

## Real performance of buses

**NTM annual member meeting 2014:  
Increasing the credibility of transport  
environmental performance**

**Nils-Olof Nylund 29.4.2014  
VTT Technical Research Centre of Finland**



### Outline

- Defining environmental performance
- Test methodology to assess the performance of buses
- National bus monitoring programme
- Alternative energies
  - what do fuel standards say?
  - OPTIBIO renewable diesel fuel
  - IEA Bus project (several alternative fuels)
  - electric buses
- Summary

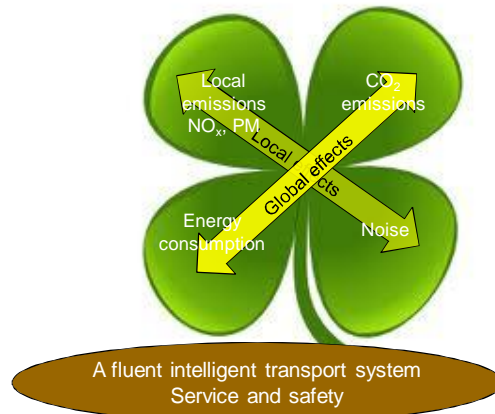


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## Environmental friendliness

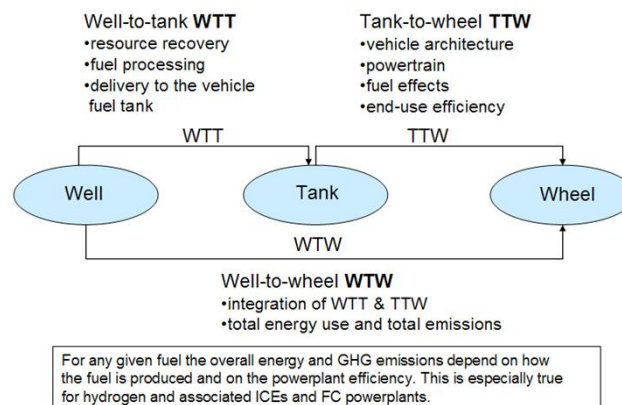
### Multi-dimensional contemplation



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## Well-to-wheel (WTW)



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## Questions to be asked

- From the fleet operators' point of view:
  - Which vehicles provide best fuel and overall economy?
- From the point of view of decision makers and those responsible for bus service procurement:
  - Which vehicles actually deliver low emissions (regulated, CO<sub>2</sub>)?

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## For passenger cars:

- The complete vehicle is tested
- Fuel consumption and CO<sub>2</sub> emissions have to be declared
- Energy efficiency marking on its way
- Emission data (regulated emissions) can be found
- Lifetime mileage 15 \* 20,000 km= 300,000 km
  - ~24,000 litres of petrol or ~18,000 litres of diesel

Energia- merkinnän päästöluokka	Raja-arvot CO <sub>2</sub> -päästöille g/km	CO <sub>2</sub> -päästöä vast. polttoaineenkulutus (pyöristettynä 0,1 l/100 km tarkkuuteen)	
		Bensiini (l/100 km)	Diesel (l/100 km)
A	max. 100	max. 4,3	max. 3,8
B	101 - 120	4,3 - 5,1	3,8 - 4,5
C	121 - 130	5,1 - 5,5	4,5 - 4,9
D	131 - 150	5,6 - 6,4	4,9 - 5,6
E	151 - 175	6,4 - 7,4	5,7 - 6,6
F	176 - 200	7,4 - 8,5	6,6 - 7,5
G	201 -	8,6 -	7,6 -

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## Heavy-duty vehicles

Heavy-duty vehicles (HDV) - trucks and buses - are responsible for about a quarter of CO<sub>2</sub> emissions from road transport in the EU and for some 6% of total EU emissions. Despite some improvements in fuel consumption efficiency in recent years, HDV emissions are still rising, mainly due to increasing road freight traffic.

The Commission is currently working on a comprehensive strategy to reduce CO<sub>2</sub> emissions from HDVs in both freight and passenger transport.

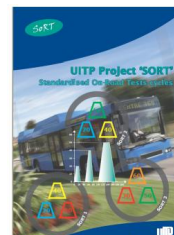
[http://ec.europa.eu/clima/policies/transport/vehicles/index\\_en.htm](http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm)

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## For buses:

- The manufacturer is only obliged to state the emission certification class of the engine itself
- No official regulations for the measurement and reporting of fuel consumption or emissions of the complete vehicle
- The manufacturer might state fuel consumption for the vehicle in accordance with UITP's SORT (Standardised On-Road Test Cycles) methodology
- Lifetime mileage  $15 * 80,000 \text{ km} = 1,200,000 \text{ km}$ 
  - ~500,000 litres of diesel
  - ~25 times higher than for a passenger car



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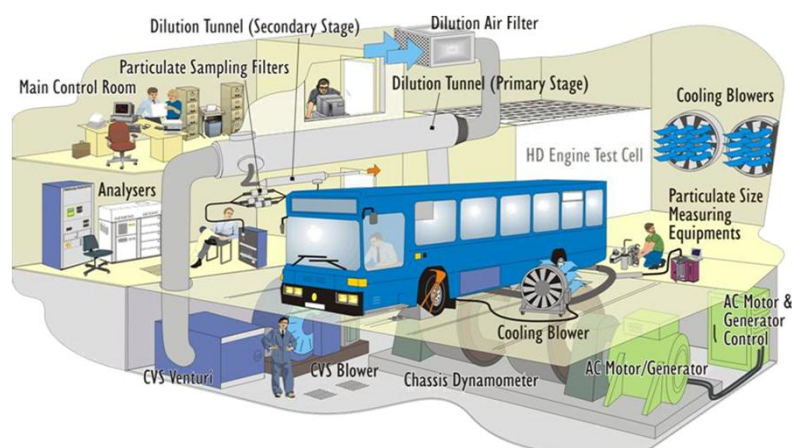
<http://www.uitp.org/publications/pics/bonus/SORT2.pdf>

