

Emissions of CO₂, CO, NO_x, HC, PM, HFC-134a, N₂O and CH₄ from the Global Light Duty Vehicle Fleet

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OUTLINE

Background
Vehicle emissions
Future outlook
Conclusions

Background

Vehicle emissions

Future outlook

Conclusions



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Background

Vehicle emissions

Future outlook

Conclusions

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William Clay Ford Jr.

Background

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Society's assessment may change in the future as the science develops, but the present risk is clear. The climate appears to be changing, the changes appear to be outside natural variation, and the likely consequences will be serious.

From a business planning point of view, that issue is settled. Anyone who disagrees is, in my view, still in denial. We at Ford Motor Company have moved on.

Speech to Greenpeace Business Conference – October 2000

As early as 2000, Ford Motor Company identified climate change as a critical issue. The subject has only grown in importance since then ...

Ford Motor Company Sustainability Report 2004/5

Our manufacturing operations have integrated sustainability goals and indicators into their scorecards to drive progress. For example, we have cut global energy use by 27 percent and water use by more than 25 percent since 2000.

Ford Motor Company Sustainability Report 2006/7



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Manufacturing versus “in-use” emissions

Life cycle CO₂ impact for typical vehicles (US)

	Mid-sized car		Mid-sized SUV	
	Tonnes of CO ₂	% of total	Tonnes of CO ₂	% of total
Raw material production (steel, aluminium, ...)	3.5	5.6%	4.3	5.2%
Manufacturing/assembly	2.6	4.2%	2.6	3.2%
Ford manufacturing logistics	0.3	0.5%	0.3	0.4%
Fuel (120,000 miles [192,000 km]) WTW	55.1	88.6%	74.6	90.4%
Maintenance and repair	0.6	1.0%	0.6	0.7%
End of life/recycling	0.1	0.2%	0.1	0.1%
Total Lifecycle	62.2	100%	82.5	100%

“In-use” dominate manufacturing CO₂ emissions (and other air pollution/climate change related compounds)

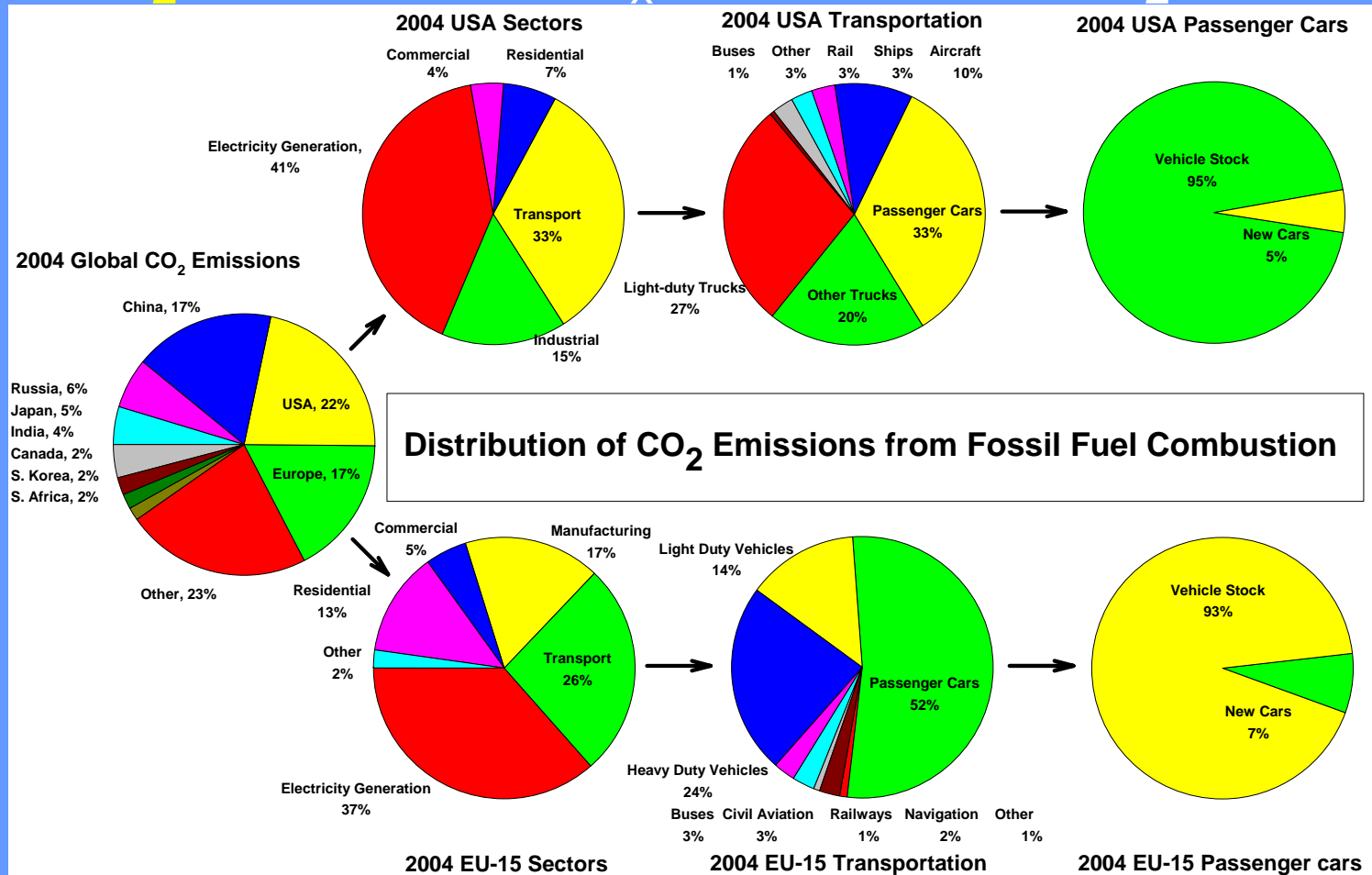
[Emissions from facilities have been reduced substantially (see <http://www.ford.com>)]

Vehicle emissions: CO₂, HCs, CO, NO_x, PM, R-134a, N₂O, CH₄.



