# 8 DEVELOPMENT TRENDS

In the transportation sector the reduction of harmful exhaust emissions and greenhouse gases will continue to direct the technical development of both fuels, engines, aftertreatment systems and complete vehicles.

Natural gas will surely play a role in achieving these goals. Natural gas, being an inherently clean fuel with no aromatic compounds and very low sulphur, will always be at an advantage over conventional fuels regarding toxic emissions. However, as discussed in previous sections, at least in the case of spark-ignited engines the decisive factors for emissions are the fuel control system and the exhaust gas aftertreatment system.

Compared to the investments in conventional technology for gasoline and diesel, most vehicle and engine manufacturers have so far put limited effort into developing engines for gaseous fuels. The bulk of the world fleet of gas fuelled vehicles are simple aftermarket converted vehicles, which do not fulfil the criteria for low emissions. Natural gas is best used in dedicated vehicles, although some recent OEM light-duty bi-fuel vehicles perform very well.

The best gasoline vehicles of today are extremely clean. In order to achieve corresponding emission levels, simple retrofit systems for gaseous fuels are not good enough. In markets with stringent emission legislation, future gas vehicles will have to have very sophisticated fuel and exhaust aftertreatment systems, and these vehicles will most probably be sold through OEM dealer networks. In order to achieve proper calibration of the fuel system, close co-operation between the supplier of the gas system and the auto manufacturer is needed. The oncoming requirements for OBD will add difficulties to the process, i.e. extensive calibrations of the fuel system and tuning of the catalyst systems will be needed.

Although the OBD requirement will be a big challenge for the alternative fuel vehicle sector, in the case of light-duty vehicles the engine technology itself is not the biggest obstacle for NGVs in achieving a significant market position. The biggest obstacles are probably related to the fuel storage and refuelling infrastructure. The best natural gas vehicles perform very well, they have enough power and they are extremely clean. However, the fuel storage can make intrusions in the passenger or luggage compartment. A good OEM bi-fuel system could be a solution to optimise fuel storage or overcome problems related to an inadequate refuelling system.

The situation is somewhat different for heavy-duty vehicles. Most buses and a great part of trucks are used in fleet operations. Therefore the question of fuel supply is technically easy, if not always cheap to handle.

The conventional diesel engine is very hard to be beaten for fuel efficiency and durability. It is not enough that gas engines perform well in certain laboratory tests, they should perform well also under normal driving conditions year after year. There are still some shortcomings regarding gas engine technology, both in the case of efficiency, performance

and engine durability. Heat is a rather common problem. However, work at the OEMs is going on to solve these issues. The ultimate goal is direct-injected gas engines with diesel-like efficiency and reliability.

The future diesel engines, running on high-quality diesel fuel and equipped with De-$NO_x$ systems and/or particulate traps, will be very clean. OEMs' views differ on the future of competitiveness of gas engines, as some say that the gas engines will become less attractive as the diesel becomes cleaner, while others think that the gas engines will have a good chance as the emission regulations are becoming more stringent.

The best gas engines of today can meet all foreseeable emissions requirements, so there is actually no expected rise of costs of meeting future emission standards. The diesel is becoming more complex, and this of course will increase the cost of the diesel engine, and might also affect reliability and/or efficiency in a negative way. As the diesel engine takes up the competition for cleanliness, the gas engines have to take up the competition for efficiency.

To facilitate the tuning of the engine for maximum fuel efficiency and driveability one may consider the use of De-$NO_x$ devices on lean-burn and direct injected gas engines. Being a virtually sulphur-free fuel, natural gas is better than diesel for aftertreatment systems, as even high-quality diesel fuel will contain traces of sulphur. To maximise this advantage, however, the sulphur contained in natural gas odorants should be kept tpo appropriately low levels. Therefore work to develop no-sulphur odorants is under way.