## Why test complete HD vehicles?

- There is a clear need for a test method to determine emissions and fuel consumption that takes into account the properties of the complete vehicle
  - "real-life" emission and fuel consumption figures (g/km based)
  - effects of payload and driving cycle
  - vehicle-to-vehicle comparisons, checking of in-use vehicles
- Chassis dynamometer testing can meet all these needs
  - accuracy for fuel consumption measurements  $\pm 1 \%$
  - accuracy for emission measurements  $\pm 15 \%$
- Directive 2009/33/EC calls for distance based performance figures
  - operational lifetime cost of the energy consumption, CO<sub>2</sub> emissions and for pollutant emissions

DIRECTIVE 2009/33/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL  
of 23 April 2009  
on the promotion of clean and energy-efficient road transport vehicles  
(Text with EEA relevance)

## VTT's chassis dynamometer



The Finnish Centre for Metrology and Accreditation  
granted accreditation for VTT's measurements in 2003  
Some 350 buses measured already!

Accuracy:  
• Fuel consumption  $\pm 1 \%$   
• Emissions  $\pm 15 \%$

## Strategy of Helsinki Region Transport

### Target 2018

Helsinki region has the most efficient transport system and the most satisfied users of public transport in Europe

### Strategic goals

1. Helsinki region has a well-functioning transport system
2. HSL provides its customers with high-quality, cost-efficient and reasonable priced public transport services
3. **HSL promotes low-emission transport choices**
4. HSL is a player on the field of transport policy
5. HSL's operations support its owner municipalities' and region's development targets
6. HSL has motivated and competent staff

### Basic task

HSL provides extensive transport options and creates conditions for a viable and pleasant Helsinki region.

### Stakeholder expectations

Owner municipalities

Customers

Business and industry

Operators

Civic organizations

State administration



Reijo Mäkinen

15.5.2012

## VTT's bus database

## Cooperation with Helsinki Region Transport



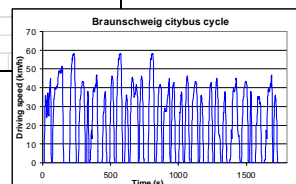
Braunschweig	Count n	Mileage Min	Mileage Max	CO g/km	HC g/km	CH <sub>4</sub> * g/km	NOx g/km	PM g/km	CO <sub>2</sub> g/km	CO <sub>2</sub> eqv** g/km	FC kg/100km	FC MJ/km
2 - axle												
Diesel Euro I	2	555025	672700	1,39	0,32		15,59	0,436	1220	1220	38,6	16,6
Diesel Euro II	13	160500	1125674	1,60	0,21		12,86	0,213	1286	1286	40,7	17,5
Diesel Euro III	14	15934	786164	0,85	0,12		8,48	0,209	1213	1213	38,4	16,6
Diesel Euro IV	8	6105	474152	2,96	0,10		8,36	0,112	1207	1207	38,2	16,5
Diesel Euro V***				2,96	0,10		7,51	0,089	1207	1207	38,2	16,5
Diesel EEV	23	1020	696931	1,07	0,04		6,38	0,080	1167	1167	36,9	15,9
Ethanol EEV	1	98032	98032		0,43		5,58	0,037	1150	1150	65,3	16,5
Diesel Hyb. EEV	4	2602	44620	0,98	0,02		5,70	0,039	844	844	26,7	11,5
CNG Euro II	2	211000	672946	4,32	7,12	6,76	16,92	0,009	1068	1224	42,1	20,7
CNG Euro III	2	37600	237189	0,05	2,64	2,51	9,44	0,019	1111	1168	43,7	21,5
CNG EEV	8	1824	640252	2,78	1,28	1,21	3,17	0,008	1196	1224	47,1	23,2
2 - axle, lightweight												
Diesel****	4	993	26436	0,88	0,03		6,70	0,047	953	953	30,17	13,0
3 - axle												
Diesel Euro V	4	1400	232494	6,68	0,03		3,16	0,089	1414	1414	44,8	19,3
Diesel EEV	6	5444	94910	1,41	0,04		5,50	0,077	1461	1462	46,2	19,9
CNG EEV	5	121773	651529	10,96	1,69	1,61	6,37	0,010	1319	1356	51,9	25,5

\*For CNG vehicles CH<sub>4</sub> = THC \* 0,95, For desels CH<sub>4</sub> = 0

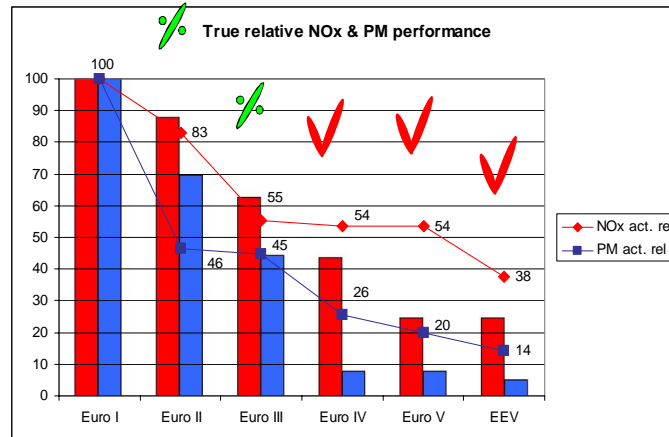
\*\* CO<sub>2</sub> eqv = CO<sub>2</sub> + 23 \* CH<sub>4</sub>