Vehicle emissions:

CO₂, HCs, CO, NO_x, PM, R-134a, N₂O, CH₄.



- On-road light-duty car and trucks contribute about 20% of US, 17% of EU-15, and 11% of global fossil fuel CO₂ emissions.
- Vehicle CO₂ emissions approximately 3 GtCO₂ yr⁻¹, total global fossil fuel CO₂ emissions were 27 GtCO₂ yr⁻¹ in 2004.

Vehicle emissions: CO₂, HCs, CO, NO_x, PM, R-134a, N₂O, CH₄.

Historical perspective on vehicle HC, CO, and NO_x emissions

Year	HC (g/mile) [g/km]	CO (g/mile) [g/km]	NO _x (g/mile) [g/km]
1957-1962 US Fleet ¹	8.8 [5.5]	81.6 [51]	3.7 [2.3]
1963-1967 US Fleet ¹	9.1 [5.7]	92.8 [58]	3.5 [2.2]
1963-1967 US Fleet ¹	4.7 [2.9]	58.7 [37]	4.9 [3.1]
1975/1976 US Federal	1.5 [0.94]	15 [9.4]	3.1 [1.9]
1991 US Federal	0.41 [0.26]	3.4 [2.1]	1.0 [0.6]
1994 US Federal	0.41 [0.26]	3.4 [2.1]	0.4 [0.25]
2000 Europe Stage III ^{2,3}	0.32 [0.20]	3.8 [2.4]	0.24 [0.15]
2004 US Federal	0.125 [0.08]	1.7 [1.1]	0.2 [0.13]
2005 Europe Stage IV ^{2,4}	0.16 [0.10]	1.6 [1.0]	0.13 [0.08]
2007 US Federal ^{5,6}	0.075 [0.05]	3.4 [2.1]	0.05 [0.03]

¹ from Table 3 in FEGRAUS ET AL., 1973; ² gasoline; ³ 80 K km; ⁴ 100 K km; ⁵ Tier II bin 5 average requirement; ⁶ 50 K mile

Major, and continuing progress, in reducing HC, CO, and NO_x emissions on per vehicle per km basis. On a global basis, the emissions of HC, CO, NO_x in 2004 from light duty vehicles were approximately 27, 160, and 8 Mt,

respectively



Vehicle emissions: CO₂, HCs, CO, NO_x, **PM**, R-134a, N₂O, CH₄.

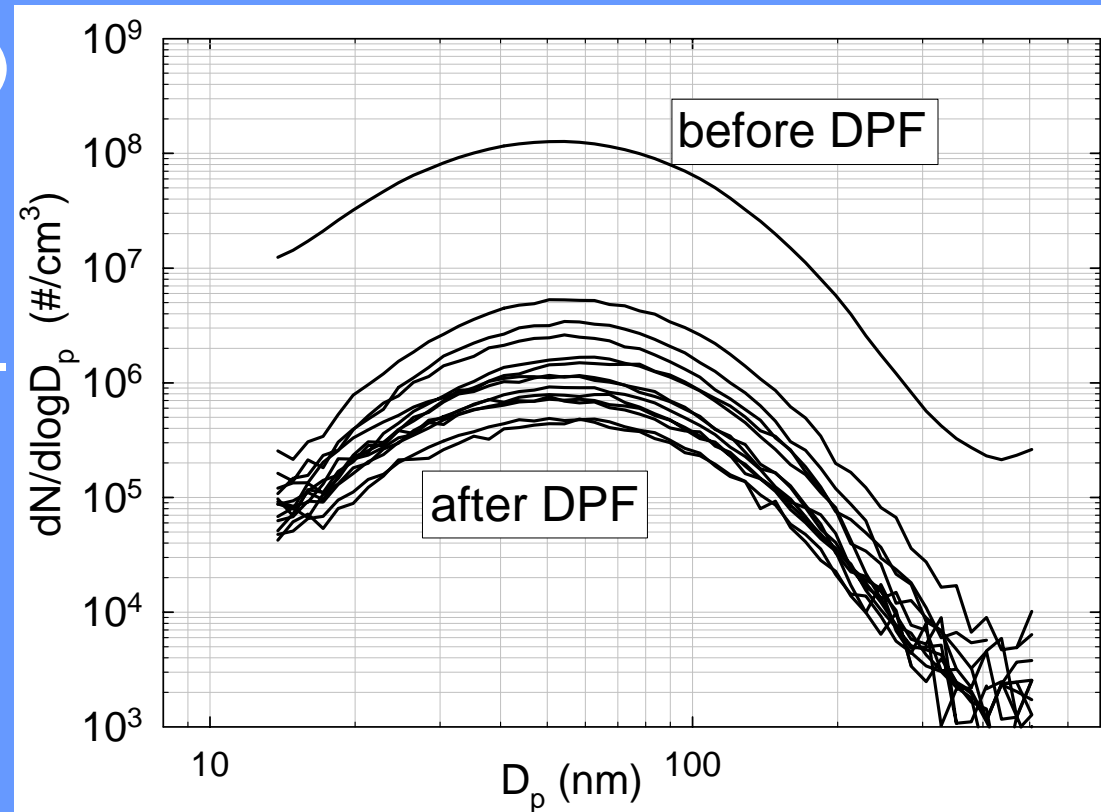
Diesel Particulate Filters (DPF) offer efficient control of soot.