One can also speculate whether there will ever be really high quality diesel fuel available for all markets, as the requirements on crude oil quality and refinery technology will limit supply and increase costs compared to conventional diesel. Natural gas is an abundant clean fuel which in theory is not limited by supply or refinery capacity.

In both light-duty and heavy-duty gas vehicles one can distinguish a trend which was seen earlier in gasoline vehicles: a shift from mechanical fuel systems (carburettors) to single-point fuel-injection systems to continuous multi-point fuel injection and ultimately to adaptive sequential multi-point fuel injection systems or even direct-injection systems. Accurate fuel metering is one of the most critical items for good emission performance.

Natural gas will be challenged by other fuel alternatives in engine applications, and the reciprocating internal combustion engine again will be challenged by fuel cells and other power sources. Fuel cells can be fuelled by natural gas, but there are many other fuels, e.g. liquid hydrocarbon mixes, methanol and of course hydrogen competing to become the future fuel for them.

In some visions natural gas is an intermediate step moving from conventional liquid fuels towards hydrogen in the future. BMW has stated that "the path towards hydrogen starts with natural gas, and in the foreseeable future there is only one sensible and really meaningful alternative to the petrol and diesel engine: the natural gas engine". Figure 8.1 illustrates this way of thinking /142/.

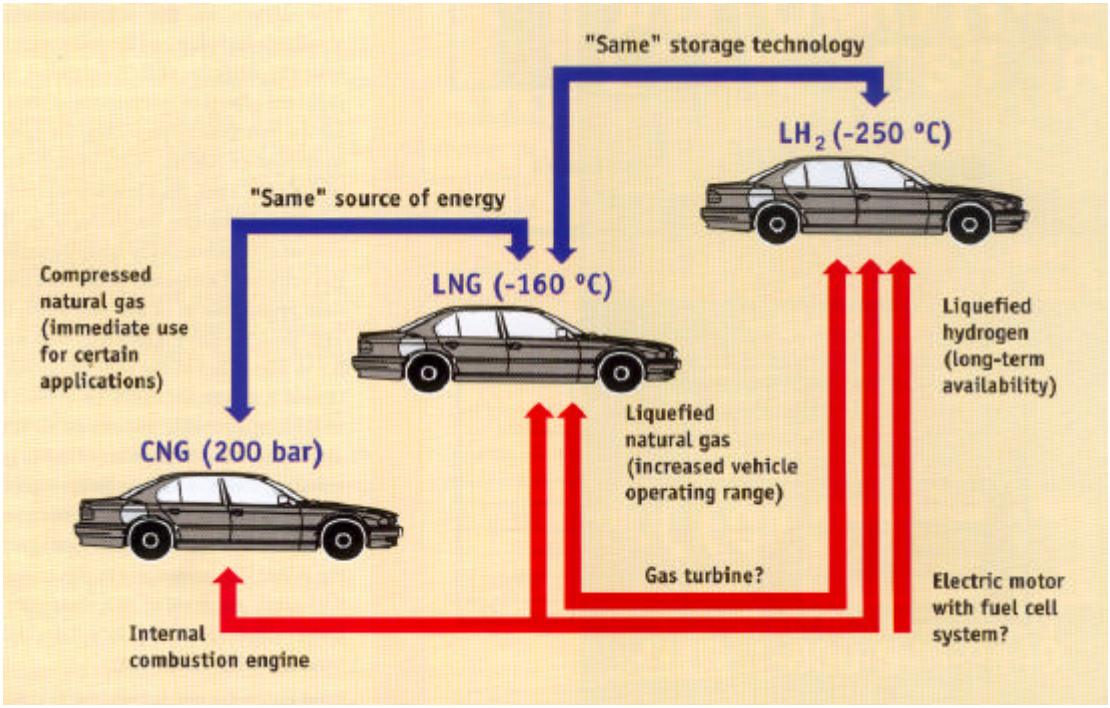


*Figure 8.1. From natural gas to hydrogen /142/.*

One can see that natural gas provides a good alternative for vehicles and transportation systems of different levels of sophistication:

- in less sophisticated applications, replacing both gasoline and diesel with natural gas gives considerable reductions in toxic emissions and especially in particulate emissions from diesel vehicles
- in sophisticated vehicles, natural gas, being a practically sulphur-free fuel with low exhaust component reactivity, is helpful in achieving SULEV emissions levels, and for heavy-duty vehicles, natural gas brings down emissions below all foreseeable emission limits
- in the future, natural gas will be a good starting point for on-site or on-board reforming of hydrogen for fuel cell vehicles

There are very promising natural gas technologies available for vehicle applications. To really make a breaktrough, the natural gas vehicles need support from the OEM manufacturers to resolve remaining technical problems. Also investments in adequate refuelling networks and market deployment of natural gas vehicles are needed.

# 8 REFERENCES


1. Obländer, K., Abthoff, J. & Schuster, H.-D. Der Dreiwegkatalysator - eine Abgasreinigungstechnologie für Kraftfahrzeuge mit Ottomotoren. In: Proc. Emissionsminderung Automobilabgase - Ottomotoren. Düsseldorf: VDI Verlag, 1984. (VDI Berichte 531). ISBN 3-18-090531-X.

2. Koberstein, E. Anforderungen an Autoabgaskatalysatoren unter Europäischen Einsatzbedienungen. In: Proc. 6. Wiener Motoren-Symposium. Düsseldorf: VDI Verlag, 1985. (VDI Fortschrittsberichte, Reihe 6 Energitechnik/Wärmetechnik Nr. 173). ISBN 3-18-147306-5.

3. Kishi, N. et al., Technologies for Reducing Exhaust Gas Emissions in Zero Level Emission Vehicles. Warrendale: SAE International, 1999. (SAE 1999-01-0772).

4. Laurikko, J., On exhaust emission from petrol-fuelled passenger cars at low ambient temperature. Doctoral Thesis. Espoo: Technical Research Centre of Finland, 1998. (VTT Publications 348). ISBN 951-38-5234-2

5. Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to the measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC. Luxembourg: The European Parliament and The Council, 13 October 1998.

6. Mori, K., Worldwide Trends in Heavy-Duty Diesel Engine Exhaust Legislation and Compliance Technologies. Warrendale: SAE International, 1997. (SAE 970753).

7. Boehner, W. & Hummel, K., Common Rail Injection Systems for Commercial Diesel Vehicles. Warrendale: SAE International, 1997. (SAE 970345).

8. Rantanen, L. et al., Effect of Fuel on the Regulated, Unregulated and Mutagenic Emissions of DI Diesel Engines. SAE International, 1993. (SAE 932686).

9. Nylund, N-O. et al., Effects of Physical and Chemical Properties of Diesel Fuel on $NO_x$ Emissions of Heavy-Duty Diesel Engines. SAE International, 1997. (SAE 92997).

10. Smedler, G. et al., Diesel Catalysts for Europe Beyond 1996. Automotive Engineering. Vol 104, Nr. 10, October 1995.

11. Heimrich, M.J., Demonstration of Lean-$NO_x$ Catalytic Converter Technology on a Heavy-Duty Diesel Engine. SAE International, 1997. (SAE 970755).

12. Laurikko, J. & Kytö, M. Moottoriajoneuvojen pakokaasupäästöt. Mittaaminen, lainsäädäntö ja päästöjen vähentämistekniikka [Motor vehicle exhaust emissions. Test procedures, legislation and emission control technology]. Espoo: Technical Research Centre of Finland, 1993. (VTT Research Notes 1501). ISBN 951-38-4435-8. (In Finnish).

13. Nylund, N-O., Traffic emission abatement and fuel technology. Co-operation in environmental field between Finland and Japan. Seminar on Environmental Policy and Technology. Espoo, FI, 15 - 17 June 1998. Technology Development Centre TEKES. Helsinki. (1998).

14. Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC. Luxembourg: The European Parliament and The Council, 13 October 1998.

15. The ZEUS project. www.zeus-europe.org

16. Nylund, N-O. et al., Performance evaluation of alternative fuel/engine concepts 1990 - 1995. Final report including addendum of diesel vehicles. Espoo: Technical Research Centre of Finland, 1996. (VTT Publications 271).

17. Stenersen, D., NGC projekt: Gassmotorer for kraft/varmeproduksjon, teknologier for emisjonsbegrensninger. Slutrapport [NGC project: Gas engines for power and heat production, emission control technology. Final Report]. Trondheim: Marintek, 1990. (In Norwegian).

18. Lenaers, G., Comparison of real traffic fuel consumption and emissions for latest bus technologies in Brussels. International Workshop: "New energy-saving and environmentally friendly technolgogies for busses and trucks. Brussels, BE, 29 April 1998. Vlaamse Instellning voor Technologisch Onderzoek (VITO), 1998.

19. Gas for transportation- Gas vehicles. IGU SG 6.3 Final Report November 1999. (To be published at the IGU Word Gas Conference in Nice, June 2000).

20. Loy, I., Caterpillar Dual Fuel Engines. Proc. Natural Gas Vehicles Conference 1999. Sydney, 12-14 April 1999. IANGV/Australasian Natural Gas Vehicles Council, 1999.

21. The Evolution of the World's Energy Systems. London: Shell International Limited (SIL), 1996.

22. Hart, H., Organic Chemistry. A Short Course. Seventh Edition. Boston: Houghton Mifflin Company, 1980.

23. Nylund, N-O., On the development of a low-emission propane engine for heavy-duty urban vehicle applications. Doctoral Thesis. Espoo: Technical Research Centre of Finland, 1995. (VTT Publications 260). ISBN 951-38-4798-5.

24. Gaseous fuels for engines. Warrendale: SAE International, 1991. 92 p. (SAE SP-888). ISBN 1-56091-184-0.

25. Elam, N., Raw materials and conversion. Automotive Fuels Survey, Part 1. Breda: Innas BV, Göteborg: Atrax Energi Ab, 1996. (Report of IEA AMF Automotive Fuels Information Service).

26. Maakaasu. Tuotetiedote syyskuu 1994 [Natural gas. Product information September 1994]. Espoo: Gasum Oy, 1994. (In Finnish).

27. Autoteknillinen käsikirja [Automotive handbook]. Helsinki: Suomen Autoteknillinen Liitto ry, 1986. (Translated from Kraftfahrtechnisches Taschenbuch, Stuttgart: Robert Bosch GmbH, 1984). ISBN 951-9155-09-0. (In Finnish).

28. Fleming, R. D. & Bechtold, R. L. Gaseous transportation fuels: a study. Automotive Engineering, 1982. Vol. 90, No. 8.

29. Klimstra, J. Carburettors for gaseous fuels - on air-to-tuel ratio, homogenicity and flow restriction. Warrendale: SAE International, 1989. (SAE Paper 892141).

30. Quader, A., Single-Cylinder Engine Facility to Study Cold Starting- Results with Propane and Gasoline.In Proc. SECC 1992 Subzero Engineering Conditions Conference. Warrendale: SAE International, 1992. (SAE P-248).

31. Körner, W. D. Abgasverhalten von Nutzfahrzeugmotoren. In: Proc. Emissionsminderung Automobilabgase-Dieselmotoren. Düsseldorf: VDI Verlag, 1985. (VDI Berichte 559). ISBN 3-18-090559-X.

32. Clark, G. H. Industrial and marine fuels reference book. London: Butterworth and Co., 1988. ISBN 0-408-01488-1.

33. Klimstra, J. Interchangeability of gaseous Fuels - the importance of the Wobbe-Index. Warrendale: Society of Automotive Engineers, 1986. (SAE Paper 861578).