\*\*\* Euro V results are interpolated from Euro IV and EEV results

\*\*\*\* Includes results from emission classes Euro III, Euro IV ja EEV



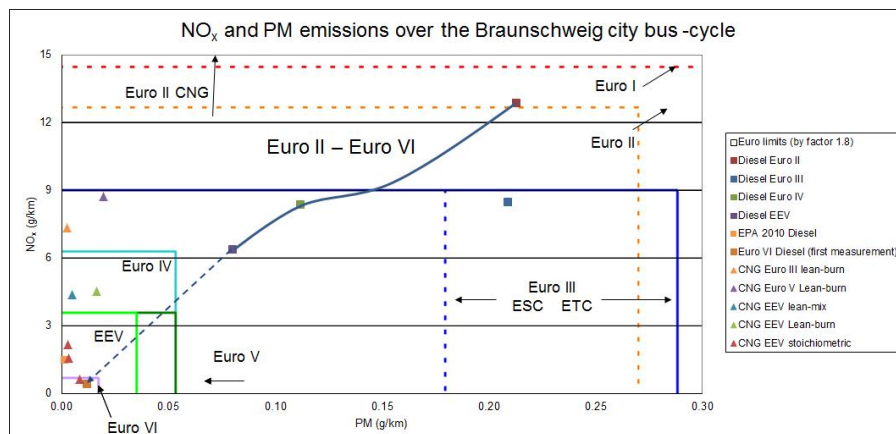
## Limit values vs. true diesel performance



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## NOx & PM emissions



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# Background for fuel specifications

VTT

March 4, 2013

Seppo Mikkonen

seppo.mikkonen@nesteoil.com

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## Specification drivers

### 1. Legislated

- European directives, regulations
- national regulations

### 2. Standardized

- prepared by technical experts in CEN Working Groups
  - oil industry, automotive industry, biofuel industry people
- commented and balloted by national standard bodies (EU + other European countries)
  - Finnish Petroleum Federation, Standardization group 1
- in principle voluntary since not prepared by authorities and not formally accepted by political processes
  - EN 14214 FAME standard legislated by EU

### 3. Fit for purpose

- cars, vans, trucks, buses, non-road mobile machinery, vessels
- different climatic conditions



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Internal for fuel specialists

# 1. Legislated

## Directive 2009/30/EC “FQD”

- exhaust and volatile emissions related properties
  - diesel: cetane number, density, 95 % point, polyaromatics, sulfur, biodiesel (FAME max 7 %), MMT
  - diesel: free use of renewable hydrocarbons (HVO, BTL)
  - gasoline: vapor pressure, octanes, distillation, aromatics, olefins, benzene, oxygenates, MMT, sulfur, lead, labeling of metallic additives (=> can not be used)
  - in force at retail points where vehicles refueled
- minimum GHG reduction; can be pooled between batches and suppliers

## Directive 2009/28/EC “RED”

- minimum bioenergy content; can be pooled between batches and suppliers

## Other regulations

- minimum flash point for safety
- distillation points in custom's CN codes

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# 2. Standardized

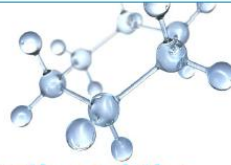
## E.g. EN 590:2013 (B7)

- requirements from FQD and regulations copied 1:1
- vehicle operability and durability related limits
  - cetane index, carbon residue, ash, water, contamination, copper corrosion, oxidation stability, lubricity, viscosity, distillation, cloud point, CFPP, additives in FAME
  - free use of HVO and co-feed as biocomponents, GTL as fossil component (provided that final blend meets EN 590)
- in force at retail points where vehicles refueled
  - if not met, warranties of vehicles not in force, shortened vehicle service intervals may be required
- vehicle owner has to trust on quality since he can not analyze fuel by himself



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Internal for fuel specialists



## The Big Picture: Microbial Growth and the Fuel Supply and Distribution System

**David Pullinger**

European S&D Product Quality Adviser - ExxonMobil

### Why The Renewed Interest?

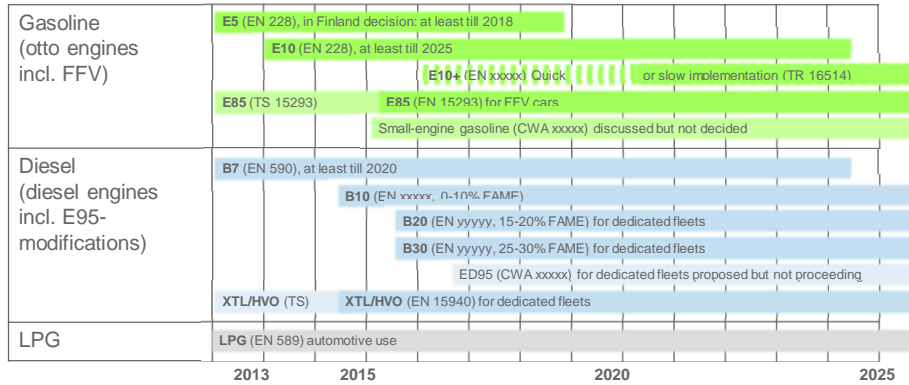


- The occurrence of Microbial Growth has increased in diesel fuels
- This increase coincides with the introduction of FAME blending into ADO
  - ADO containing FAME is more susceptible to microbial growth
  - FAME levels in ADO will continue to rise due to FQD/RED



# Estimated schedules in Europe

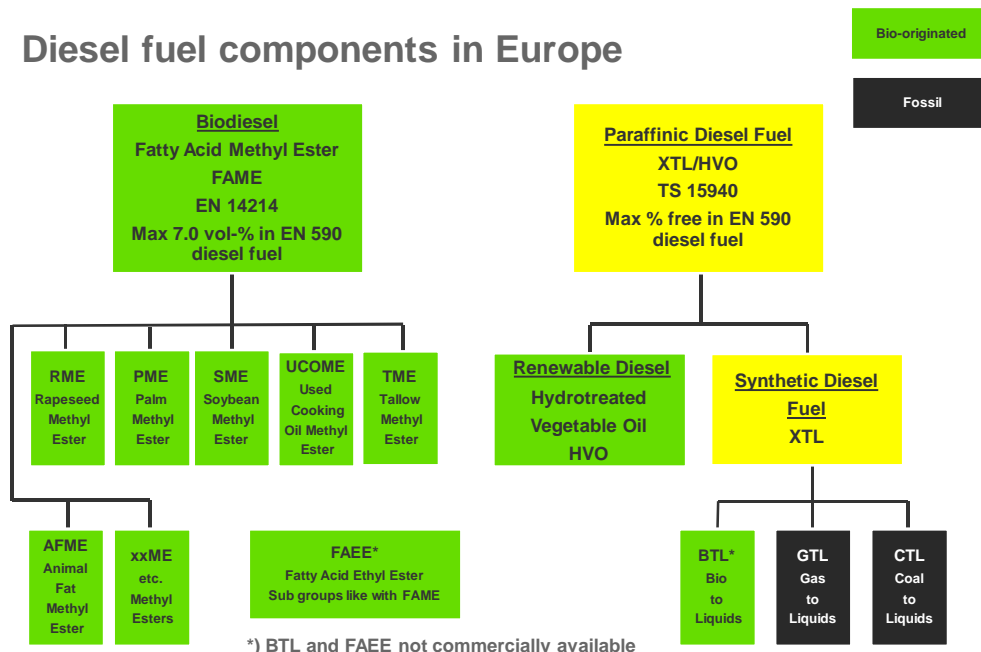
Note! Schedules based on estimations or planned CEN schedules and FQD review