Ford equipping diesel vehicles with DPF starting 2007 (US), 2005-2010 (Europe).

DPFs have small FE penalty - no free lunch.

On a global basis, the emissions of PM in 2004 from light duty vehicles were approximately 0.9 Mt

Source: World Business Council for Sustainable Development, 2004: Mobility 2030: meeting the challenges to sustainability. -- ISBN: 2-940240-57-4, Geneva, Switzerland.



Source: Guo, G.; Xu, N.; Laing, P. M.; Hammerle, R. H.; Maricq, M. M., SAE Paper 2003-01-0047



Vehicle emissions:

CO₂, HCs, CO, NO_x, PM, R-134a, N₂O, CH₄.

R-134a (CF₃CFH₂), replacement for CFC-12 (CF₂Cl₂) in vehicle AC units. Four emission modes: regular, irregular, servicing, disposal.

Schwarz (2001): overall average emission = 0.24±0.06 g/day

Siegl et al. (2002): overall average emission = 0.41±0.27 g/day.

Schwarz and Harnish (2003): regular plus irregular = 0.19 g/day

Stemmler et al. (2004): regular plus irregular = 0.336 g day⁻¹

Vincent et al. (2004): overall average emission 0.24 g/day.

Assuming 0.3 ±0.1 g/day emission, 25 mpg, 10000 miles/year, GWP = 1300, then climate forcing impact of R-134a is approx. 3-5% that of tailpipe CO₂

Sources: Schwarz: <http://www.oekorecherche.de/english/berichte/volltext/MAC-LOSS-2001.pdf>; Siegl et al., Environ. Sci. Technol., 36, 561 (2002); Schwarz and Harnish, Final Report B4-3040/2002/337136/MAR/C1, for European Commission (2003); Stemmler et al., Environ. Sci. Technol., 38, 1998 (2004); Vincent et al., SAE paper 2004-01-2256.



Vehicle emissions:

CO₂, HCs, CO, NO_x, PM, R-134a, N₂O, CH₄.

Several measurements of on-road emission factors including:

Berges et al. (1993): (g N₂O/ g CO₂) = (6 ± 3) × 10⁻⁵.

Becker et al. (1999): (g N₂O/ g CO₂) = (6 ± 2) × 10⁻⁵.

Becker et al. (2000): (g N₂O/ g CO₂) = (4.1±1.2) × 10⁻⁵.

Jimenez et al. (2000): (g N₂O/ g CO₂) = (8.8±2.8) × 10⁻⁵.

Recent lab measurements:

Behrentz et al. (2004): 20 mg/km (average from 35 vehicles)

Huai et al. (2004): half < 7 mg/km, half > 7 mg/km (60 vehicles)

Using GWP for N₂O = 330 (100 year time horizon) estimate that N₂O emissions from vehicles have climate forcing impact of approximately 1-3% that of CO₂ emissions from vehicles.

Sources: Berges et al. J. Geophys. Res., 98, 18527 (1993); Becker et al. Environ. Sci. Technol., 33, 4134 (1999); Becker et al. Chemosphere Global Change Sci., 2, 387 (2000); Jimenez et al. Chemosphere Global Change Sci. 2, 397 (2000); Huai et al., Atmos. Environ., 38, 6621 (2004); Behrentz, et al., Atmos. Environ. 38, 4291 (2004).



Vehicle emissions:
CO₂, HCs, CO, NO_x, PM, R-134a, N₂O, CH₄.

Nam et al. (2004): average emission factor for the U.S. on-road vehicle fleet of (g CH₄/ g CO₂) = (15±4) x 10⁻⁵.

Using GWP for CH₄ = 23 (100 year time horizon) calculate that CH₄ emissions from vehicles have global warming impact which is 0.3-0.4% of that of CO₂ emissions from vehicles.

Source: Nam et al. Environ. Sci. Technol., 38, 2005 (2004).



Future Outlook

Background
Vehicle emissions
Future outlook
Conclusions



Model projects CO₂, CO, NO_x, PM, HC, emissions in 11 geographical areas to year 2050. Excel spreadsheet available.