34. Ekelund, M., Egnell, R. & Gabrielsson, R. Naturgas som kolvmotorbränsle [Natural gas as a fuel for piston engines]. Stockholm: Styrelsen för teknisk utveckling, 1989. STU Information nr 751-1989). ISBN 91-7850-317-5. (In Swedish).

35. Dietrich, W. R., Gegenüberstellung des Schadstoffverhaltens moderner Verbrennungsmotoren im stationären wie im Nutzfahrzeugbetrieb. MTZ Motortechnische Zeitschrift, 1991. Vol. 52, No. 6..

36. Kanury, A. M. Introduction to combustion phenomena. London: Gordon and Breach Science Publishers, 1975.

37. MacCarley, C. A. Hydrogen fuel applications for urban transit. In: Proc. Soc and Aerosp Technol Workshop. North Hollywood: Western Period Company, 1979.

38. Brandberg, Å., Ekelund, M., Johansson, L. & Roth, A. The life of fuels. Motor fuels from source to end use. Stockholm: Ecotraffic Ab, 1992. ISBN 91-88370-09-7.

39. Pohjanpalo, S., Ilmastonmuutoksen torjunta stimuloi uutta tekniikka. [Fighting the climate change will stimulate new technology]. Tekniikan Näköalat, 1999, no. 4. (In Finnish. Publisher TEKES).

40. Nubuo, I., MITI/NEDO Advanced Clean Energy Vehicles Project. Co-operation in environmental field between Finland and Japan. Seminar on Environmental Policy and Technology. Espoo, FI, 15 - 17 June 1998. Technology Development Centre TEKES. Helsinki. (1998).

41. Verbeek, R. et al., Global assessment of Dimethyl-ether as an automotive fuel. Delft: TNO Road-Vehicles Research Institute, 1996. (TNO Report 96.OR.VM.029.1/RV).

42. Walwijk, M. van et al., Distribution and use. Automotive Fuels Survey, Part 2. Breda: Innas BV, Göteborg: Atrax Energi Ab, 1996. (Report of IEA AMF Automotive Fuels Information Service).

43. Rijkeboer, R. et al., Potential Impact of Four Different Car Fuels on the Dutch Environment. Warrendale: SAE International, 1994. (SAE Paper 941914).

44. Mangelsdorf, I. et al., Durchfuhrung eines Risikovergleiches zwischen Dieselmotoremissionen und Ottomotoremissionen hintsichtlich ihrer kanzerogenen und nicht kanzerogenen Wirkungen. Berlin: Erich Schmidt Verlag, 1999. (Berichte 2/99).

45. Mitsubishi DI Gasoline Engine Prototype. Automotive Engineering (Vol. 103), September 1995.

46. Nylund, N-O. & Mäkelä, S., The Finnish Experience with Heavy-Duty Gas Fuelled Vehicles. International Workshop: "New energy-saving and environmentally friendly technolgogies for busses and trucks. Brussels, BE, 29 April 1998. Vlaamse Instellning voor Technologisch Onderzoek (VITO), 1998.

47. Duggal, V.K., Cummins Natural Gas Products and Field Experinces. In: Proc. NGV'96, The Fifth International Conference and Exhibition on Natural Gas Vehicles. 1996. Kuala Lumpur: IANGV, 1996.

48. Eklund, T., Kytö, M. & Nylund, N-O., Lean-burn-kaasumoottoreiden päästöjen minimointi voimantuotannossa [Minimisation of exhaust emissions of gas engines for power production]. Espoo: Technical Research Centre of Finland, 1997. (VTT Tiedotteita - Meddelanden - Research Notes : 1813). ISBN 951-38-5088-9. (In Finnish).

