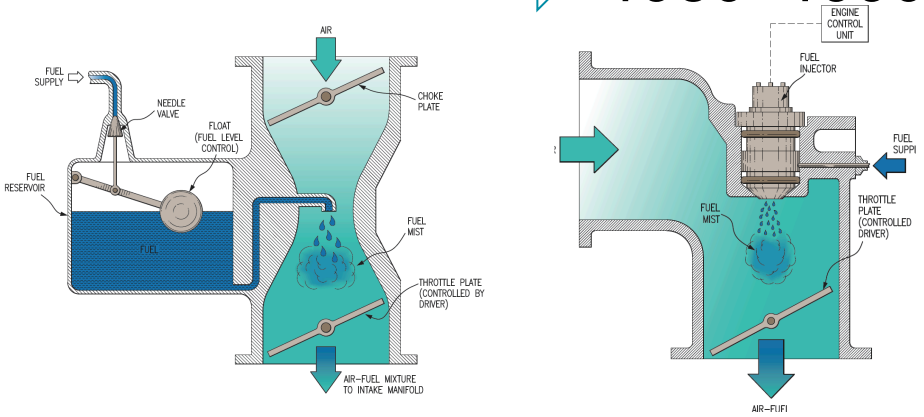
Emission Control Technologies

- Gasoline

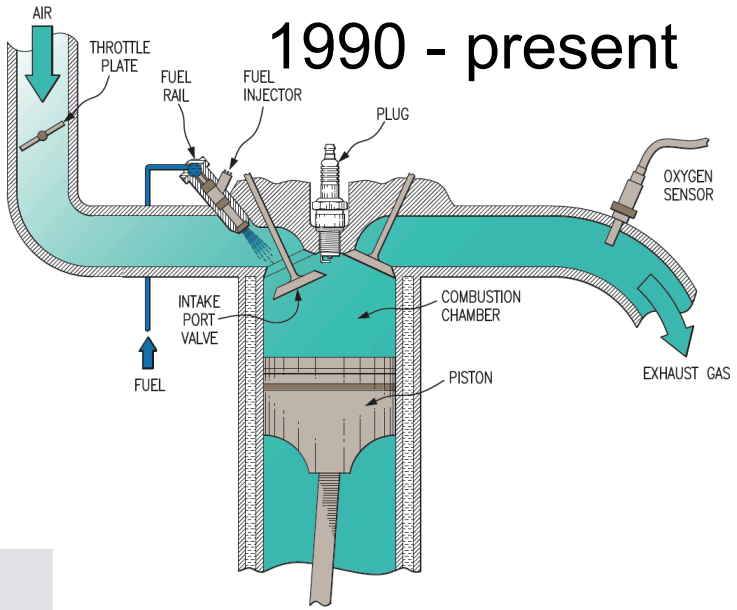
In-cylinder

- Air-Fuel ratio control
  - Fuel injection (**TBI or MPI**)
  - **O_2 sensor** (O2S, HO2S, UEGO)
- Geometry
  - Reduce crevices
  - Intake ports
  - Spark plug position
- **EGR**

1910~1980 ⇨ 1980~1990



1990 - present



Emission Control Technologies

- Gasoline

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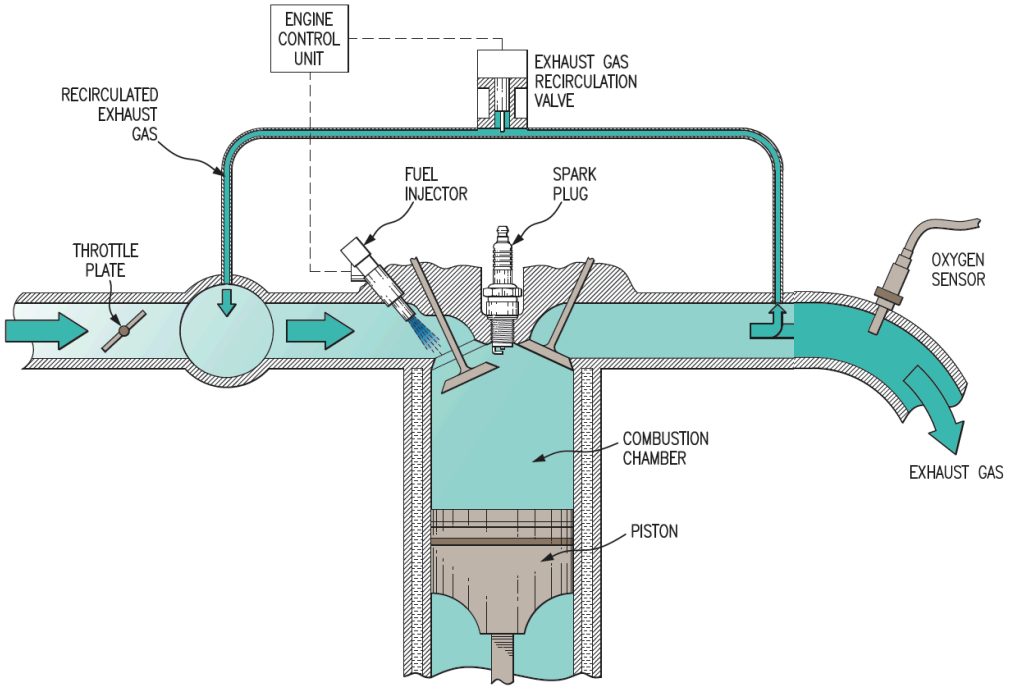
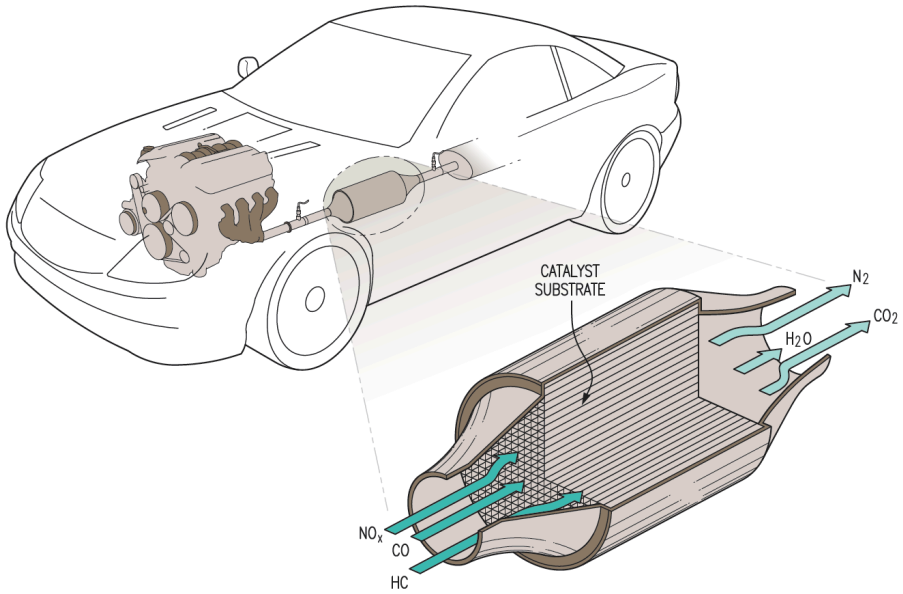


Emission Control Technologies

- Gasoline



Aftertreatment

- **Three-Way Catalyst (TWC)**
  - NOx, HC, CO
- PM generally not an issue with port injected, but it is on GDI. **Gasoline Particulate Filters (GPF)**

Emission Control Technologies

- Diesel

In-cylinder	Aftertreatment

• Air-fuel management syst.
  • Rotary pump, Common-rail
  • Direct or Indirect Inj.
  • Low or High pressure
  • Turbocharging with intercooling
  • Variable geometry turbo (VGT)
  • Variable valve timing (VVT)
• Geometry
  • Nozzle (sac vol., #holes, etc)
  • Comb. chamber
• EGR system -NOx Control
  • Mechanic or Electronic
  • Cooled or not
	• Diesel Oxidation Catalyst (DOC)
	  • CO (90%), HC (70%)
	  • SOF fraction of PM (10-50%)
	• Diesel Particulate Filter (DPF)
	  • PM (95%)
	  • PN
	• Lean NOx Trap (LNT)
	  • NOx (70-90%)
	  • Require ULSD
	• Selective Catalytic Reduction (SCR)
	  • NOx (95%)