<http://www.wbcds.ch/plugins/DocSearch/details.asp?type=DocDet&ObjectId=NjA5NA>

Lifecycle WTW analysis of costs and benefits of future automotive fuels and powertrains. Participants include JRC, BP, Total, Shell, ExxonMobil, Renault, Ford, VW, BMW, PSA, DaimlerChrysler



WELL-TO-WHEELS ANALYSIS OF
FUTURE AUTOMOTIVE FUELS AND
POWERTRAINS
IN THE EUROPEAN CONTEXT



<http://ies.jrc.cec.eu.int/Download/eh>





World Business Council for Sustainable Development: Mobility 2030 Report

Report and Excel spreadsheet available on web at WBCSD site: <http://www.wbcd.ch/>

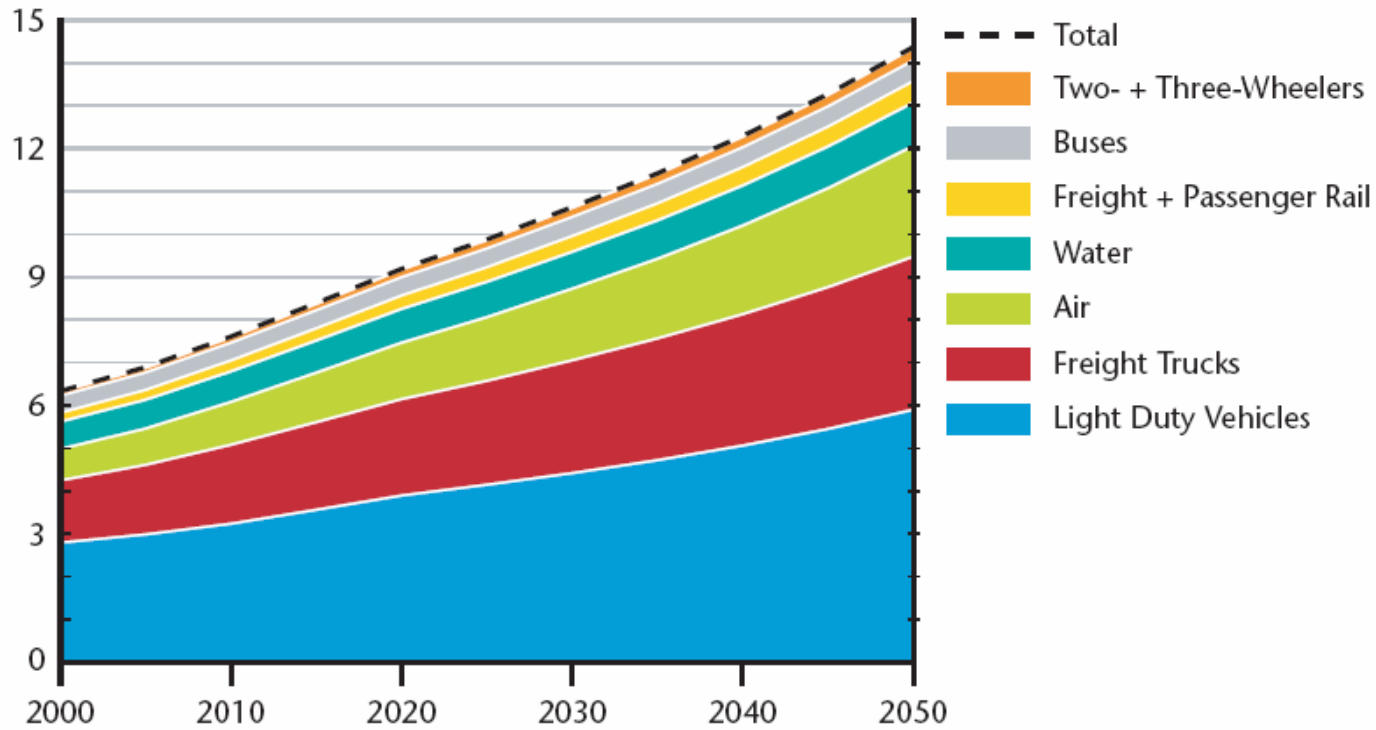
Detailed (ca. 10 Mb) Excel spreadsheet dealing with essentially all modes of transport ... useful reference for future transportation related emissions.

Sectors, Fuels, Regions and Data Contained in the Spreadsheet Model

Sectors / Modes	Vehicle Technologies/ Fuels	Regions	Variables
<ul style="list-style-type: none"> • Light-duty vehicles (cars, minivans, SUVs) • Medium trucks • Heavy-duty (long-haul) trucks • Mini-buses ("paratransit") • Large buses • 2-3 wheelers • Aviation (Domestic + Int'l) • Rail freight • Rail passenger • National water-borne (Inland plus coastal) • Int'l shipping 	<ul style="list-style-type: none"> • Internal combustion engine: <ul style="list-style-type: none"> ◊ Gasoline ◊ Diesel ◊ LPG-CNG ◊ Ethanol ◊ Biodiesel • Hybrid-Electric ICE (same fuels) • Fuel-cell vehicle <ul style="list-style-type: none"> ◊ Hydrogen <p>(With feedstock differentiation for biofuels and hydrogen)</p>	<ul style="list-style-type: none"> • OECD Europe • OECD North America • OECD Pacific (Japan, Korea, Australia, NZ) • Former Soviet Union (FSU) • Eastern Europe • Middle East • China • India • Other Asia • Latin America • Africa 	<ul style="list-style-type: none"> • Passenger kilometres of travel • Vehicle sales (LDVs only) • Vehicle stocks • Average vehicle fuel-efficiency • Vehicle travel • Fuel use • CO₂ emissions • Pollutant emissions (PM, NO_x, HC, CO, Pb) • Safety (road fatalities and injuries)

Figure 2.13 Transport-related Well-To-Wheels CO₂ emissions by mode

Gigatonnes CO₂-Equivalent GHG
Emissions/Year



Source: Sustainable Mobility Project calculations.

