E.1.1 Vehicle investment costs

Data for vehicle investment costs has been made available by different sources, the table in picture E-2a illustrates the raw data variations found.

Vehicle costs	Wibera 2005/2006 articulated bus [€/Jahr]	BOGG 2009 [SFR/km]	Gaz de France [€]	Faltenbacher /SSB 2007 standard bus [€]	Faltenbacher /SSB 2007 articulated bus [€]	Eberwein/ BVG 2008 standard bus [€]	USA 2003 [$]	ÜSTRA Hannover 2008 standard bus [€]	ÜSTRA Hannover 2008 articulated bus [€]
Diesel bus	43232	0,58	209000	260000	355000	270000	285000	278000	376000
CNG-bus	48231	0,697	244000	299000	408000		310000	317000	414000
Diesel-Hybrid				312000	426000		420000		470000
CNG-Hybrid				359000	490000				
Fuel cell/Hydrogen						470000			
Fuel cell-Hybrid				500000	630000				

Picture E-2a: Vehicle investment costs of different bus technologies (raw data)

To allow an easier comparison the table has been converted in percentages – using Diesel vehicles as a reference (=100), see picture E-2b.

Vehicle costs	Wibera 2005/2006 articulated bus	BOGG 2009	Gaz de France	Faltenbacher /SSB 2007 standard bus	Faltenbacher /SSB 2007 articulated bus	Eberwein/ BVG 2008 standard bus	USA 2003	ÜSTRA Hannover 2008 standard bus	ÜSTRA Hannover 2008 articulated bus
Diesel bus	100	100	100	100	100	100	100	100	100
CNG-bus	112	120	117	115	115		109	114	110
Diesel-Hybrid				120	120		147		125
CNG-Hybrid				138	138				
Fuel cell/Hydrogen						174			
Fuel cell-Hybrid				192	177				

Picture E-2b: Vehicle investment costs of different bus technologies (percentages)

It is obvious that all sources see higher investment costs for all alternatives to Diesel buses. Those range from about 10-20% additional costs for CNG buses, 20-40% for hybrid buses up to 70-90% for hydrogen/fuel-cell applications.

Recent Swiss studies assume about 1.0 – 1.1 Mio SFR for an articulated trolleybus (≈ 680000 – 750000€) which results in additional costs of about 100% compared to articulated Diesel-buses. However, one should calculate modern trolleybuses with a lifespan of at least 20 years which is compensating the cost increase to some extent.

Absolute cost differences between Diesel and CNG-buses are about 40000€ per bus, between Diesel and Diesel-Hybrid about 80000€ can be assumed.

E.1.2 Fuel consumption, energy efficiency and fuel costs

Raw data for fuel consumption is illustrated in picture E-3a.

Energy consumption	INFRAS/ Schaffhausen 2008 [%]	LVB 2008 articulated bus [l/km]	BOGG 2009 [l/km]	Wibera 2005/2006 articulated bus [l/km]	NOVATLANTIS Olten 2005 [l/km]	NOVATLANTIS Glarus 2005 [l/km]	Eberwein/ BVG 2008 standard bus [l/km]	Dresden tests 2007 articulated bus [l/km]	ÜSTRA Hannover 2008 [l/km]
Dieselbus	100	0,575	0,443	0,606	0,407	0,36	0,44	0,571	0,481
Hybridbus	81	0,475						0,493	
Trolleybus	52	*2kWh/km*							
CNG-bus	137		0,565	*0,538kg/km*	*0,41kg/km*	*0,41kg/km*			*0,491 kg/km*
Biogas-bus	137								
Hydrogen							*0,17kg/km*		

Picture E-3a: Energy/fuel consumption of different bus technologies (raw data)

To make consumption data comparable it is first of all required to convert all data in “liter Diesel equivalent” (see picture E-3b), which is done by a calculation integrating the different energy content of fuels. Doing so, 1 kg CNG is equivalent to 1.32l Diesel, 1kg Hydrogen to about 3.2l Diesel, 1 kWh to about 0,10l Diesel.