Emission Control Technologies

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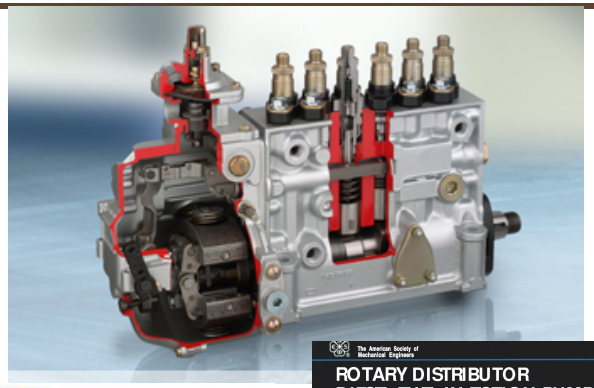
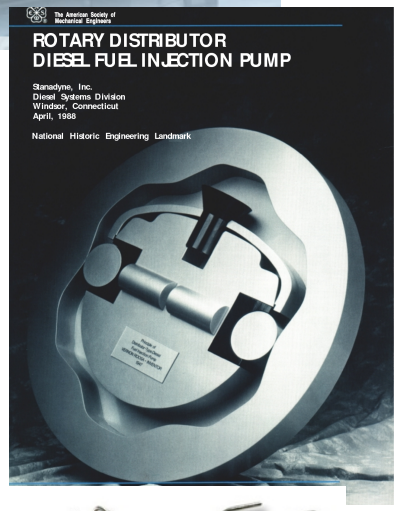
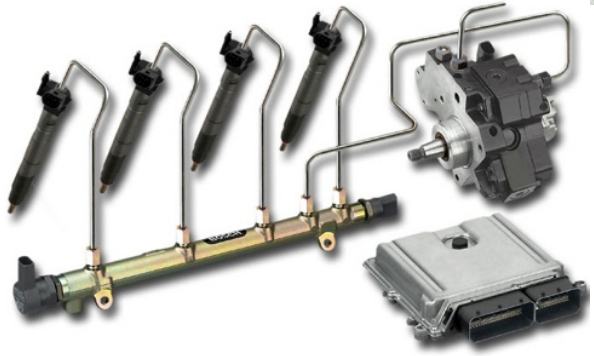


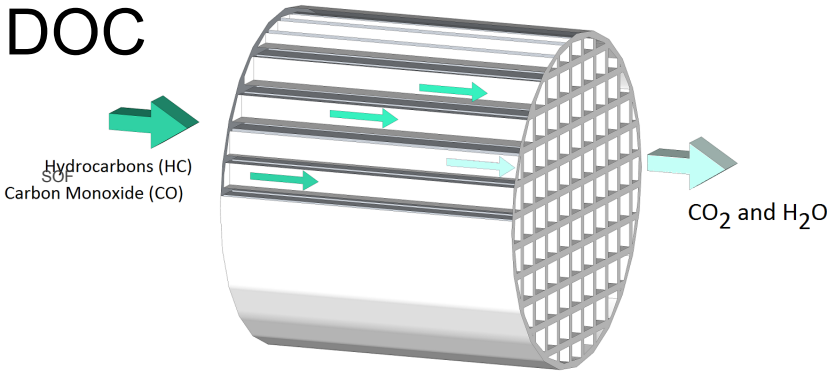




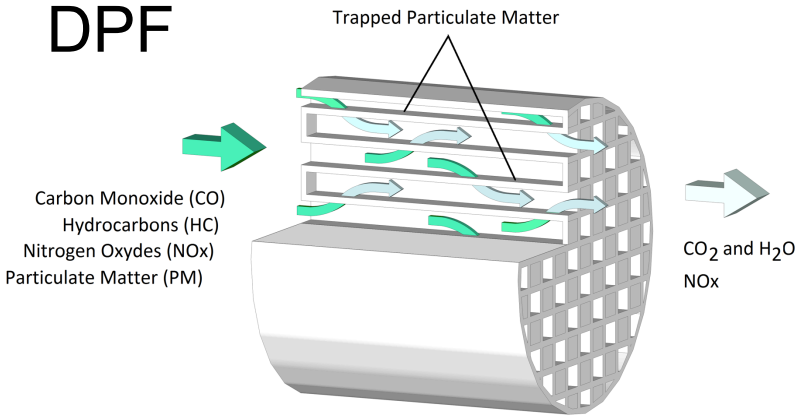
Emission Control Technologies

- Diesel

DOC



DPF



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Emission Control Technologies

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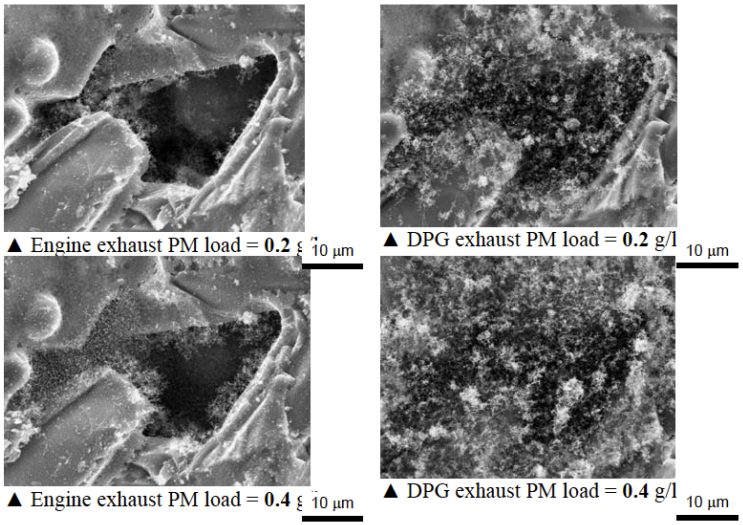
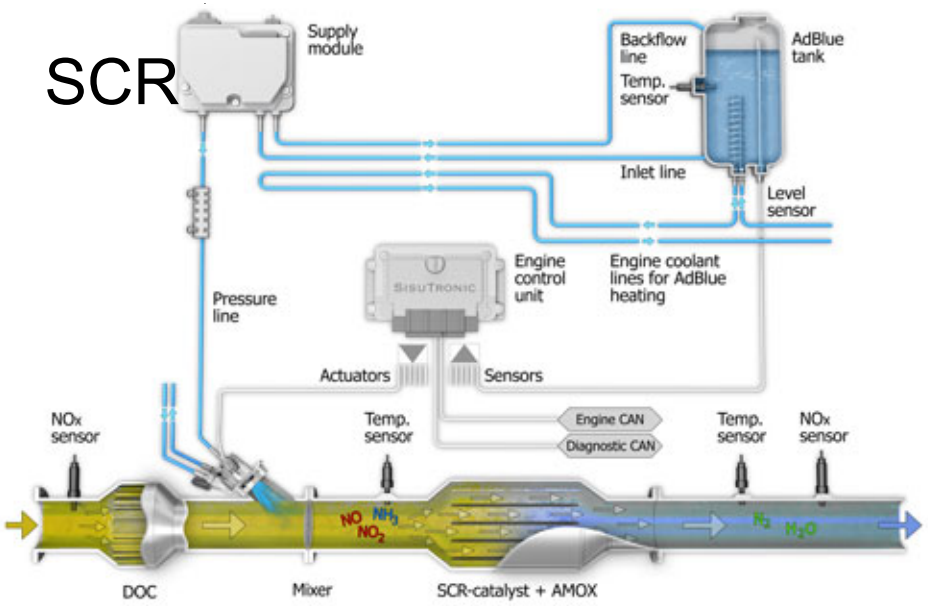


SCR



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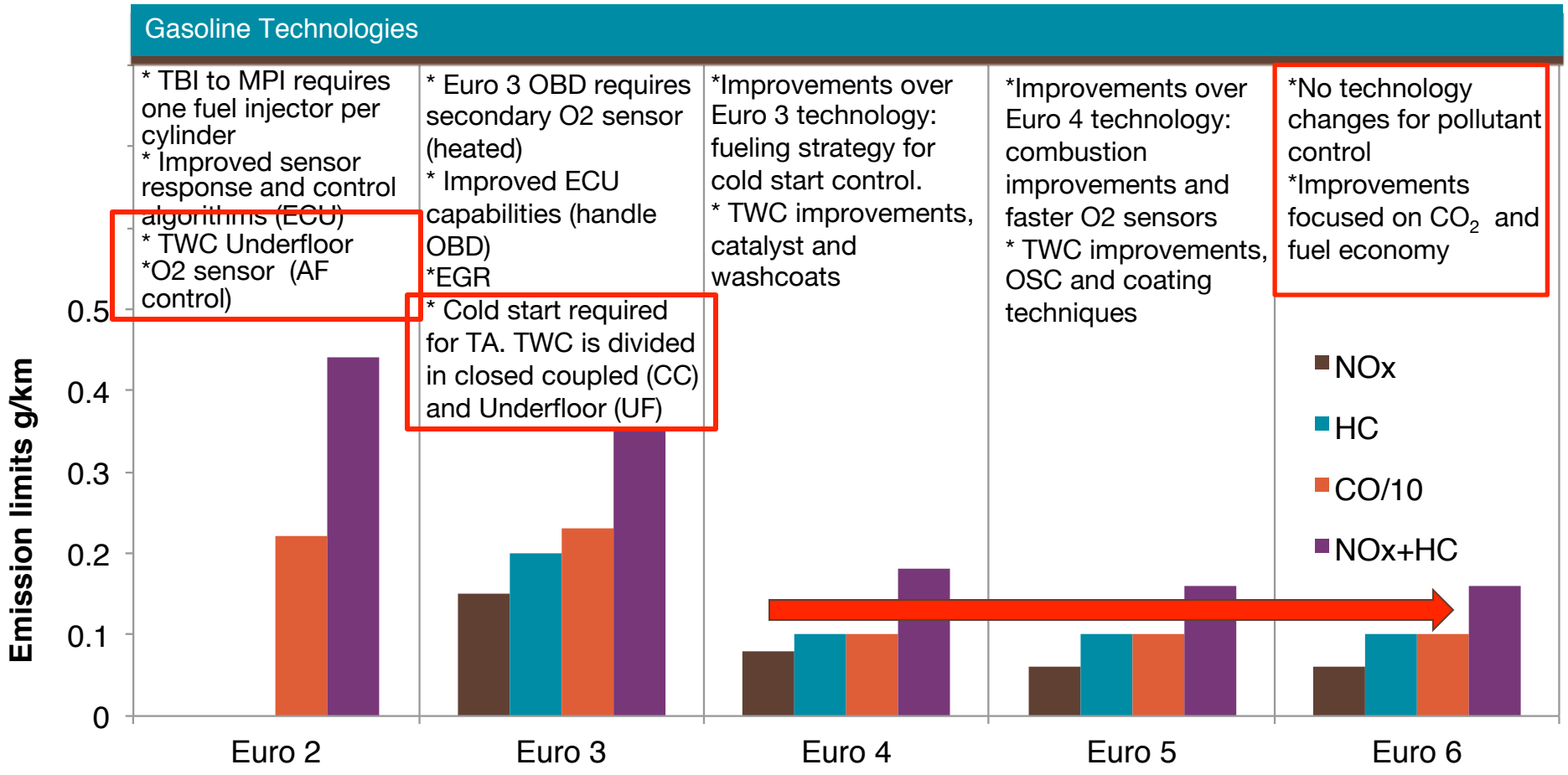
ECT per regulatory level - Gasoline