CEN = European Committee for Standardization, CWA = CEN Workshop Agreement, E10+ = 20-25% ethanol or corresponding biocontent, EN = European Standard, LPG = Liquefied Petroleum Gas, TS = Technical Specification, TR = Technical Report, XTL/HVO = paraffinic diesel

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## Diesel fuel components in Europe



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# Bus Fleet Operation on Renewable Paraffinic Diesel Fuel

Reijo Mäkinen, Helsinki Region Transport  
Nils-Olof Nylund & Kimmo Erkkilä, VTT  
Pirjo Saikkonen, Neste Oil  
Arno Amberla, Proventia Emission Control



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JSAE201119172 SAE 2011-01-1965

## Objective of the project

- ▶ The goal of the “OPTIBIO” project was to verify the feasibility of high quality, high concentration “drop-in” biofuels as fuels for urban bus fleets
  - general functionality
  - cold-weather performance
  - compatibility with existing infrastructure and existing vehicles
  - emission benefits
- ▶ In this case, the fuel was paraffinic renewable diesel fuel made by hydrotreatment of vegetable oils and animal waste fats (HVO)



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## Work program

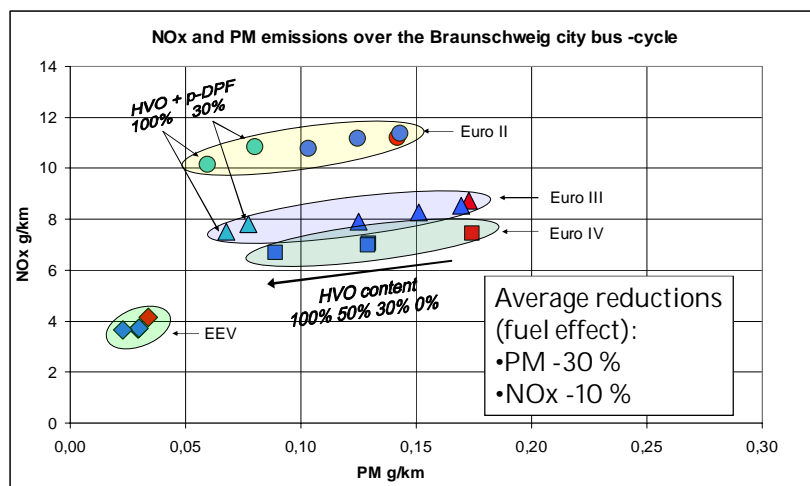
- ▶ Field test with 300 buses
- ▶ Engine and vehicle tests in laboratory conditions
- ▶ Analysis of fuels, lubricants and diesel injection equipment



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## Emissions – summary

For details see JSAE 20119239



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## Conclusions..

- ▶ High quality HVO is the fast track to biofuels implementation
  - a 30 % HVO blend fulfils all current diesel fuel standards
  - a CEN Technical Specification is in place for 100 % HVO
- ▶ HVO can be implemented without any “blending wall” limitations in existing refuelling infrastructure and vehicles over night, delivering significant emission reductions especially for particulate matter, PAH and exhaust toxicity
- ▶ The buses of the OPTIBIO project travelled some 50 million kilometers on HVO fuels, of which some 1.5 million kilometers on 100 % HVO, without any problems in the field



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## ..Conclusions

- ▶ Based on the results of the OPTIBIO project, Scania has decided to allow the use of 100 % HVO (NExBTL) in its engines
  - announcement 26.8.2011
- ▶ Helsinki Region Transport now has confidence in the suitability of HVO for bus services
  - the procurement process for bus services now takes into account services provided running on biofuels (special bonus)
- ▶ The door for HVO (and BTL) is now fully open!



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## IEA Technology Network Cooperation: Fuel and Technology Alternatives for Buses Overall energy efficiency and emission performance



SAE 2012 Commercial Vehicle Engineering Congress

October 2-3, 2012

Rosemont, Illinois USA

Kati Koponen & Nils-Olof Nylund

VTT Technical Research Centre of Finland

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SAE 2012-01-1981



## Bus project objective

- To produce data on the overall energy efficiency, emissions and costs, both direct and indirect costs, of various technology options for buses
- Provide solid IEA sanctioned data for policy- and decision-makers
- Bring together the expertise of various IEA Implementing Agreements:
  - Bioenergy: fuel production
  - AFC & Hydrogen: automotive fuel cells
  - AMF: fuel end-use
  - AMT: light-weight materials
  - Combustion: new combustion systems
  - HEV: hybrids & electric vehicles