Energy consumption	INFRAS/ Schaffhausen 2008 [%]	LVB 2008 articulated bus [l/km]	BOGG 2009 [l/km]	Wibera 2005/2006 articulated bus [l/km]	NOVATLANTIS Olten 2005 [l/km]	NOVATLANTIS Glarus 2005 [l/km]	Eberwein/ BVG 2008 standard bus [l/km]	Dresden tests 2007 articulated bus [l/km]	ÜSTRA Hannover 2008 [l/km]
Dieselbus	100	0,575	0,443	0,606	0,407	0,36	0,44	0,571	0,481
Hybridbus	81	0,475						0,493	
Trolleybus	52	0,169							
CNG-bus	137		0,565	0,710	0,541	0,541			0,648
Biogas-bus	137								
Hydrogen							0,544		

Picture E-3b: Energy/fuel consumption of different bus technologies (l/km Diesel equiv)

Picture E-3c compares all consumption results to the Diesel consumption which is used as a reference (=100).

Energy consumption	INFRAS/ Schaffhausen 2008 [%]	LVB 2008 articulated bus [%]	BOGG 2009 [l/km]	Wibera 2005/2006 articulated bus [l/km]	NOVATLANTIS Olten 2005 [l/km]	NOVATLANTIS Glarus 2005 [l/km]	Eberwein/ BVG 2008 standard bus [l/km]	Dresden tests 2007 articulated bus [l/km]	ÜSTRA Hannover 2008 [l/km]
Dieselbus	100	100	100	100	100	100	100	100	100
Hybridbus	81	83						86	
Trolleybus	52	29							
CNG-bus	137		128	117	133	150			135
Biogas-bus	137								
Hydrogen							124		

Picture E-3c: Energy/fuel consumption of different bus technologies (percentages)

The table confirms two things:

⇒ a reduced consumption for hybrid Diesel buses of about 15-20%, a range which is also confirmed by other sources.

⇒ an increased consumption for CNG-buses (includes biogas buses) of about 30-40%, lower and higher results seem to be reasoned by local factors (regional cycles?).

The consumption percentages for the trolley bus which are derived from Schaffhausen and the Leipzig source (see red numbers in picture E-3c) need some clarification as they clearly represent only the electric efficiency “at wire” but do not include the total production process of electric energy and the losses involved with it! In this respect it is not a fair comparison with the two fossil fuels!

A similar comment can be made regarding hydrogen: the Berlin source did not present data on the hydrogen production route (see chapter C.5) but one should assume that also here the total efficiency is considerably lower as indicated by “only” 24% higher consumption then Diesel!

A number of fuel cost data from different sources are illustrated in pictures E-4a/b.

Costs/km	TL2007 [SFR/km]	Wibera 2005/2006 [€/km]	BOGG 2009 [SFR/km]	Gaz de France 600000km/ 10years [€/bus-10y]	NOVATLANTIS Olten 2005 [SFR/year-bus]	NOVATLANTIS Glarus 2005 [SFR/year-bus]
Electric	0,394					
Gas	0,414	0,389	0,326	126000	16500	33600
Diesel	0,655	0,52	0,423	249000	24600	23900

Picture E-4a: Fuel cost comparison (raw data)

Costs/km	TL2007 [%]	Wibera 2005/2006 [%]	BOGG 2009 [%]	Gaz de France 600000km/ 10years [%]	NOVATLANTIS Olten 2005 [%]	NOVATLANTIS Glarus 2005 [%]
Electric	60					
Gas	63	75	77	51	67	141
Diesel	100	100	100	100	100	100

Picture E-4b: Fuel cost comparison (percentages)

The comparisons confirm that CNG costs/km usually are about 30-40% lower then Diesel costs/km and this fact must be seen in most cases the driving force for running gas buses, at least as long as the fuel cost savings over-compensate the higher consumption and result overall in a reduction of operating costs. The boom in implementing CNG as a fuel alternative was starting about the time when the oil price started to increase much stronger then the gas price (see picture C-14b), ecological advantages which were given at that time placed an additional argument!

Kostenvergleich (2): Treibstoffpreis Erdgas ist ein zentraler Unterschied im Beispiel Olten und Glarus.

	Einheit	Olten	Glarus
Fahrleistung	Km / Jahr	65000	65000
Verbrauch Diesel	l /100 km	40.7	36.0
Verbrauch Erdgas	kg / 100 km	41.0	41.0
Dieselpreis nach Rückerstattung	CHF / l	0.93	1.02
Erdgaspreis nach Rückerstattung	CHF / kg	0.62	1.26
Energiekosten Diesel	CHF / Jahr	24600	23900
Energiekosten Erdgas	CHF / Jahr	16500	33600

Tabelle 5: *Vergleich von Fahrleistung, Treibstoffverbrauch und -preis mit den resultierenden Energiekosten, für die Busbetriebe in Olten und Glarus.*

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Picture E-5: Gas cost comparison of Olten and Glarus (both Switzerland)

(Source: NOVATLANTIS/EMPA)

However, as the Olten-Glarus comparison illustrates in picture E-5, gas costs mustn't be similarly "inviting" everywhere – even within a rather small country like Switzerland there appear rather large cost differences reasoned by local supply costs and also policies of the energy supplier! As pointed out before, it is very difficult to forecast how oil and gas prices will develop over time and whether the remaining economical advantage of CNG-buses will stay.