CO₂ ↑ x 2, but ...

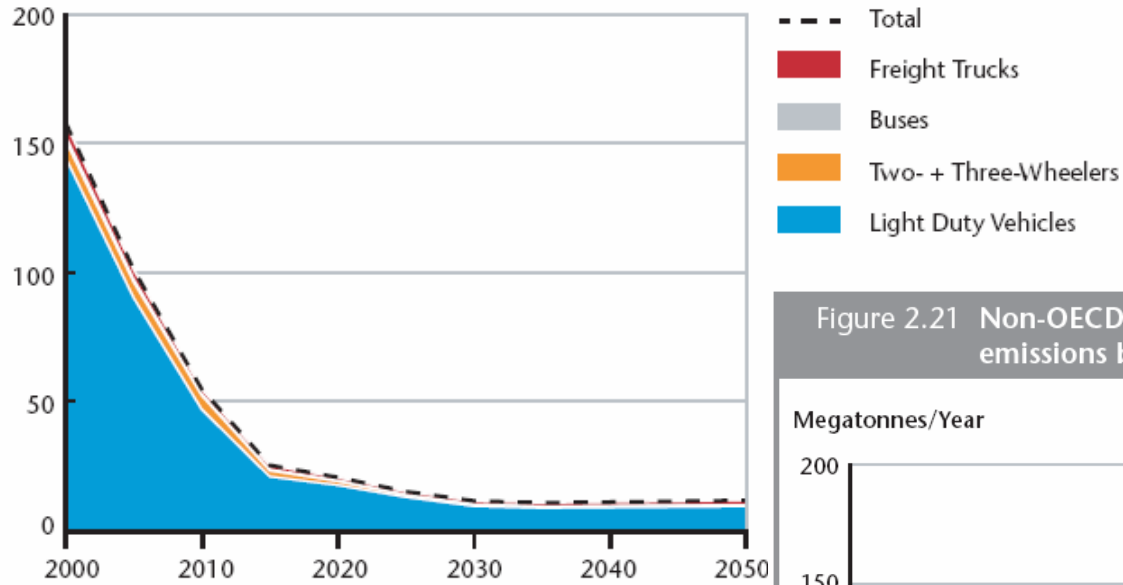


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Source: World Business Council for Sustainable Development, Mobility 2030: meeting the challenges to sustainability. -- ISBN: 2-940240-57-4, Geneva, Switzerland.

Figure 2.16 OECD regions: Transport-related Carbon Monoxide (CO) emissions by mode

Megatonnes/Year

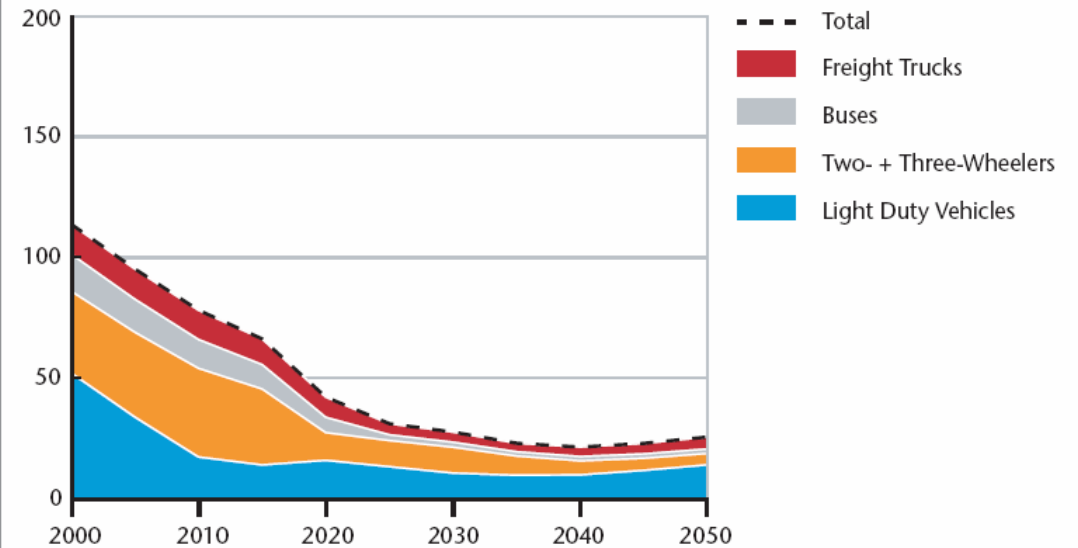


Sc

Background
Vehicle emissions
Future outlook
Conclusions

Figure 2.21 Non-OECD regions: Transport-related Carbon Monoxide (CO) emissions by mode

Megatonnes/Year



Source: Sustainable Mobility Project calculations.