49. Jönsson, L. et al., Volvo THG103- A Low Emission CNG Engine. In: Proc. NGV 92, The Third International Conference & Exhibition on Natural Gas Vehicles. Gothenburg: IANGV, 1992.

50. Weide, J. van der, Haas, J. de, Ling, J. A. N. van, Rijke, J. de & Steen, M. van der. CNG city bus engine with optimized part-load efficiency, high mean effective pressure and low emissions. In: Proc. NGV 94, The Fourth International Conference & Exhibition on Natural Gas Vehicles. Toronto: IANGV,1994.

51. Clarke, D. P. & Such, C. H. Development of a medium duty, turbo-charged, lean burn natural gas engine. In: Proc. NGV 92, The Third International Conference & Exhibition on Natural Gas Vehicles. Gothenburg: IANGV, 1992.

52. Schoenmakers, P., New Energy Efficient and Environmentally Friendly Technologies for Buses and Trucks. International Workshop: "New energy-saving and environmentally friendly technolgogies for busses and trucks. Brussels, BE, 29 April 1998. Vlaamse Instellning voor Technologisch Onderzoek (VITO), 1998.

53. Gaudio, R., The IVECO Attitude to Environmental Problems. International Workshop: "New energy-saving and environmentally friendly technolgogies for busses and trucks. Brussels, BE, 29 April 1998. Vlaamse Instellning voor Technologisch Onderzoek (VITO), 1998.

54. Bruner, G., Chmela, F. & Pachta-Reyhofen, G. Flüssiggasbetrieb bei Omnibussen. Wien: Österreichische Automobilfabrik ÖAF - Gräf & Stift Aktiengesellschaft, 1989.

55. Oberkirch, U., Mercedes-Benz Erdgas Niederflur-Linienomnibusse O 405 N/ O 405 GN. Forum Erdgas-Busse, Hannover 5- 9.9 1994. Stuttgart: Mercedes-Benz AG, 1994.

56. www.detroitdiesel.com

57. Cole, J.J. et al., Development of the Hercules GTA3.7L and GTA5.6L Engines for Low Emissions using an Open-Chamber Lean-Burn Combustion System. In: Proc. NGV 92, The Third International Conference & Exhibition on Natural Gas Vehicles. Gothenburg: IANGV, 1992.

58. Hammarberg, G., Scania Natural Gas Engine Development. In: Proc. NGV 92, The Third International Conference & Exhibition on Natural Gas Vehicles. Gothenburg: IANGV, 1992.

59. Natural gas and biogas. Volvo Buses and alternative fuels. Göteborg: Volvo Bus Corporation, 1997.

60. Hollemans, B. & Schmal, P. Light and heavy duty engine equipment developments within the Netherlands for gaseous fuel usage. In: Proc. NGV 92, The Third International Conference & Exhibition on Natural Gas Vehicles. Gothenburg: IANGV, 1992.

61. Century CNG System. Pensacola, FLA: Pacer Industries, 1985.

62. Einang, P. M., Valberg, I. & Gausen, H. Emission optimized lean-burn gas engine using open-loop electronic control system. In: Proc. NGV 92, The Third International Conference & Exhibition on Natural Gas Vehicles. Gothenburg: IANGV, 1992.

63. Material from GFI Control Systems, Inc. Kitchener, 1999.

64. Jaasma, A. M. Development of multi point CNG metering technology. In: Proc. Metha Motion 1993. Amsterdam: Metha Motion, 1993.

65. Koltec News: Multi point gas injection system. LPG & CNG. Breda: Koltec Autogas Systems, 1993.

66. Transcom Natural Gas Vehicle Systems (NGVS). Electronic Fuel Injection. Hersman: Transcom Engine Corporation Limited, 1999.

67. Gaudio, R., The New Generation of IVECO CNG Engines. In: Proc. NGV 98, The Sixth International Conference & Exhibition on Natural Gas Vehicles. Cologne: IANGV, 1998.