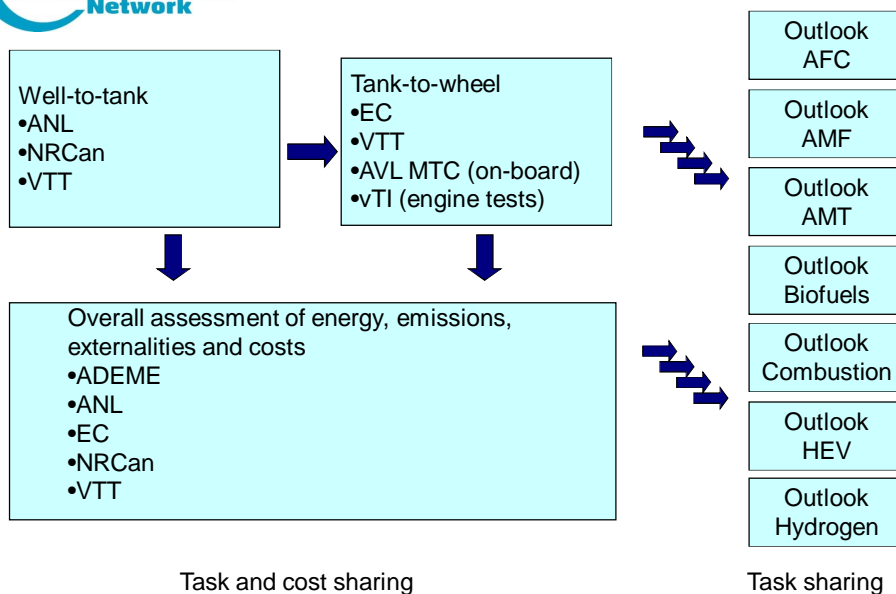
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SAE 2012-01-1981

## Contents

- Well-to-tank analysis
  - based on existing data for various fuel options
  - ranges depending on feedstock and process
- Tank-to-wheel analysis
  - actual testing of the most relevant technology and fuel options
  - fuel efficiency and exhaust emissions
  - effects of driving conditions
  - new vehicles as well as fuel switches for older vehicles
- Well-to-wheel analysis
  - synthesis of WTT and TTW
- Cost estimates
  - direct costs (infrastructure, fuel and vehicle)
  - external costs (valuation of exhaust emissions)



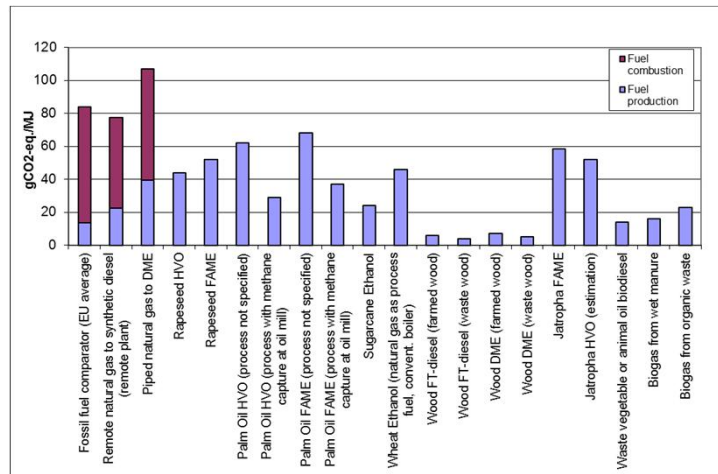
## Elements of the project



Task and cost sharing

Task sharing

## Example of emission factors according to the RED



Sources:  
RED, Directive of the European Parliament of the council on the promotion of the use of energy from renewable sources. 2009/28/EC  
Edwards et al. Well-to-wheels analysis of future automotive fuels and powertrains in the European context.  
Kirkinen et al. Greenhouse impact of fossil, forest residues and jatropha diesel: a static and dynamic assessment.

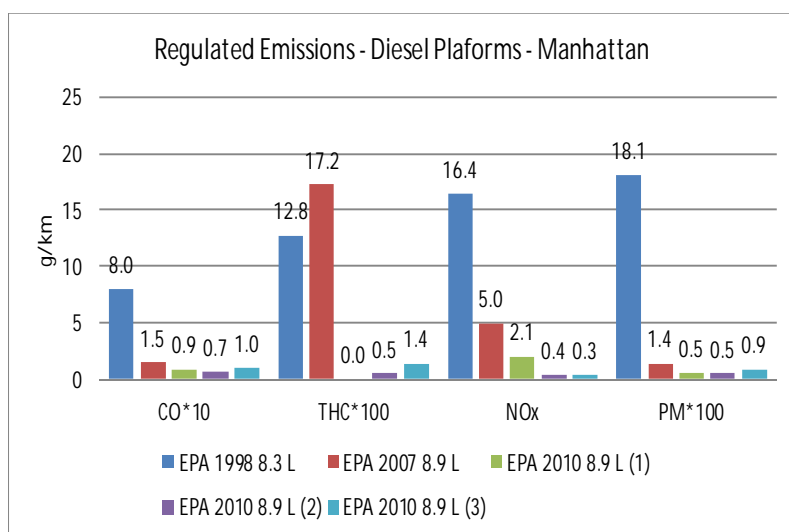
## Environment Canada test matrix

- Vehicles
  - 5 diesel vehicles with conventional powertrain, EPA 1998 - 2010 certification
  - 2 diesel hybrid vehicles, EPA 2007 certification
- Fuels
  - ULSD (commercial, oil-sands derived and certification fuel)
  - biodiesel blends with FAME from canola, soy and tallow
  - in addition, EC tested HVO as a blending component and as such
- Test cycles
  - 7 different test cycles (UDDS, MAN, CBD, OCTA, BRA, ADEME, JE05)
- Total number of combinations evaluated at EC was 68