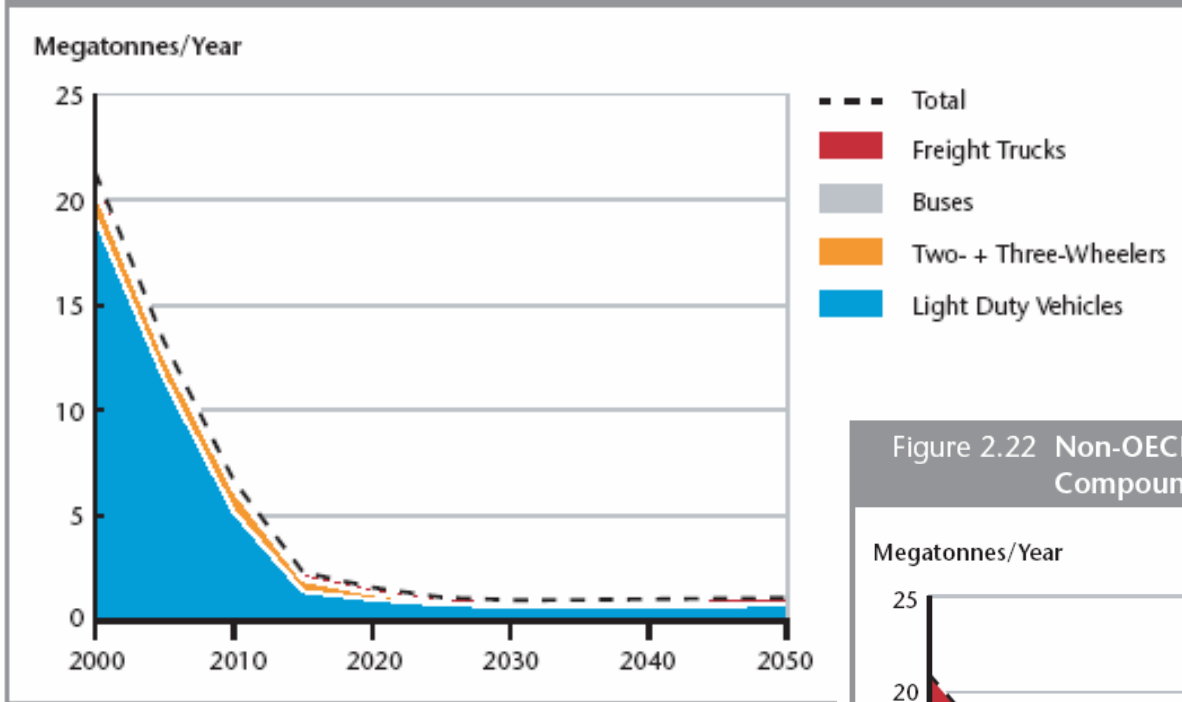
CO ↓ x 10



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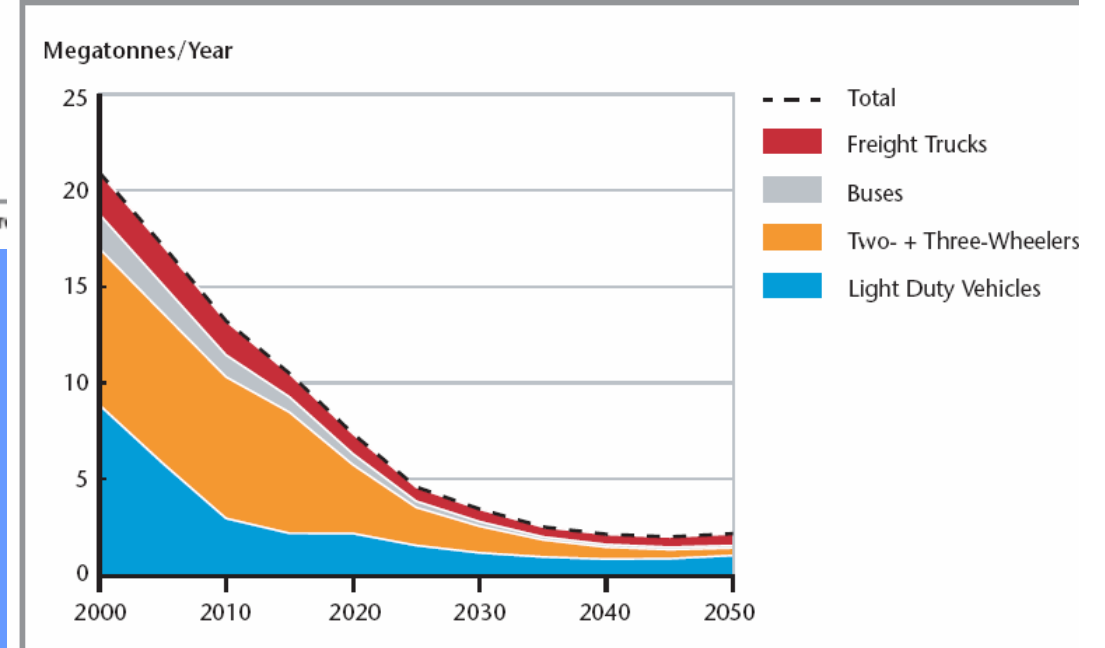
Source: World Business Council for Sustainable Development, Mobility 2030: meeting the challenges to sustainability. -- ISBN: 2-940240-57-4, Geneva, Switzerland.