Costs for biofuel have already been given in chapter C (see picture C-13 illustrating the German situation in 2006) – principally one can assume slightly lower fuel costs compared to Diesel for most biofuels except BtL. Hydrogen prices depend also on production routes, Faltenbacher/Wiedemann speak of 1.3 €/l Diesel equiv. for steam reforming and of 2.4 €/l for electrolysis, for both assuming electricity costs of 10 cent/kWh and 5 cent/kWh for gas.

E.1.3 Operational costs

As with other cost data presented, also for operational costs of different bus types a variety of sources has been available. Again not all data is easily comparable, as some sources include driver costs others show comparisons without those as they are not influenced by technology choice.

Total operational costs	Basler/ Winterthur 2002 [SFR/km]	BERNMOBIL 2006 [%]	TL2007 [%]	Infras /Schaffhausen 2008 [%]	BOGG 2009 without driver [SFR/km]
Diesel	7,45	100	100	100	1,027
Trolley	9,21		144		
Gas	7,75			101	1,075
Biogas		105			

Picture E-6a: Total operational costs comparison (raw data)

Total operational costs	Basler/ Winterthur 2002 [%]	BERNMOBIL 2006 [%]	TL2007 [%]	Infras /Schaffhausen 2008 [%]	BOGG 2009 without driver [%]
Diesel	100	100	100	100	100
Trolley	124		144		
Gas	104			101	105
Biogas		105			

Picture E-6b: Total operational costs comparison (percentages)

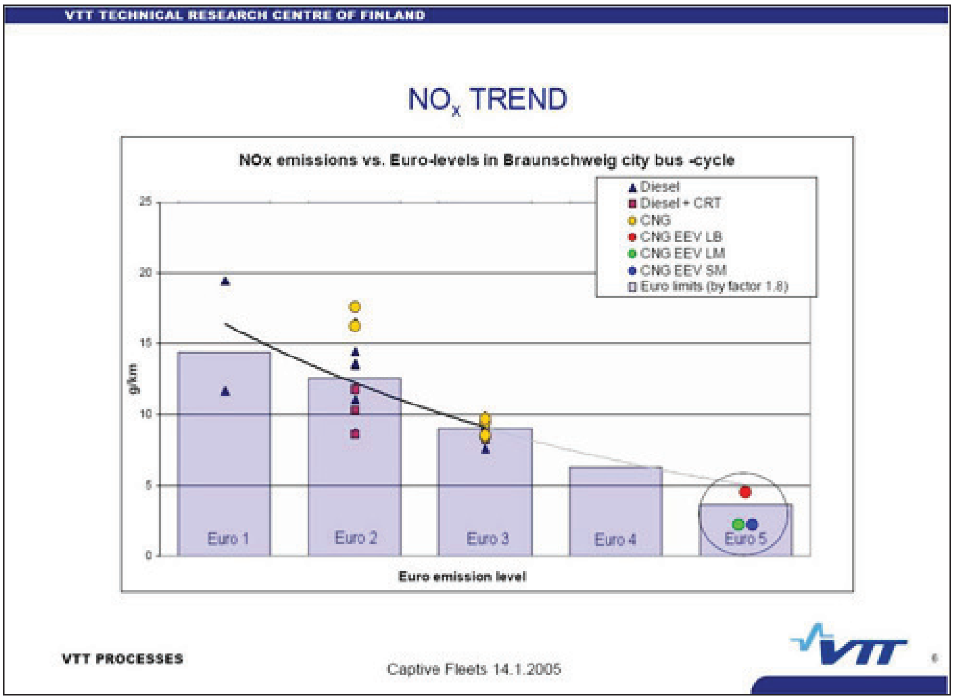
It is, however, evident that total costs for gas and biogas application are only slightly higher than the Diesel reference while the trolley is given about 20-40% more expensive.