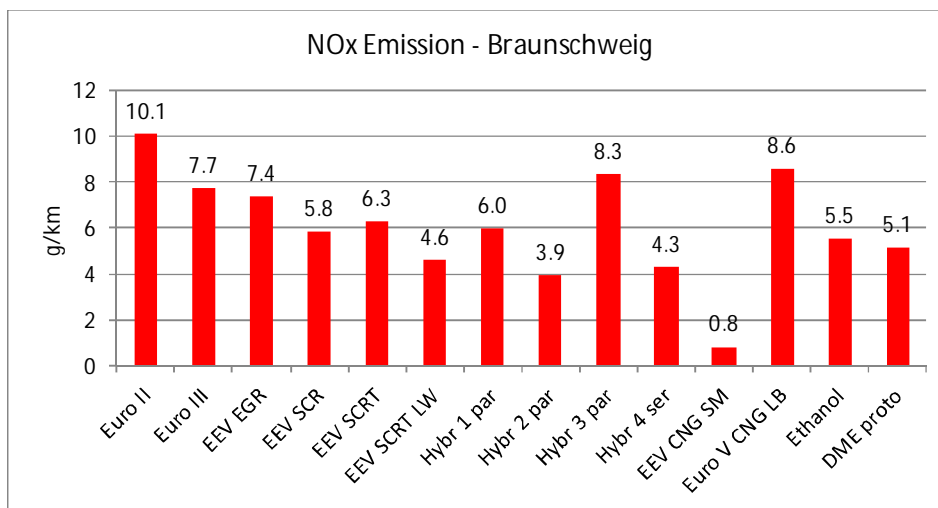
## VTT test matrix

- Vehicles
  - 6 diesel vehicles with conventional power train, Euro II – EEV certification
  - 4 diesel hybrid vehicles
  - 4 alternative fuel vehicles: 2 CNG, 1 ethanol, 1 prototype DME vehicle
- Fuels
  - conventional diesel, paraffinic GTL and HVO, FAME from Jatropha and FAME from rapeseed, straight and blended fuels
  - methane, additive treated ethanol, DME
- Test cycles
  - 6 different test cycles (ADEME, BRA, UDDS, JE05, NYBUS, WTV)C)
- Total number of combinations evaluated at VTT was 112

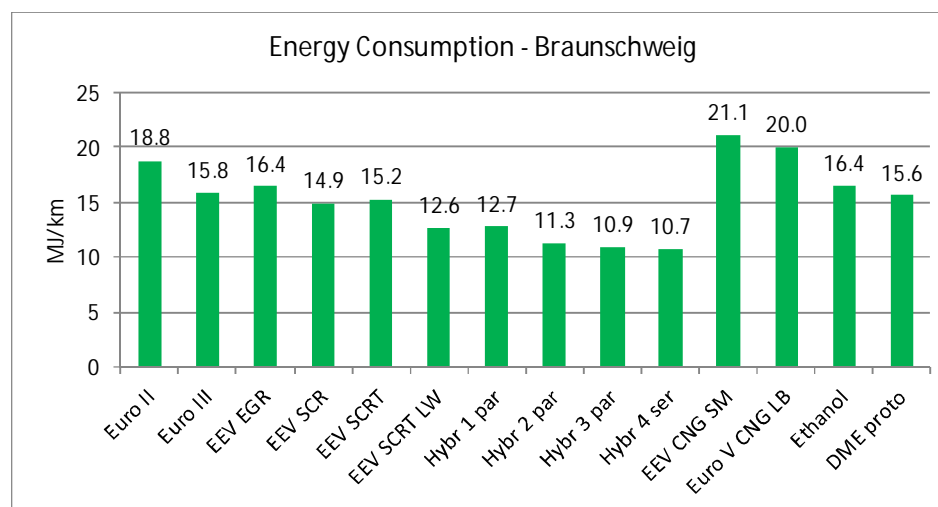
## Regulated emissions North-American vehicles, Manhattan cycle



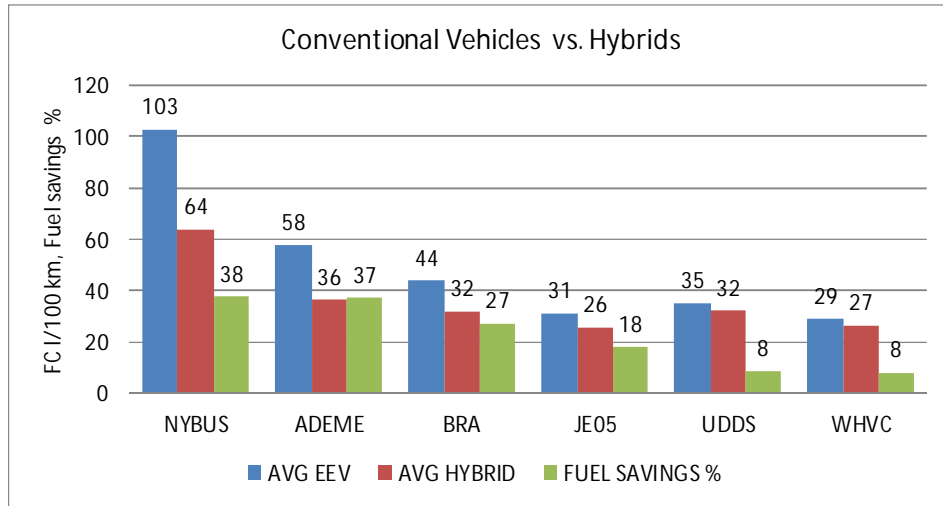
## NOx emissions of European vehicles Braunschweig cycle



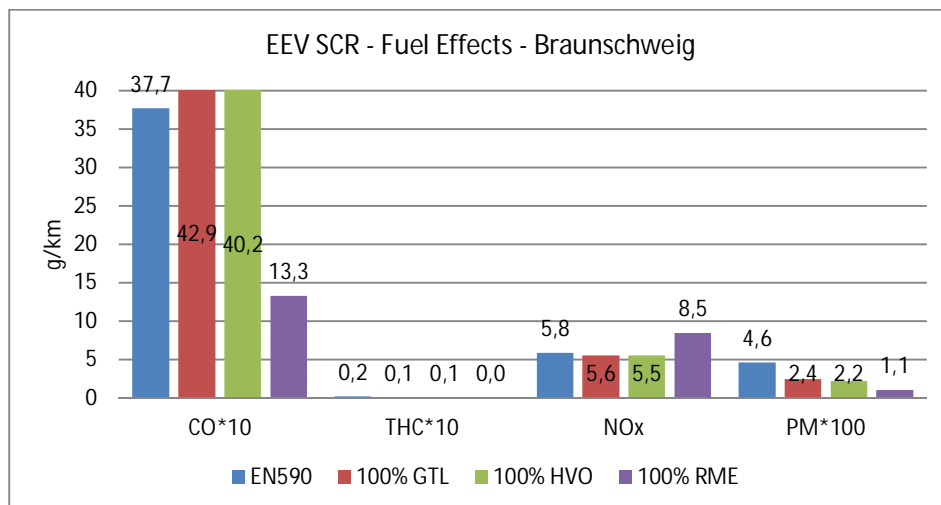
## Energy consumption of European vehicles Braunschweig cycle