Programa Europeo



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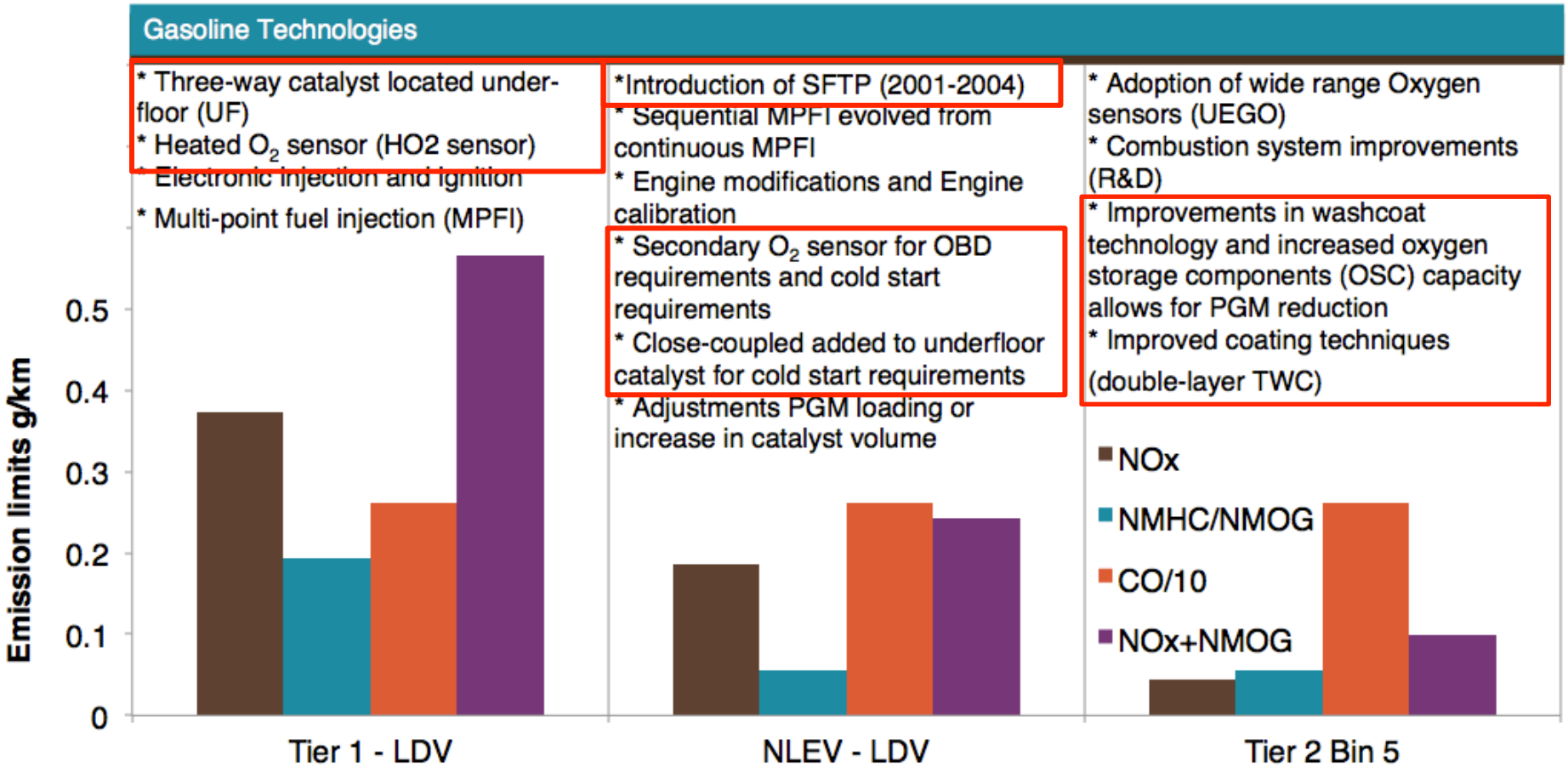
ECT per regulatory level - Gasoline

Programa EPA



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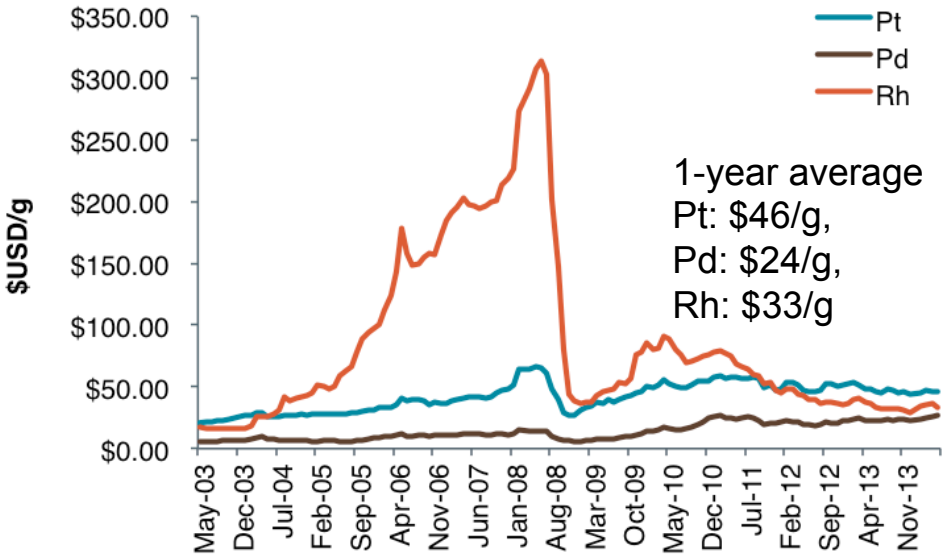
An example: TWC Catalysts costs

Technology and cost review accounts for price changes and technology improvements

Historic PGM Load

Region	Regulation	Pt, g/L	Pd, g/L	Rh, g/L
US	Tier 1	1.0-1.4	0.7-2.5	0.2
	NLEV	0.15-0.90	1.8-4.0	0.1-0.2
	Tier 2	0.1	1.3-2.6	0.1-0.2
EU	Euro 1	1.0	-	0.2
	Euro 2	1.0	-	0.2
	Euro 3	0.6-0.7	-	0.10-0.15
	Euro 4	-	0.6	0.10-0.15
	Euro 5	-	0.6	0.13-0.18
	Euro 6	-	0.6	0.13-0.18



Current PGM Load

Region	Regulation	Pt, g/L	Pd, g/L	Rh, g/L
US	Tier 1	0.1	1.0	0.1
	NLEV	0.1	1.3	0.1
	Tier 2	0.1	1.6	0.1
EU	Euro 1	0.1	0.5	0.1
	Euro 2	0.1	0.5	0.1
	Euro 3	0.1	0.6	0.1
	Euro 4	0.1	0.6	0.1
	Euro 5	0.1	0.7	0.1
	Euro 6	0.1	0.7	0.1

PGM loading Cost for each regulatory level for current technology, V_d= 2.0 L

Region	Regulation	SVR	CV, L	Cost, $USD
US	Tier 1	0.80	1.6	$47
	NLEV	0.90	1.8	$58
	Tier 2	1.00	2.0	$71
EU	Euro 1	0.80	1.6	$38
	Euro 2	0.85	1.7	$40
	Euro 3	0.90	1.8	$45
	Euro 4	0.95	1.9	$47
	Euro 5	1.00	2.0	$51
	Euro 6	1.00	2.0	$51

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Gasoline LDV Technology Costs

Estimated costs of emission control technologies for US and European PFI gasoline LDVs, I-4, Vd=2.0 L