68. Kok, P. de, Application of LPG in Heavy-Duty Engines. In: Proc. European Conference and Exhibition LPG: A Clean and Efficient Motor Fuel, Maastricht 1995. Utrecht: NOVEM, 1995. ISBN 90-72130-75-8.

69. Matsuura, H. et al., HONDA Dedicated CNG Passenger Vehicle. In: Proc. NGV'96, The Fifth International Conference and Exhibition on Natural Gas Vehicles. 1996. Kuala Lumpur: IANGV, 1996.

70. US Code of Federal Regulations 40 Part 86 Subpart B, revised as of July 1, 1999. (www.access.gpo.gov).

71. Altronic CD1 ignition system. Girard: Altronic Inc, 1993. (Form CD1 8-93).

72. Guntrum, R. Emissionsbegrenzung bei Gasmotoren. MTZ Motor-technische Zeitschrift, 1990. Vol. 51, No. 3.

73. Koberstein, E. Abgaskatalysatoren/Bauarten - Funktion - Verfügbarkeiten. In: Proc. Emissionsminderung Automobilabgase-Ottomotoren. Düsseldorf: VDI Verlag, 1984. (VDI Berichte 531). ISBN 3-18-090531-X.

74. Ikeda, Y. et al., Development of $NO_x$ Storage-Reduction Three-Way Catalysts for D-4 Engines. Warrendale: SAE International, 1999. (SAE Paper 1999-01-1279).

75. $SINO_x$: Sauber nach EURO 4. Diesel-Systeme. Regensburg: Siemens AG, 1999.

76. Seiffert, U. & Walzer, P., Automobiltechnik der Zukunft.Dusseldorf: VDI-Verlag GmbH, 1990. ISBN 3-18-400836-3.

77. Brauch, H. Abgasreinigung, Katalysator-Russfilter. Esslingen: J. Eberspächer, 1985.

78. Nylund, N.-O. & Eklund, T. Low emission heavy-duty vehicles for urban services. In: Proc. 27 th ISATA/Dedicated Conference on Electric, Hydrid & Alternative Fuel Vehicles and Supercars (Advanced Ultralight Hybrids). Croydon: Automotive Automation Limited, 1994. ISBN 0 947719 63 6.

79. Kim, J.-W. et al., Development of the Daewoo dedicated light duty NGV II. In: Proc. NGV 94, The Fourth International Conference & Exhibition on Natural Gas Vehicles. Toronto: IANGV,1994.

80. Klimstra, J., Catalytic converters for natural gas fuelled engines - a measurement and control problem. Warrendale: Society of Automotive Engineers, 1987. (SAE Paper 872165).

81. Varde, K. S. & Cherng, J. C. Emissions and their control in natural gas fuelled engines. In: Automotive Emissions and Catalyst Technology. Warrendale: SAE International, 1992. (SAE SP-938). ISBN 1-56091-302-9.

82. Nylund, N-O. et al., ECOBUS: Uuden sukupolven vähäsaasteinen kaupunki-linja-auto. Seurantatutkimuksen loppuraportti. [ECOBUS: A new generation low-emission citybus. Final report of the follow-up study]. Espoo: Technical Research Centre of Finland, 1997. (MOBIL D3). (In Finnish).

83. Abgaskatalysatoren für Erdgasbetrieb. MTZ Motortechnische Zeitschrift, 1994. Vol. 55, No 12.

84. www.bosch.com

85. Steuergerätediagnose uber die CARB-Schnittstelle. Steuergreätediagnose. Plochingen: Robert Bosch GmbH, 1996.

86. Motor vehicle emission regulations and fuel specifications. Part 2. Detailed information and historic review (1970-1996). Brussel: CONCAWE, 1997. (Report no. 6/97).

87. Motor vehicle emission regulations and fuel specifications. Part 1. Summary and annual 1997/1998 update. Brussel: CONCAWE, 1998. (Report no. 9/98).