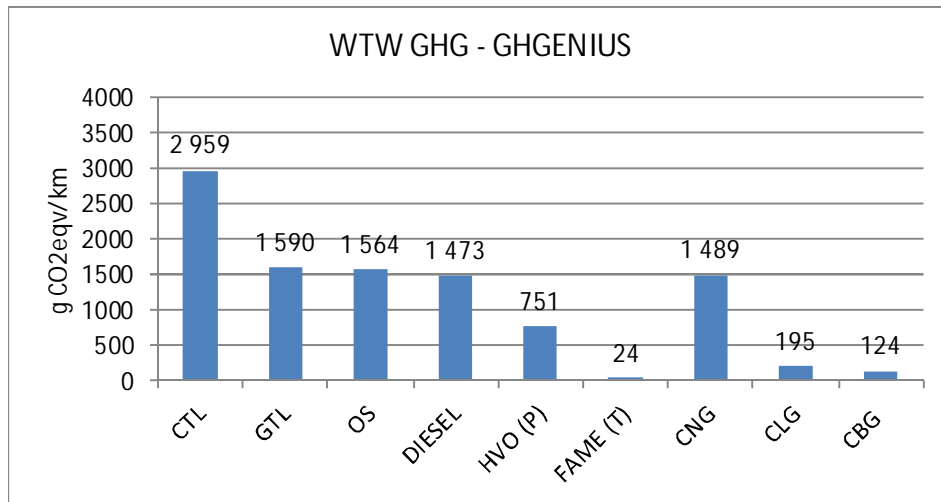
## Fuel savings through hybridization European vehicles



## Fuel effects on emissions



## WTW GHG emissions - GHGenius



## Summary - Vehicle

- Old vs. new diesel vehicles
  - 10:1 and even more for regulated emissions
  - 100:1 for particulate numbers
  - close to neutral for fuel efficiency
- Hybridization and light-weighting
  - 20 - 30 % reduction in fuel consumption
  - not automatically beneficial for regulated emissions
  - energy consumption ratio between the least fuel efficient vehicle with conventional power train and the most efficient hybrid 2:1
- Effect of driving cycle
  - 5:1 for fuel consumption and regulated emissions

## Summary – Fuel performance

- Coal-based synthetic diesel vs. best biofuel for WTW CO<sub>2eqv</sub>
  - 120:1
- Fuel effects on tailpipe emissions (when replacing regular diesel)
  - 2.5:1 at maximum for regulated emissions (particulates)
  - 4:1 for unregulated emissions
- Alternative fuels (in dedicated vehicles)
  - low PM emissions but not automatically low NO<sub>x</sub> emissions
  - fuel efficiency depends on combustion system (compression or spark-ignition)
  - diesel vs. spark-ignited CNG roughly equivalent for tailpipe CO<sub>2</sub>

## Final report available



### Fuel and Technology Alternatives for Buses

Overall Energy Efficiency and Emission Performance

Nils-Olaf Nylund | Kati Koponen



**Fuel and Technology Alternatives for Buses**

In 2009-2011, a comprehensive project on urban buses was carried out in cooperation with E.ON Engineering Systems and Wärtsilä Motor Fuels and Emissions, with input from additional E.ON Engineering Systems. The objective of the project was to generate unbiased and solid data for use by policy- and decision-makers responsible for public transport using buses. The project comprised four major parts: (I) a well-to-tank (WTT) assessment of alternative fuel pathways; (II) an assessment of bus and use (tank-to-wheel, TTW) performance; (III) combining WTT and TTW data into well-to-wheel (WTW) data; and (IV) a cost assessment, including related to well-to-wheel costs.

Experts at Argonne National Laboratory, Natural Resources Canada and VTT worked on the WTT part. The WTT emissions of various fossil fuels and biofuels were assessed by using GREET models from the United States, CHANCE model from Canada and RECI methodology of the European Union. All these models follow the same work of life-cycle assessment.

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ISBN 978-952-10-7466-5 (pdf)

VTT E.ON Energy Research Center IAA Bioenergy

Some 400 pages including a 20-page Executive Summary

<http://www.vtt.fi/inf/pdf/technology/2012/T46.pdf>  
<http://www.iea-amf.vtt.fi/8annexreports.html>



## From well to wheel. Ett helhetsperspektiv på buss och miljö

Energieffektiv kollektivtrafik och elbussar  
Stockholm 9.10.2013



Nils-Olof Nylund & Kimmo Erkkilä  
VTT Technical Research Centre of Finland  
Reijo Mäkinen  
Helsinki Region Transport  
Sami Ojamo  
Veolia Transport Finland



### Will the future be electric?

#### ACTUALITÉ

RATP will be fully electric in 10 years!



**Le président de la RATP a annoncé sa volonté de faire migrer tout son parc d'autobus vers l'électrique, dans l'espoir de stimuler la filière industrielle.**

« Nous avons décidé la migration complète de notre parc de bus vers le tout électrique d'ici 2025 ». En faisant cette annonce lors de la conférence parlementaire sur les transports qui s'est tenue à Paris le mercredi 5 février 2014, Pierre Mongin, P-DG du groupe RATP, vient déjà d'électrifier les industriels présents dans la salle.

Car ce sont 4 500 autobus parisiens qu'il va falloir changer auprès d'une entreprise qui, chaque année, dépense 2,8 milliards d'euros auprès de ses fournisseurs. Or les autobus électriques dont rêve Pierre Mongin n'existent pas encore. « Nous voulons un produit différent de ce qui existe aujourd'hui. La solution est encore à construire. La RATP veut être le prescripteur de cette mutation et permettre l'émergence d'une filière industrielle qui, à terme, deviendra rentable ».