E.2 Ecological comparisons

Similarly to the economic cost chapter also for the ecological comparisons the majority of background information will be found in the appendix.

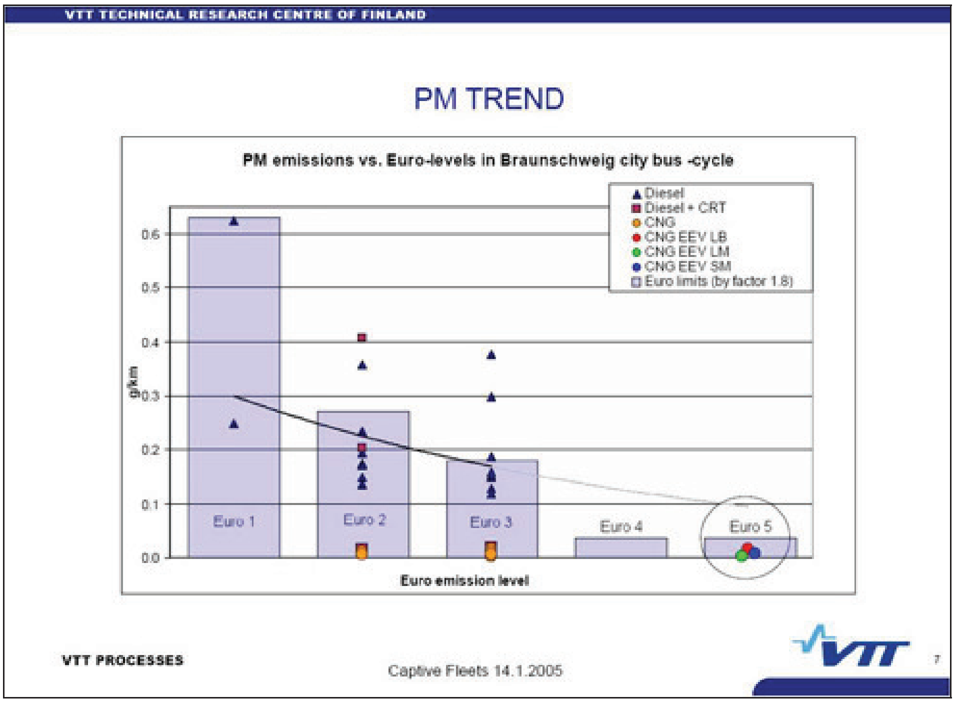
E.2.1 Emissions and emission trends

Emissions are always a result of applied standards and the technology used, as it is nicely illustrated in the two diagrams in pictures E-7a/b.



Picture E-7a: NOx emissions for Diesel and Gas alternatives

(Source: VTT)