	Regulation	US			EU					
	Cost item	**Tier 1**	**NLEV**	**Tier 2**	**Euro 1**	**Euro 2**	**Euro 3**	**Euro 4**	**Euro 5**	**Euro 6**
1.	**A/F control & engine-out emissions**									
	Oxygen sensor set (typical minimum required)	HO2S x2	HO2S x2	UEGO+ HO2S	O2S	O2S	HO2S x2	HO2S x2	UEGO+ HO2S	UEGO+ HO2S
	Oxygen sensor set costs	$40	$40	$53	$16	$16	$40	$40	$53	$53
	TBI/PFI Fuel system – 1/3 of cost (a)	$52	$65	$65	$52	$52	$65	$65	$65	$65
	A/F management and combustion improvements	R&D	R&D	R&D	R&D	R&D	R&D	R&D	R&D	R&D
	Faster microprocessor (b)	-	$4	$8	-	-	$4	$4	$8	$8
	Engine modifications	$15	$20	$20	$15	$15	$15	$15	$20	$20
	EGR system (c)	$25	$39	$39	$25	$25	$39	$39	$39	$39
	Cost of hardware A/F control & engine-out emissions	**$132**	**$168**	**$185**	**$108**	**$108**	**$163**	**$163**	**$185**	**$185**
2.	**Aftertreatment systems**									
	TWC system (TWC catalyst + fitting elements)	$82	$105	$121	$73	$76	$92	$95	$101	$101
	Exhaust pipe hardware	$12	$18	$18	$12	$12	$18	$18	$18	$18
	Low thermal capacity manifold	-	$24	$24	-	-	$24	$24	$24	$24
	Cost of aftertreatment systems	**$94**	**$147**	**$163**	**$85**	**$88**	**$134**	**$137**	**$143**	**$143**
3.	**Total cost of hardware [1+2]**	**$226**	**$315**	**$348**	**$193**	**$196**	**$297**	**$300**	**$328**	**$328**
4.	**R&D, tooling, certification**	**$24**	**$36**	**$42**	**$24**	**$24**	**$31**	**$42**	**$42**	**$42**
5.	**Total cost of emission control tech. [3+4]**	**$250**	**$351**	**$390**	**$217**	**$220**	**$328**	**$342**	**$370**	**$370**

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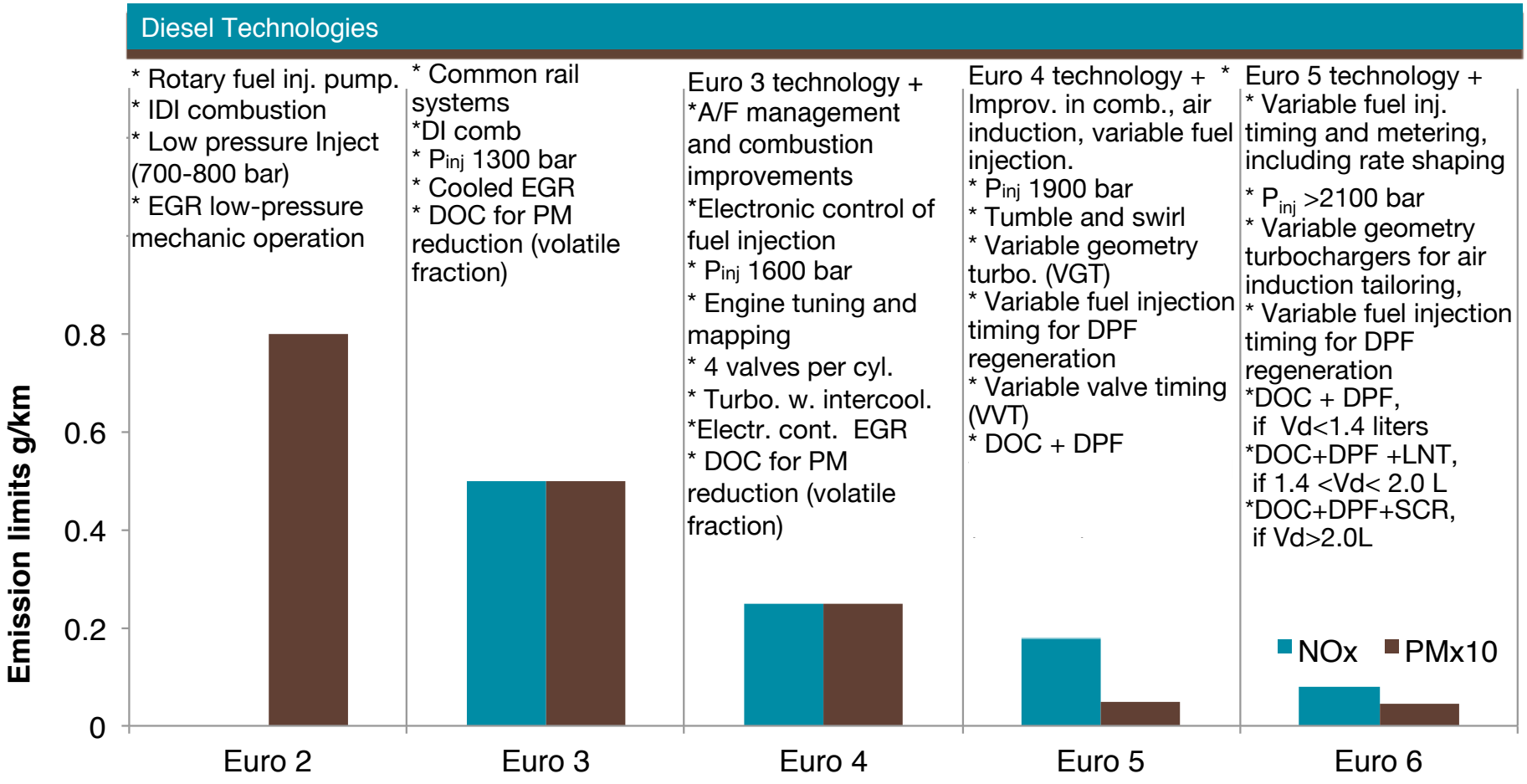
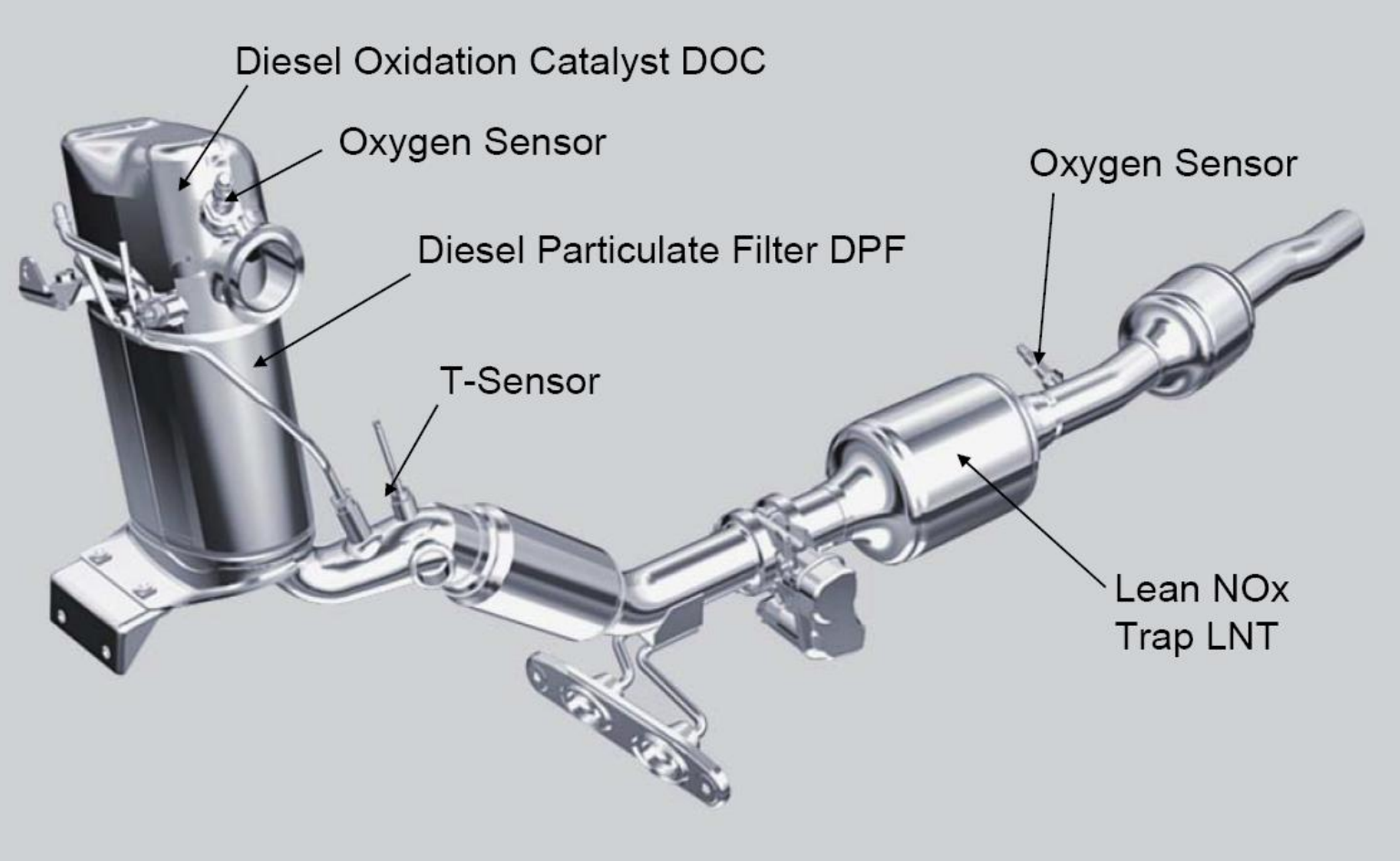
PV Euro Standards - Diesel