**LE MONITEUR.fr**

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## The Metropolitan Helsinki eBUS project



### The transport system

How do electric buses fit into the public transport system?

- Ministry of Transport
- Helsinki Region Transport
- City of Espoo
- Veolia, Aalto University

Public sector  
Private sector  
Bus operator  
Research organization

### Green Public E-Mobility

### The vehicle

How do electric buses perform?

- Veolia, VTT
- Bus manufacturers (BYD, Caetano, others to follow)
- Component manufacturers (European Batteries, Vacon)
- Transport Safety Agency

### The energy supply

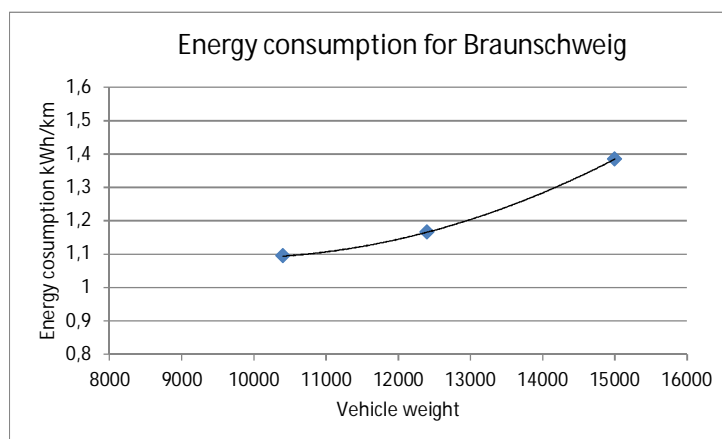
How can electric buses be recharged and how is the grid affected?

- Smart grid and smart bus depot
- Fortum
- Veolia, Metropolia Polytechnic, VTT



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## Energy consumption of an electric bus

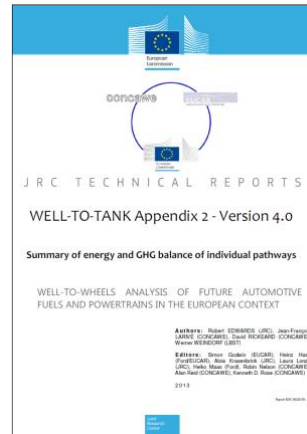


Source: VTT

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## JEC WTW 2013

	WTT MJ/MJ	WTT g CO <sub>2</sub> eq/MJ final fuel
Diesel	0,2	15,4
CNG EU mix	0,16	13
CBG mun. waste	0,99	14,8
BTL waste wood/BL	0,91	2,5



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So what does all this mean?



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## WTW energy use

	Diesel	BTL	Hybrid	Hybrid BTL	CNG	CBG	BEV ren. el.	BEV NG	BEV biogas	BEV solid bio conv.
Final energy (MJ/km, VTT)	15	15	11	11	21	21				
Final energy (kWh/km, VTT)	4,2	4,2	3,1	3,1	5,8	5,8	1,4	1,4	1,4	1,4
WTW factor (JEC 2013)	1,2	1,91	1,2	1,91	1,16	1,99				
Power generation 1/n (Ecofys, JEC 2013) *)							1	2,1	2,1	2,6
Gas production & transport (JEC 2013)								1,09		
Gas production % clean-up (derived JEC 2013)									1,5	
Transmission factor (est.)							1,05	1,05	1,05	1,05
Total WTW energy (kWh/km)	5,0	8,0	3,7	5,8	6,8	11,6	1,5	3,4	4,6	3,8
Total WTW energy (MJ/km)	18	29	13	21	24	42	5	12	17	14

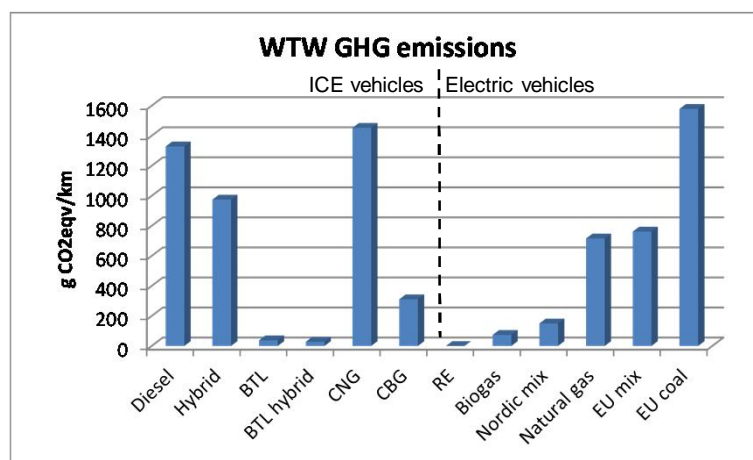
\*) 2,1 ~ 48 % eff., 2,6 ~ 38 % eff.



For a given amount of gas or solid biomass,  
you get 1,5 – 2,5 times more mileage going the electric route!

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## WTW GHG



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## Summary

- VTT carries out multidimensional assessment on bus performance in cooperation with Helsinki Region Transport (HRT)
- HRT uses the data to formulate policies and to develop the tendering systems for bus service procurement
- Over the last 15 years, tightening emission regulations and improved engine and exhaust after-treatment technology have reduced regulated emissions dramatically
  - however, the reductions in real-life emissions are smaller than indicated by the emission certification classes
  - Euro VI looks promising
- On the engine side the improvements in fuel efficiency have not been that spectacular, but hybridization and light-weighting can reduce fuel consumption

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## Summary

- The largest variations and also uncertainties can be found for WTW CO<sub>2eqv</sub> emissions, or in fact the WTT part of the CO<sub>2eqv</sub> emissions
- The most effective way to reduce regulated emissions is to replace old vehicles with new ones
- The most effective way to cut GHG emissions is to switch from fossil fuels to efficient biofuels or low-carbon electricity in electric buses

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