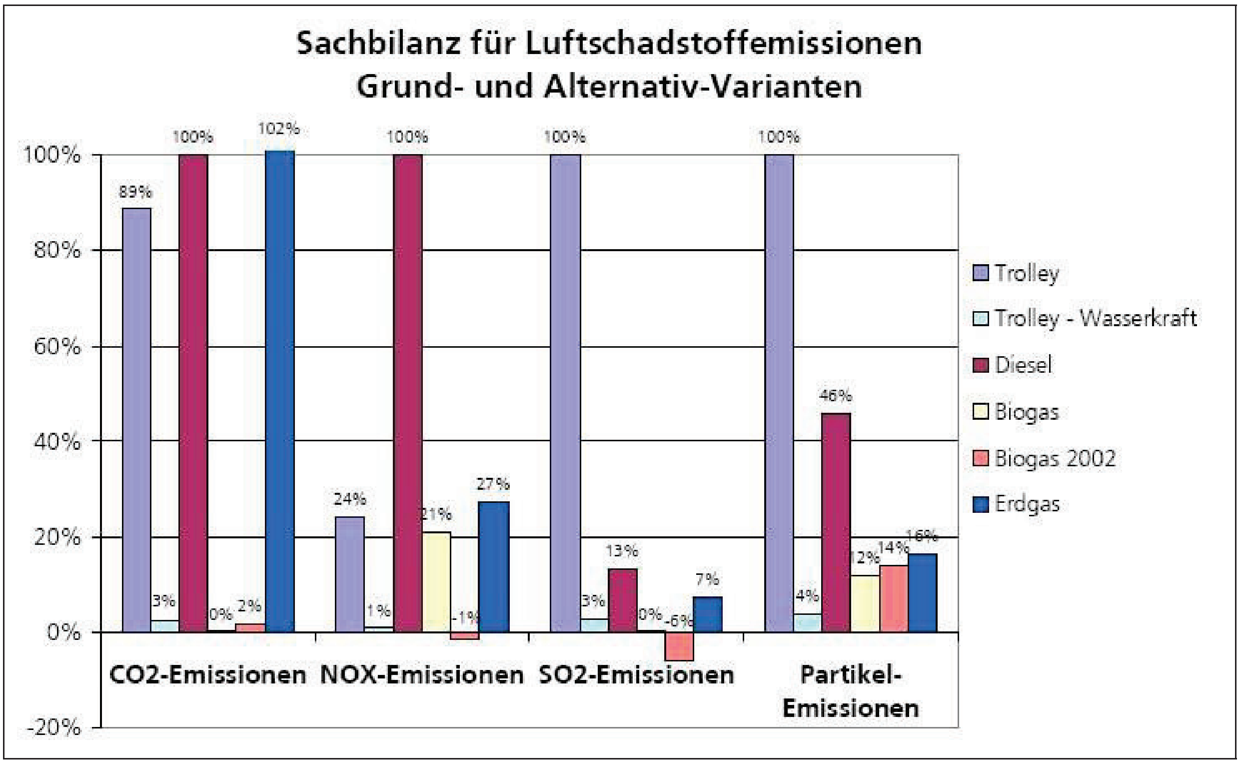


Picture E-7b: PM emissions for Diesel and Gas alternatives

(Source: VTT)

The diagrams illustrate measured emissions for Diesel and CNG buses of different brands and with different EURO 1-3 levels and the trend towards EURO 5. It becomes also clear that the development in EURO standards will definitely bring Diesel and CNG technology on the same level ("in the same small corner"), even more with the upcoming EURO 6 standard (2013). See also chapter C.1 in this regard.

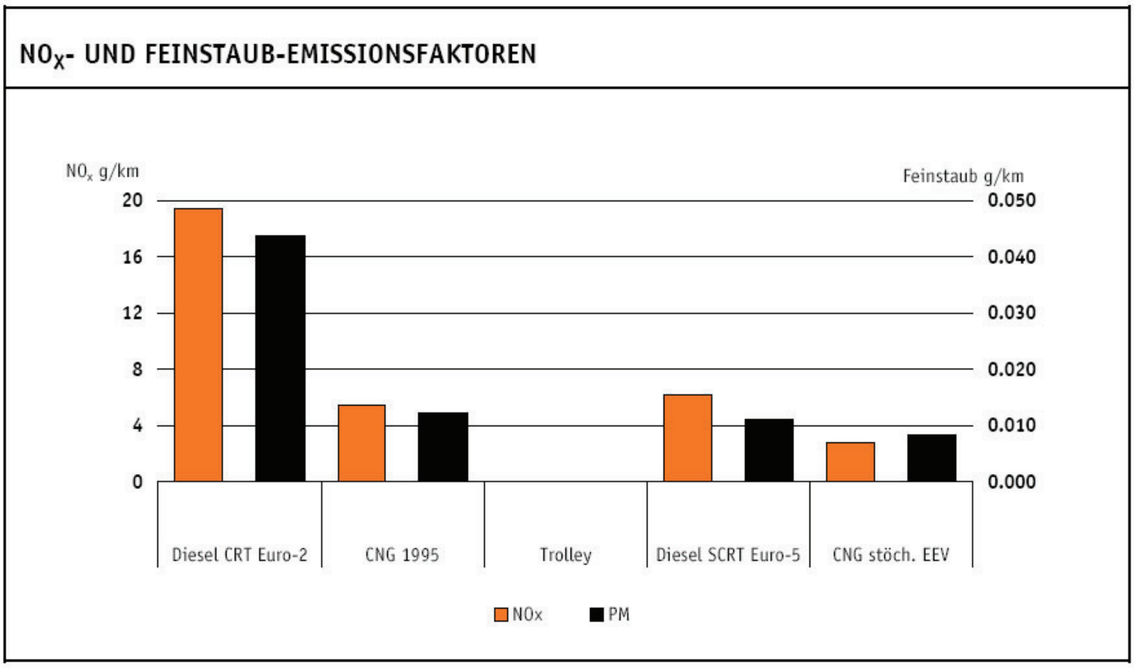
It is also easily understandable that any technology comparisons (i.e. between Diesel and gas technology) made during EURO 3 times will deliver results which are different from results which would be achieved when answering the very same question today! This statement relates certainly only to emissions which are touched by those standards, thus older results related to the CO2 subject may still be relevant.