Figure 2.17 OECD regions: Transport-related Volatile Organic Compound (VOC) emissions by mode



Background
Vehicle emissions
Future outlook
Conclusions

Figure 2.22 Non-OECD regions: Transport-related Volatile Organic Compound (VOC) emissions by mode

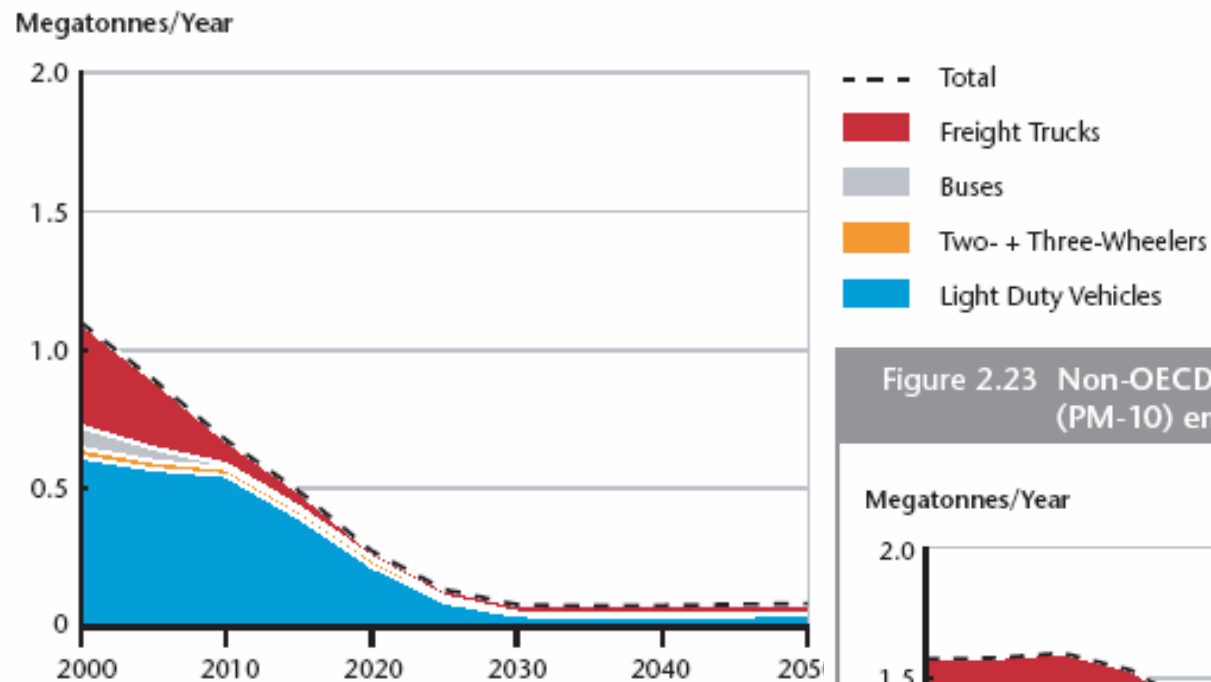


Source: Sustainable Mobility Project calculati

VOC ↓ x 10

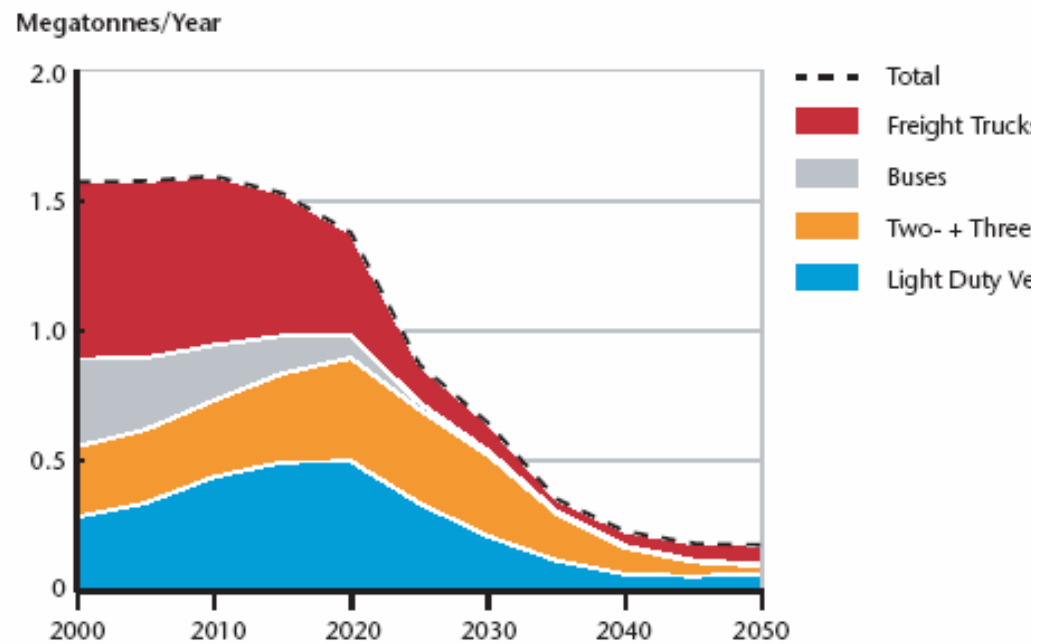
Source: World Business Council for Sustainable Development, Mobility 2030: meeting the challenges to sustainability. -- ISBN: 2-940240-57-4, Geneva, Switzerland.