Diesel LDV Technology Costs

- US Tier 2 Bin 5 Diesel technology - Aftertreatment



Diesel LDV Technology Costs

- Example: Aftertreatment control system costs

SCR System, Vd= 2.0 L

No	Cost Item	
1	Average engine displacement, Vd, liters	2.0
2	Catalyst volume, CV (SVR=1.0), liters	2.0
3	Pt, Pd, and Rh are not required for NOx control	$0
4	NH3 catalyst, CV (SVR=0.2), 1 g/L PGM @ $43/g	$17
5	Total PGM ([3]+[4])	$17
6	Substrate and washcoat ($20/L*CV)	$40
7	Canning ($15*CV)	$30
8	**Total SCR catalysts**: PGMs + substrate+ washcoat	**$87**
9	Urea tank volume (8*Vd), liters	16
10	Urea tank cost	$114
11	Urea level sensor ($60 commercial price/2.5)	$24
12	Urea tank accessories (brackets, bolts, spacers)	$15
13	Urea pump ($130 commercial price/2.5)	$52
14	Urea injector ($86 commercial price/2.5)	$34
15	Tubing Stainless Steel ($35 commercial price/2.5)	$14
16	Urea Injection pipe section D2.5"x38cm	$14
17	Urea Injection mounting parts (brackets, bolts, gaskets, spacers, tubing connectors)	$15
18	Urea heating system- 200 W, 12 V DC.	$40
19	Temperature sensors (x2)	$42
20	Urea mixer	$50
21	**Total Urea System** ([9]+[10]+…+[20])	**$414**
22	Total Manufacturing: SCR Cat and urea syst.	$501
23	Labor costs with overhead	$48
24	Total Direct Costs to Manufacturing ([22]+[23])	$549
25	**Long term cost** (0.8*[24])	**$440**

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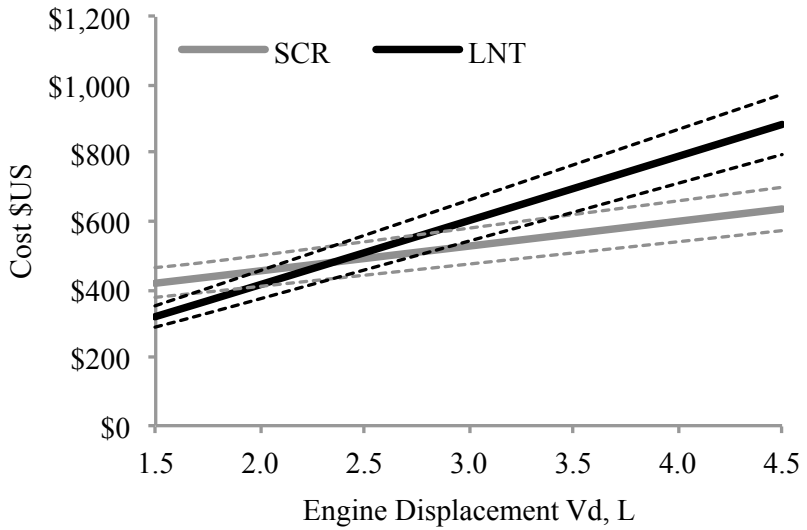
Detailed part cost estimations were done for each aftertreatmemt system: DOC, DPF, LNT and SCR

System	Cost = f(V_d)
DOC	$DOC($V_d$)= 37*$V_d$+6
DPF	$DPF($V_d$)= 135*$V_d$+53
LNT	$LNT($V_d$)= 188*$V_d$+27
SCR	$SCR($V_d$)= 72*$V_d$+297



Diesel LDV Technology Costs

- Estimated costs of emission control technologies for European diesel LDVs, I-4, V_d=2.0 L

	Regulation	EU					
	Cost item	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
1.	A/F control & engine-out emissions						
	Fuel system - 50% of cost (a)	-	$50	$323	$355	$390	$429
	Turbocharger - 50% of cost (b)	-			$75	$75	$138
	Intercooler - 50% of costs (b)	-			$32	$32	$32
	VGT (extra cost) - 50% of costs (b)	-					$55
	EGR valves (c)	$30	$30	$30	$38	$38	$38
	EGR cooling system (c)		$36	$36	$44	$51	$58
	Engine mapping and tuning (d)	-	R&D	R&D	R&D	R&D	R&D
	Improvements on combustion chamber & nozzle geometry (e)	-	R&D	R&D	R&D	R&D	R&D
	Cost of A/F control & engine-out emissions	$30	$116	$389	$543	$586	$750
2.	Aftertreatment systems						
	Diesel oxidation catalyst (DOC) (f)	-	-	$78	$78	$78	$78
	Diesel particulate filter (DPF) (f)	-	-	-	-	$322	$322
	Lean NOx trap (LNT) (f)	-	-	-	-	-	$402
	Selective catalytic reduction (SCR) (g)	-	-	-	-	-	-
	Cost of aftertreatment systems (h)	$0	$0	$78	$78	$400	$802
3.	Total cost of hardware [1+2]	$30	$116	$467	$621	$986	$1,552
4.	Fixed costs (R&D, tooling, certification)	$26	$26	$51	$51	$51	$51
5.	Total cost of emissions control tech [3+4]	$56	$142	$518	$672	$1,037	$1,603

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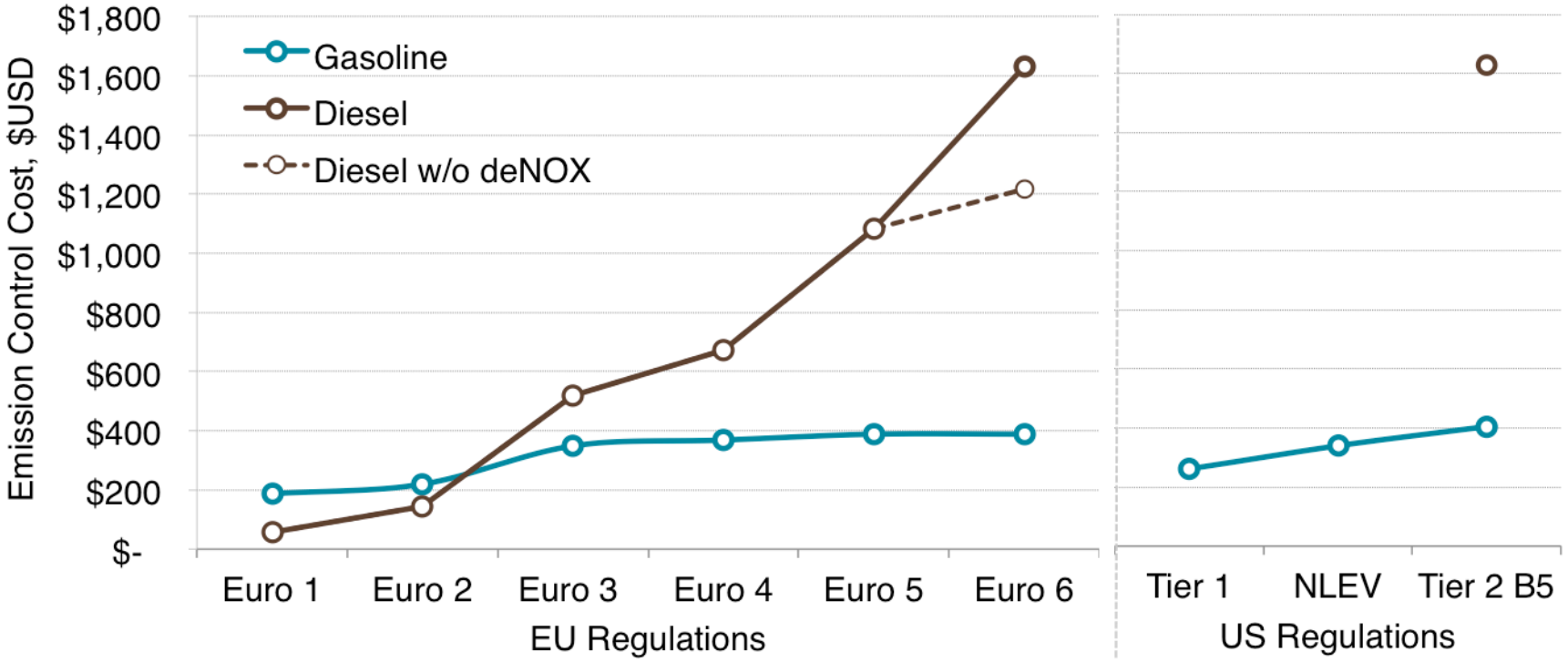
Costos de la Tecnologia para el control de emisiones

- Estimated cumulative emission control technology cost for gasoline and diesel LDVs assuming a 2.0 L engine