Picture E-8: Winterthur 2002 – emissions of different technologies

(Source: Basler)

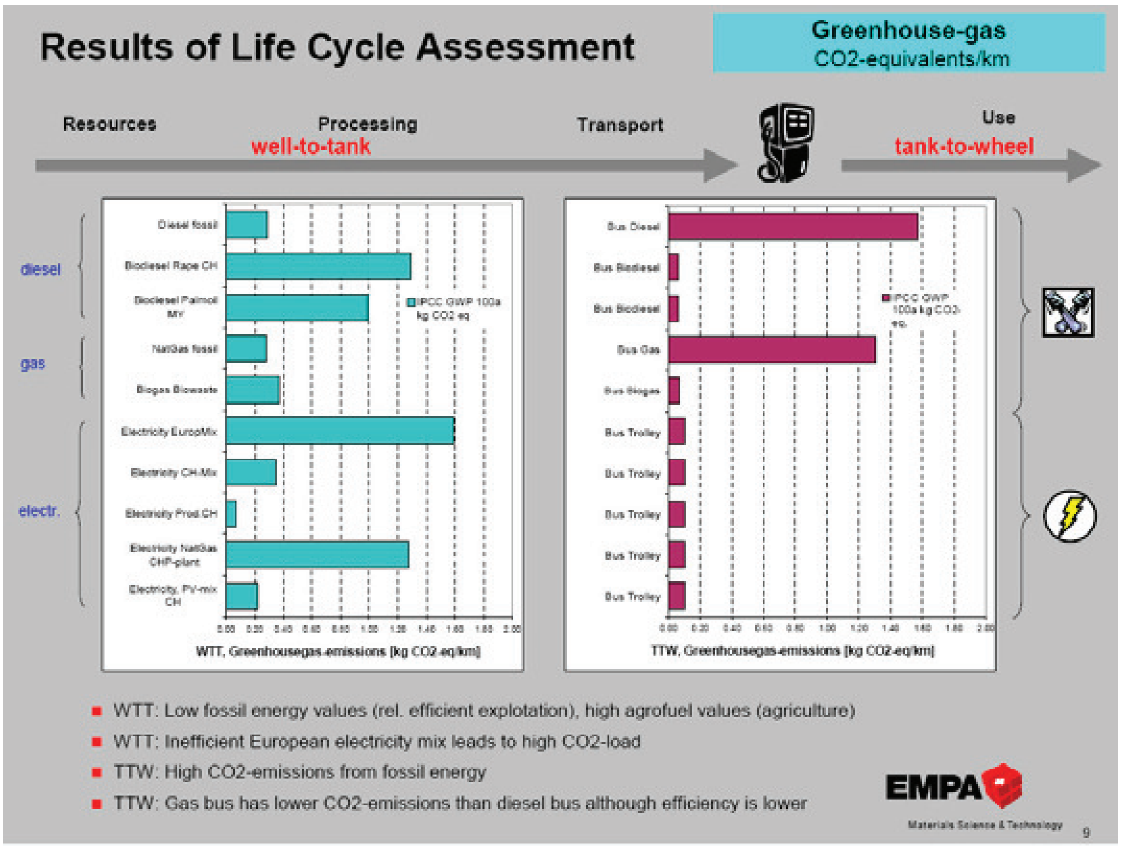
Picture E-8 illustrates the comparison made within the 2002 study for Winterthur, based on EURO 3 standards applied for the Diesel alternative. While the CO2 results would not have changed in the meantime the regulated emissions (local air quality) are certainly no more valid today. It should also be mentioned that the PM comparison between a trolley-bus based on European Mix and its competitors is not fully fair – the particulates emitted during electricity production are different, involving larger and less dangerous particles and appearing likely in less densely populated areas while the Diesel and CNG emissions take place in urban streets where population density will be much higher. This is illustrated perfectly in picture E-9 which compares NOx and PM emissions od Diesel Euro 5 (SCRT) not only with CNG (EEV) and trolley but also with Diesel Euro 2 (CRT).