Figure 2.18 OECD regions: Transport-related Particulate Matter (PM-10) emissions by mode



Background
Vehicle emissions
Future outlook
Conclusions

Figure 2.23 Non-OECD regions: Transport-related Particulate Matter (PM-10) emissions by mode



Source: Sustainable Mobility Project calculations.

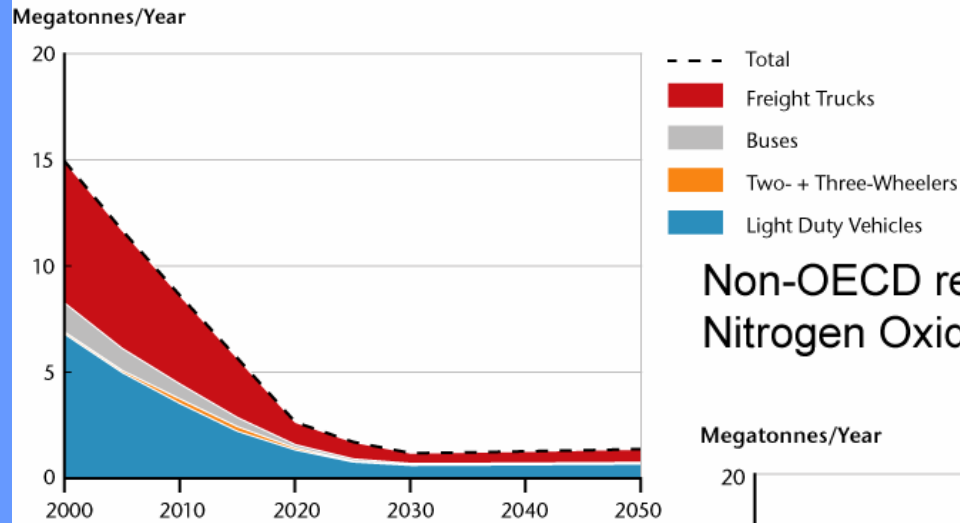
PM ↓ x 6



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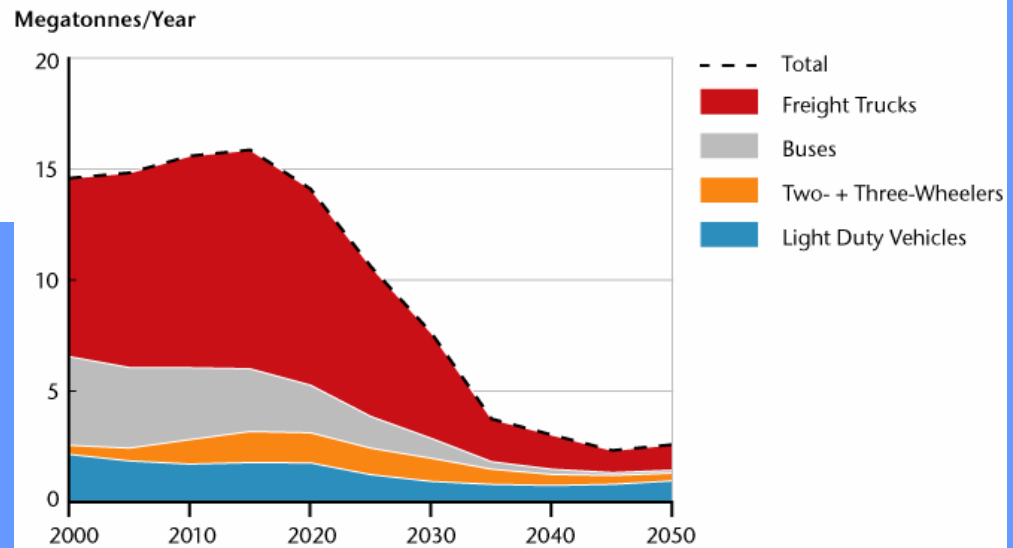
Source: World Business Council for Sustainable Development, Mobility 2030: meeting the challenges to sustainability. -- ISBN: 2-940240-57-4, Geneva, Switzerland.

OECD regions: Transport-related Nitrogen Oxide (NOx) emissions by mode



Source: Sustainable Mobility Project calculations.

Non-OECD regions: Transport-related Nitrogen Oxide (NOx) emissions by mode



Source: Sustainable Mobility Project calculations.

NO_x ↓ x 6

Source: World Business Council for Sustainable Development, Mobility 2030: meeting the challenges to sustainability. -- ISBN: 2-940240-57-4, Geneva, Switzerland.



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Future Outlook



Road transport emissions (2000- 2050):

CO₂ up x 2

CO down x 10

VOC down x 13

NO_x down x 6

PM down x 6



Conclusions

HCs, CO, NO_x, PM, R-134a, N₂O, CH₄ are small
and/or short term issues.

CO₂ is large and long term issue.



Some options to reduce life cycle CO₂ emissions

Background
Vehicle emissions
Future outlook
Conclusions

Ecodriving

Reduce weight

Reduce power

Diesel versus gasoline

Hybrid technology

Biomass derived fuel

Electric vehicles

H₂ ICE (internal combustion engine)

H₂ fuel cell technology

[no “silver bullet” here, need to consider life cycle impacts, systems thinking approach]



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Light Duty Vehicle Emissions

Concluding remarks:

There has been substantial progress in reducing emissions of VOCs (and NO_x and PM) from vehicles.

Climate change is the future challenge