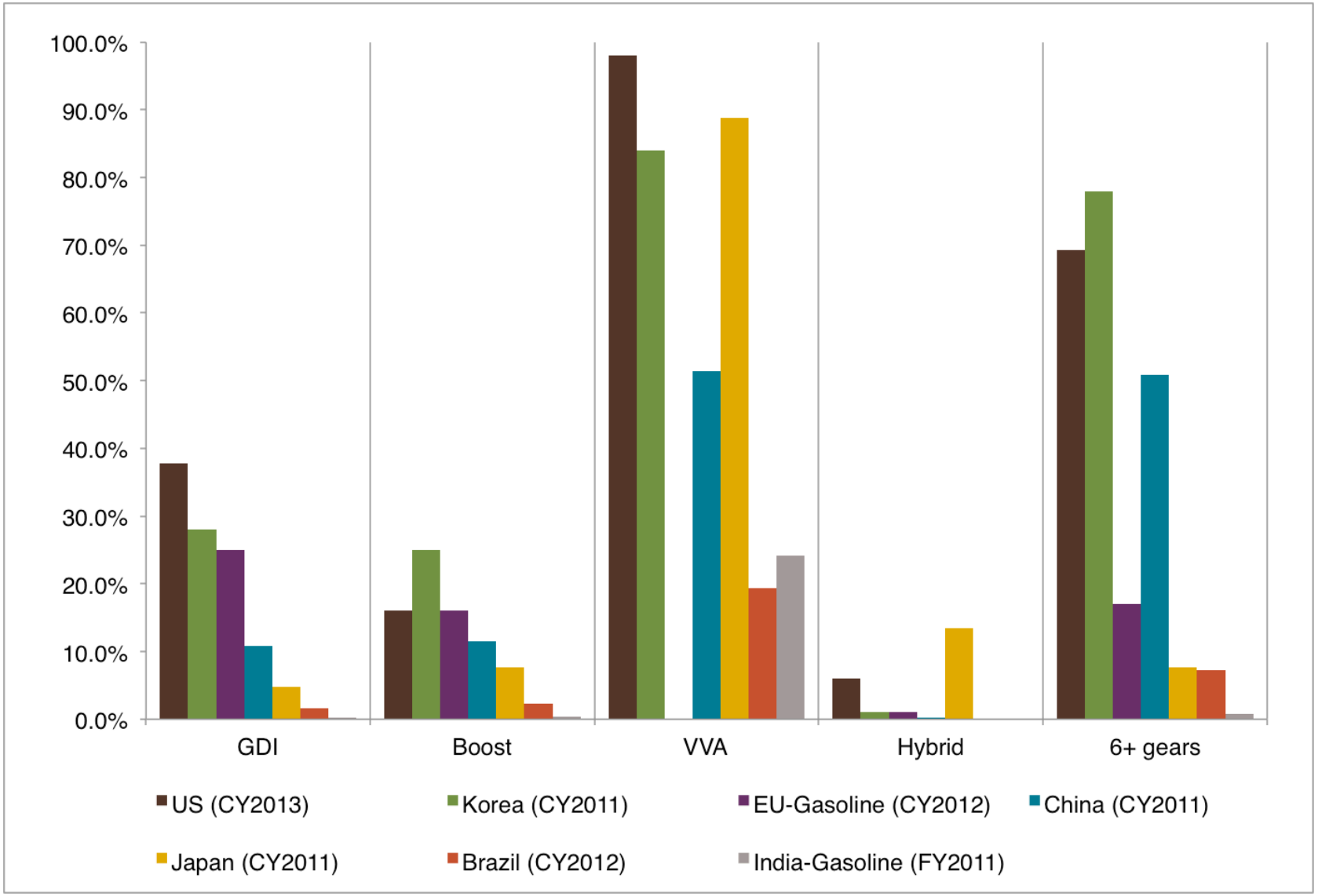


Vehiculo	Euro	Costo, $USD	EPA	Costo, $USD
Gasolina	Euro 3 a Euro 6	$40	Tier 2 Bin 10 a Tier 2 Bin 5	$140/$40
Diesel		$1085		$1085