Picture E-9: Basel 2006 – emissions of different technologies

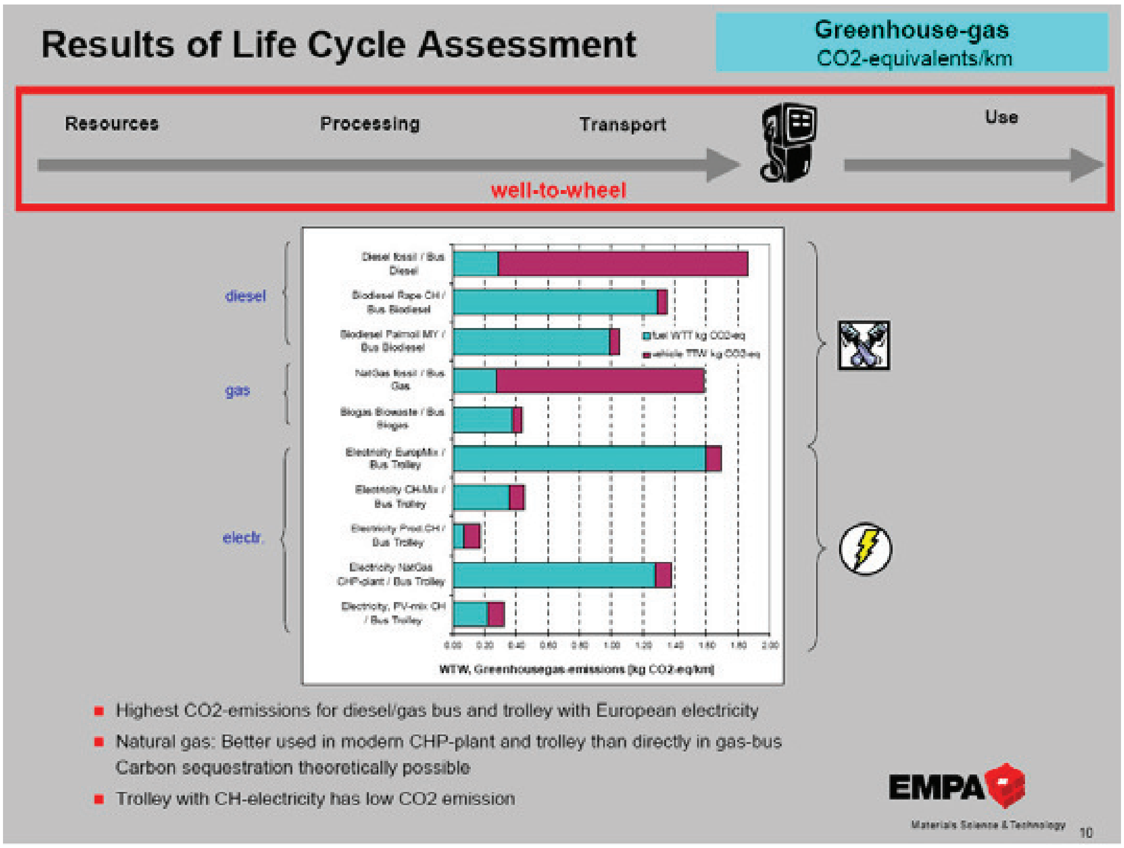
(Source: INFRAS)

Pictures E-10a and b illustrate the CO2 emissions of different fuel types (fossil + renewable) both with regard to the well-to-tank / tank-to-wheel phases and the total result.



Picture E-10a: EMPA life cycle analysis of different fuel aternatives

(Source: EMPA)



Picture E-10b: EMPA life cycle analysis of different fuel aternatives

(Source: EMPA)

It is evident that in the total balance (picture E-10b) Diesel is leading, a trolley with European electricity mix comes in second and CNG third. Interesting is the fourth rank which is made by electricity produced from natural gas in a combined heat and power plant (CHP-plant). This means that burning CNG in a state-of-the-art power plant (including heat use!) is more sustainable than direct use as a fuel in a bus! This option is only slightly worse than Bio-Diesel from rape! It is interesting to look for the latter in picture E-10a and one notices that this Bio-Diesel option is ranking very bad in the well-to-wheel (production) phase, on the same level as CNG burnt in a CHP-plant, but much better than Diesel or CNG. Fossil Diesel and CNG show a dramatically different result, however, in the tank-to-wheel (operation) phase, which contribute heavily to the overall result.

Compared to all other emission, noise has had to step back a bit in the discussion but at least shortly the situation is described here. There is a general opinion (evidence) that gas buses are less noisy than Diesel buses which is confirmed by the IVECO diagram in picture E-11.