Tecnologías para la eficiencia del combustible

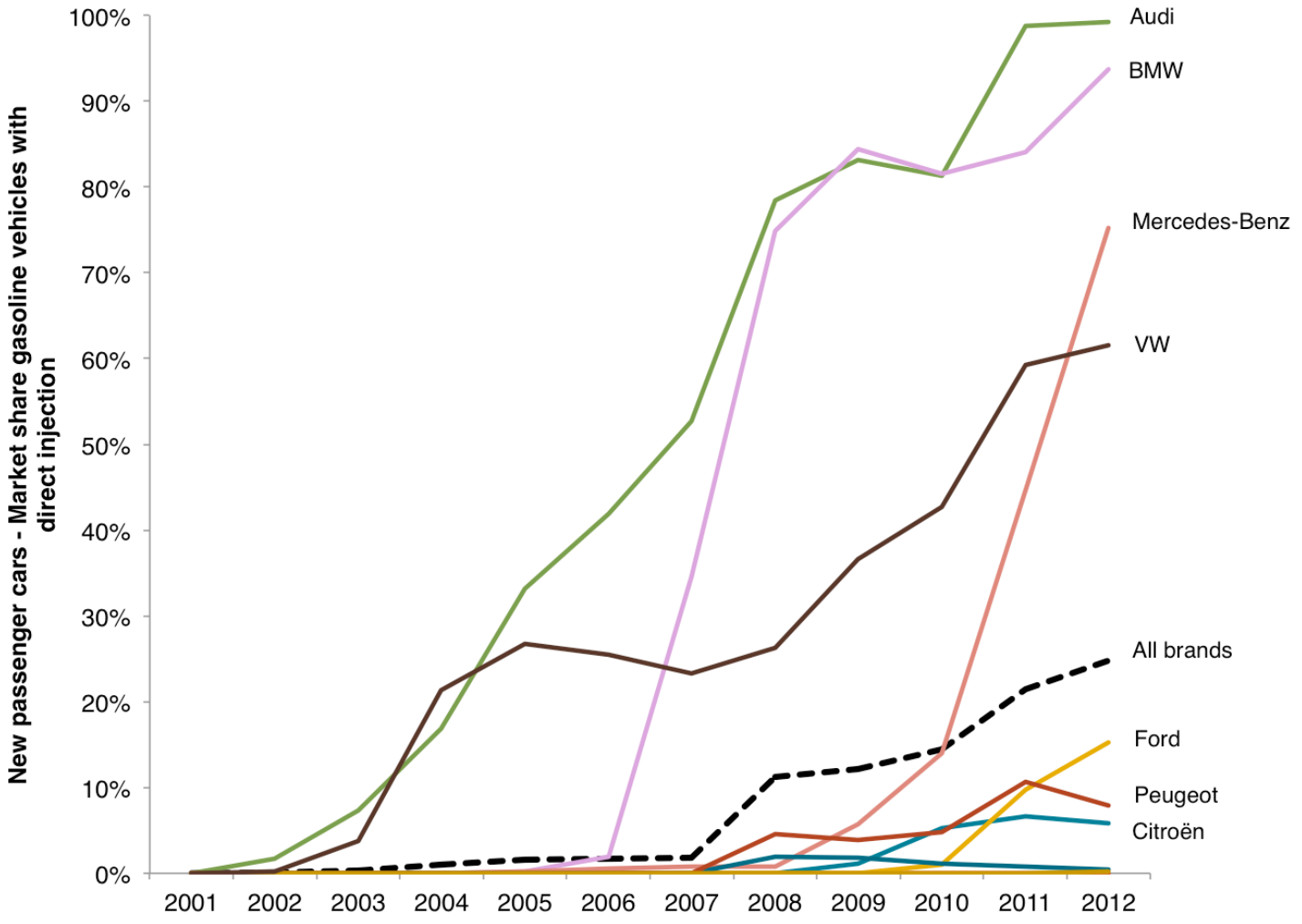
Gasoline Direct Injection - GDI

FE/GHG technologies in major vehicle markets

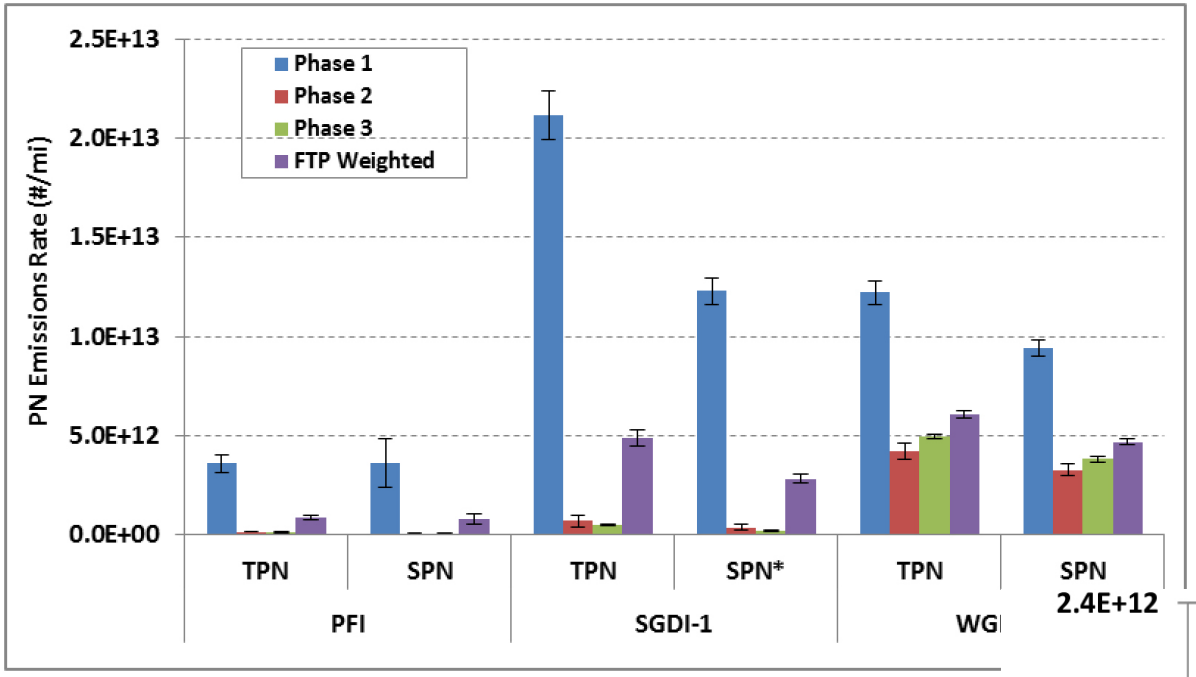


GDI adoption in major vehicle markets

Europe



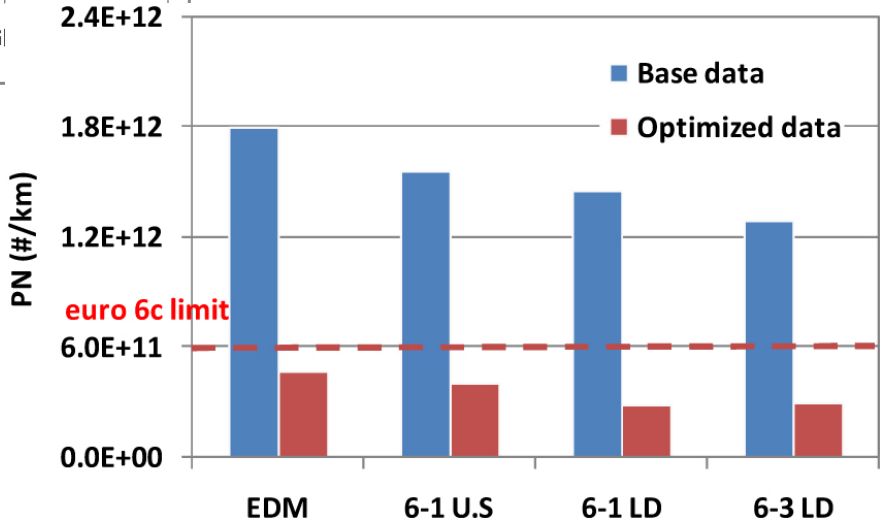
Emisiones de partículas (PN) de los motores GDI son ordenes de magnitud mas altas que las de PFI



Emisiones totales y solidas en numero (PN) sobre el FTP Cycle

Zhang et al., ARB, SAE 2012-01-0442

La misma situacion bajo el NEDC, pero algunos fabricantes han demostrado cumplimiento con Euro 6 PN sin GPF (SAE 2013-01-1556)



Kim et al., Hyundai, SAE 2013-01-1556

Estimated Cost of GPF

- Previous assessment on GPF costs (2011)
  http://www.theicct.org/sites/default/files/publications/GFPworkingpaper2011.pdf
- Very limited information relevant to cost had been published at the time

Add-on GPF

Engine Displacement	Estimated Long-Term Production Cost (USD 2010)
1.5	$88
2.0	$106
2.5	$124
3.0	$143

SVR: 0.55
PGM loading 1.0 g/L,
Pt/Pd/Rh: 0.75/0.25/0.0

TWC on GPF

Engine Displacement	Estimated Long- Term Production Costs (including TWC credit)*	
	High PGM Load	Low PGM Load
1.5	$121	$91
2.0	$154	$114
2.5	$186	$136
3.0	$219	$158

* TWC Credit refers to costs avoided from production of separate three-way catalyst.

SVR: 1.0
PGM loading: “High” and “Low”
Assumption: 1.9 g/L – 0.8:1.0:0.1 (High)
SAE 2010-01-0365 – by SwRI

Estimated Cost of GPF – 2014 update

- A couple new SAE papers with useful cost data
- Preliminary work for this presentation

GPF add-on

Engine Displacement Vd, Liters	Vd = 2.0 L
Catalyst volume, CV (SVR=0.75), L	1.5
Pd, 0.1 g/liter x CV x $24/gr	$4
Rh, 0.05 g/liter x CV x $33/gr	$2
Total PGM	**$6**
Substrate - Wall flow - ($30.0*CV)	$45
Washcoat ($10.0*CV)	$15
Total PGMs + substrate+ washcoat	**$66**
Filter can Housing ($5*CV)	$8
Accessories	$5
Differential pressure sensor	$28
Total Manufacturing	**$107**

TWC@GPF

Engine Displacement , Vd, Liters	Vd = 2.0 L
Catalyst volume, CV (SVR=0.8), L	1.6
Pt, 0 g/liter x CV x $46/gr	$-
Pd, 1.9 g/liter x CV x $24/gr	$73
Rh, 0.2 g/liter x CV x $33/gr	$11
Total PGM	**$84**
Substrate - Wall flow - ($30.0*CV)	$48
Washcoat ($10.0*CV)	$16
Total PGMs + substrate+ washcoat	**$148**
Filter can Housing ($5*CV)	$8
Accessories	$5
Differential pressure sensor	$28
Total Manufacturing	**$189**
Credit for UF TWC	$(56)
Total TWC@GPF	**$133**

Sources: SAE 2014-01-1513 and SAE 2012-01-1244. UMICORE

US LDV Tier 3 – Vehicle and Fuel Standards

- Vehicle standards highlights
  - Starts in MY2017-18 and fully phased-in by 2025.
  - Main changes with respect to Tier 2
    - 80% reduction in fleet average NOx+NMOG (160 mg/mile to 30 mg/mile)
    - 70% reduction in per vehicle PM (10 mg/mile to 3 mg/mile)
    - Eventual harmonization of PC and LDT standards by 2025
  - 150,000 mile durability by 2020
  - 120,000 mile durability option for smaller classes, but 15% tighter standard
- Fuels standards highlights
  - Sulfur content S < 10 ppm annual average
  - **E10 cert fuel**
  - Evaporative emissions tightening
  - Much flexibility and credits

http://www.epa.gov/otaq/tier3.htm

US LDV Tier 3 – TWC Cost Impacts

- ICCT's Tier 3 Incremental costs for catalysts (wr to T2B5)

ITEM	TIER 3 - PGM COST PER VEHICLE 30 MG/MILE NMOG+NOX		
$/L	I-4, 2.0L	V-6, 3.0L	V-8, 4.0L
Total costs	$106	$159	$212
Incremental costs with respect to Tier 2 Bin 5	$18	$27	$36

- EPA incremental costs with respect to T2B5

Table 2-48 Cost per Vehicle for the Combined Tier 3 Exhaust and Evaporative Emission Standards (2011$)

	2017	2018	2019	2020	2021	2022	2023	2024	2025
Passenger car	$46	$51	$53	$57	$59	$63	$63	$64	$65
Light-duty truck	$0	$73	$78	$82	$86	$88	$87	$87	$86
All light-duty	$29	$59	$62	$66	$68	$72	$71	$72	$72

Sistemas OBD

Una breve descripcion

Que es el OBD?

- Sistema de diagnostico abordo (On-Board Diagnostics OBD)

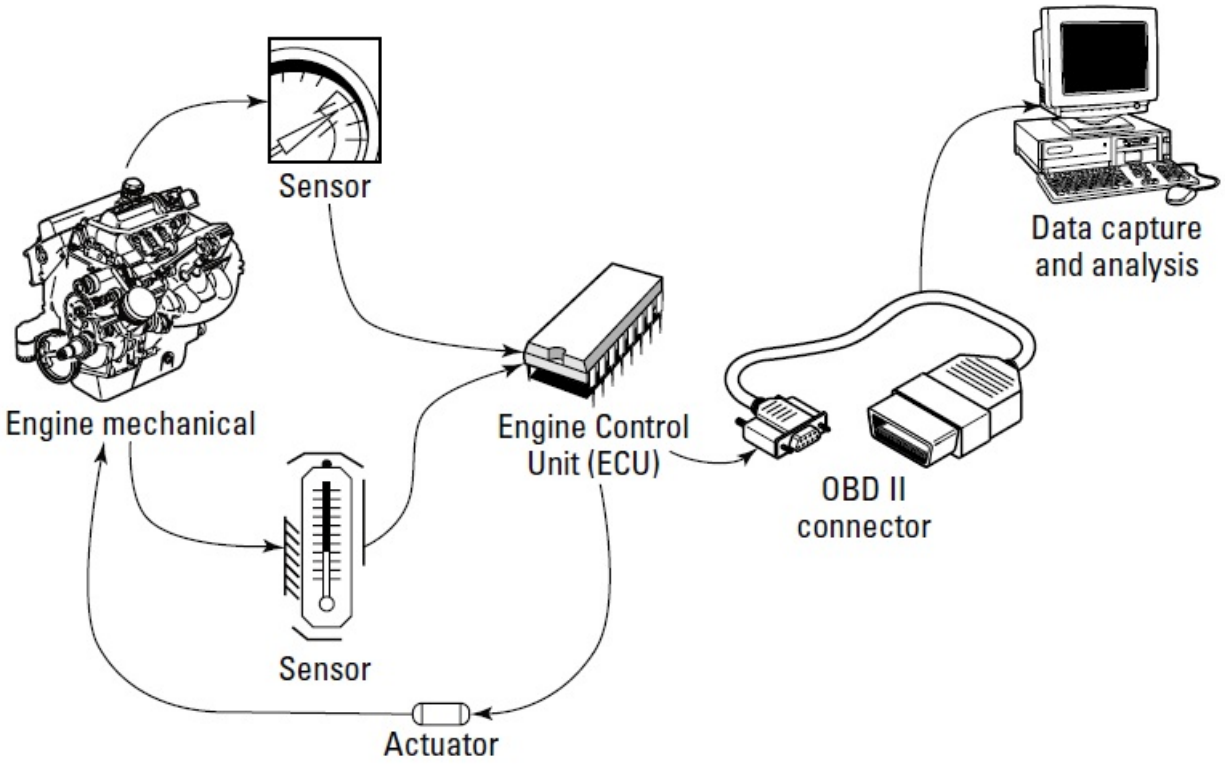
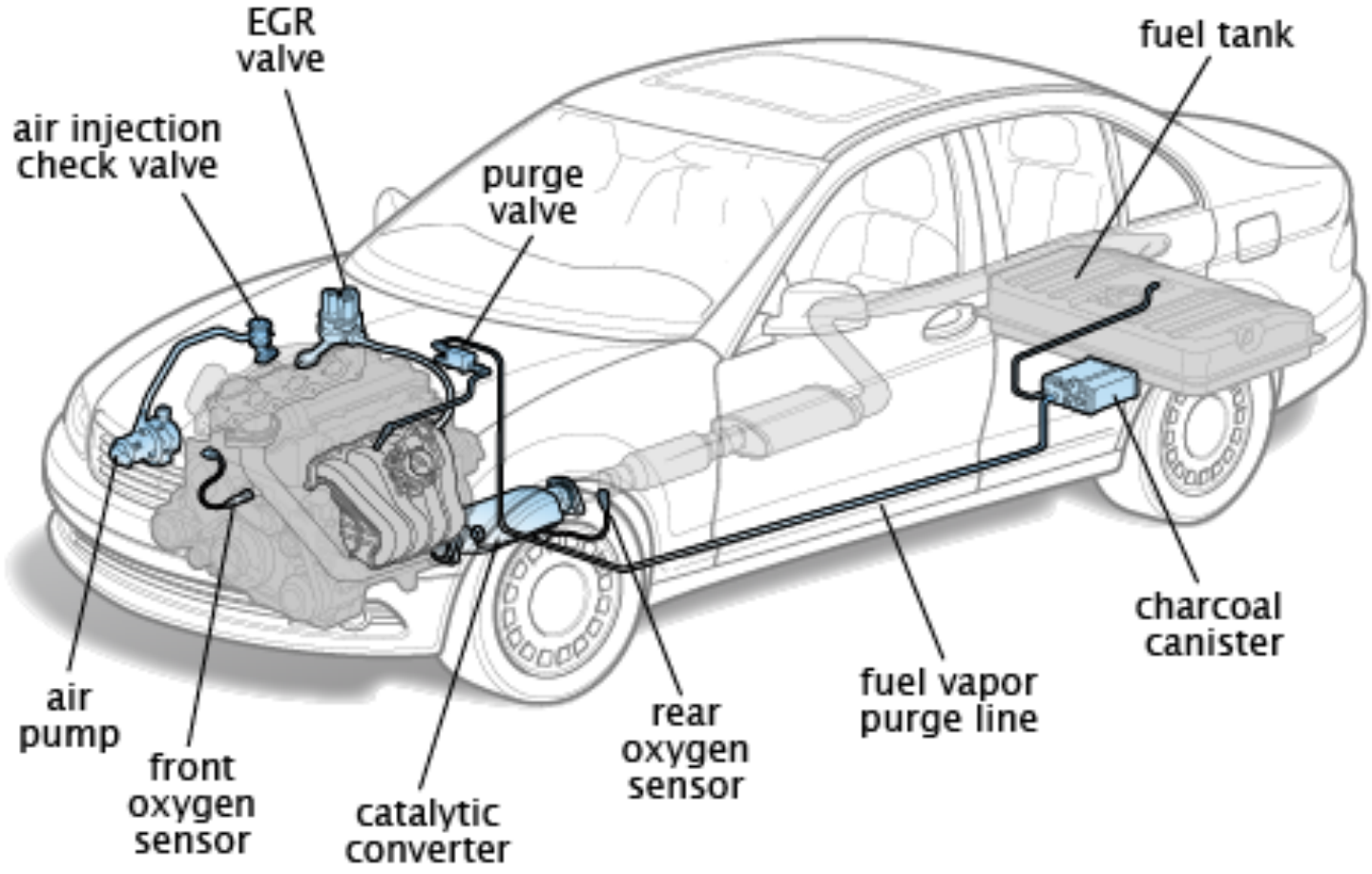


FIGURE 1: On-board diagnostics block diagram

http://etechnologytips.com/own-made-automotive-diagnostic/

Algunos de los sistemas monitoreados



http://arlingtonshell.com/wp-content/uploads/2013/06/Emissions_System_06_18_11.png

Historia

- Vehículos Ligeros
  - OBD-I introducido en California en 1991
  - OBD-II requerido en todos los vehículos ligeros y camionetas (LDV + LDT) desde MY1996
  - European OBD – EOBD , requerido desde 2001 (Euro 3). Este es equivalente a OBD-II.
  - **Mexico: NOM-042-2003 require OBDII / EOBD** o similar
- Vehículos Pesados
  - OBD requerido en vehículos pesados (HDV) de hasta 14,000 lbs GVWR desde el 2005
  - OBD para vehículos pesados de mayor peso bruto, es introducido entre el 2010 and 2016

Detalles tecnicos relevantes

- OBD-I: limitado al monitoreo de un numero limitado a sistemas ligados al control de emisiones y sin umbrales de emisiones
- OBD-II: cada componente del OBD es monitoreado por funcionamiento
  - Indicación de Fallos: el sistema OBDII ilumina una luz de alerta por fallo (Malfunction indicator lamp – MIL)
  - El sistema también almacena información sobre el fallo que puede ser usado por los técnico para hacer reparaciones

- Los umbrales de emisiones son específicos a cada sistema OBD (Europeo o EUA) y por estandard

EPA OBDII

Area de Monotoreo	Condicion de Falla
Catalizador	Umbral OBD: 1.5 x FTP limit
Falla de ignición (engine misfire)	
O2 Sensors	
EVAP (sistema control de fugas evaporativas)	Fuga equivalente a un agujero de diametro 0.04”
Otros componentes relacionados con emisiones	Monitoreo por continuidad, racionalidad y funcionalidad

EOBD cambia entre Euro 3/4 y Euro 5/6

- Euro 5 añade umbrales de monitoreo de partículas PN para Gasolina GDI
- Euro 5 añade sistemas adicionales de monitoreo

Expanded Monitoring area starting Euro 5
EGR system efficiency monitoring
EGR flow and cooler monitoring
Catalyst against NMHC [3]
Catalyst against NOx (> Euro 5+) [3] [4]
NOx aftertreatment device with or without reagent efficiency monitoring [3]
All O_2 Sensors to monitor cat (in addition to front sensor)
PM monitoring [3]
IUPR (> Euro 5+) [4]

- Euro 5 reduce el valor de umbrales de emisiones

Cambios en OBD para Tier 3

- EPA adoptara para MY2017 el estándar OBD de CARB
  - Requerimientos detallados por sistema de control de emisiones
- Requerimientos adicionales en el área de control de emisiones evaporativas

Summary

- El análisis de costos de tecnologías para el control de emisiones es fundamental para la implementación de nuevos estándares de emisiones a nivel global
- Tecnologías mejoran reducen sus costos rápidamente; México y otros países pueden tomar ventaja de esta situación
- Mejorar de Euro 3 a Tier 2 B5 /Euro 6 tiene un costo muy bajo para los vehículos a gasolina:
  - EPA: ~$40/140 dependiendo de la base actual
  - Euro: ~$40
- Alcanzar Tier 2 B5 /Euro 6 es mucho mas costoso para vehículos a diesel ~$1000
- El mercado de GDI esta creciendo rápidamente: incremento potencial en emisiones de partículas
  - Adopción de GPF dependerá de la regulaciones en PN que estan siendo desarrolladas
- Tier 3 es un tema de estudio para los fabricantes y OEMs
  - Se estima que los costos seran bajos
- OBD-II/EOBD se esta requiriendo en este momento en México, pero se puede mejorar con estándares avanzados

Gracias!

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Artista Liang Kegang posa en una galería de arte en Beijing con una jarra de aire puro que el recolecto en la campiña francesa
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