88. Box, G. et al., Detecting Malfunctions in Dynamic Systems. St. Gallen: University of St. Gallen, 1999. (ITEM QM&T Report No. 2).

89. ENGVA News, 1999, Issue 10.

90. ENGVA News, 1999, Issue 11-12.

91. The EU's new directive for commercial vehicles' exhaust emission limits was today approved by the European Parliament. Bulletin from Volvo Truck Corporation, November 16, 1999. (www.volvotrucks.volvo.se)

92. Directive 1999/96/EC of the European Parliament and of the Council on the approximation of the Laws of the Member states relating to measures to be taken against the emission of gaseous and particulate pollutants from compression ignition engines for use in vehicles, and the emission of gaseous pollutants from positive ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles and amending Council Directive 88/77/EEC. Brussels: The European Parliament and The Council, 13 December 1999. (Working Document).

93. Proposal for draft amendments to Regulation No. 49 (incorporating of LPG-fuelled engines). Informal Document to the 29th GRPE, 17 - 19 January 1995. Geneva: Economic Council for Europe/GRPE, 1995.

94. Proposal for draft amendments to Regulation No. 49 (incorporating of NG-fuelled engines). Informal Document to the 30th GRPE, 10 - 13 July 1995. Geneva: Economic Council for Europe/GRPE, 1995.

95. www.arb.ca.gov

96. US Code of Federal Regulations 40 Parts 9 and 86. Control of Air Pollution from Highway Heavy-Duty Engines, Final Rule, October 21, 1997. (www.access.gpo.gov)

97. www.epa.gov

98. Aakko, P. & Niemi, A., ECE R49- ja OICA-testimenetelmien vertailu Volvo DH10A-285 moottorilla. [Comparison of ECE R49 and OICA test methods using a Volvo DH10A-285 engine]. Espoo: Technical Research Centre of Finland, 1997. (MOBILE 125Y-6). (In Finnish).

99. EC MVEG Working documents on test cycle comparisons (ECE R49/ESC/ETC). Not published.

100. Chang, T.Y. et al., Alternative transportation fuels and air quality. Environmental science and technology, 1991, Vol. 25, No. 7.

101. Documentation on equipment to measure unregulated emissions. Espoo: VTT Energy/Engine Technology, 1999.

102. Seisler, J.M., NGV Retrospective and Realities: Yesterday and today. In: Proc. NGV 98, The Sixth International Conference & Exhibition on Natural Gas Vehicles. Cologne: IANGV, 1998.

103. World-Wide Fuel Charter. AAMA, ACEA, EMA & JAMA, December 1998.

104. La BMW 523g. Plus propre que la voiture électrique. Communique de Presse. Bornem: BMW Belgium, 1999.

105. www.media.chrysler.com

106. www.afdc.doe.gov

107. Multipla Fiat.Torino: Fiat Auto Pubblicita, 1998. (Publication no. 04.2.2112.08-S).

108. www.fleet.ford.com

109. Brachmann, T. & Yatabe, F., The Natural Gas Honda Civic GX, an Unique Clean Vehicle for Today and the 21st Century. In: Proc. NGV 98, The Sixth International Conference & Exhibition on Natural Gas Vehicles. Cologne: IANGV, 1998.

110. NGV2000 Yokohama, Japan. NGV: Transportation for the New Century. Tokyo: The Japan Gas Association, NGV Project Department, 1999.

111. Volvo S70&V70 Bi-Fuel. Göteborg: Volvo Personvagnar, 1998. (MS/PV 9980-98).

112. New Volvo S80 Bi-Fuel version now also available. Presse-Information. Köln: Volvo, Abteilung Presse und Öffentlichkeitsarbeit, 28.5.1998.

113. Ardisana, B., NGV Emissions Control & Super ULEV Truck Emissions. In: Proc. NGV 98, The Sixth International Conference & Exhibition on Natural Gas Vehicles. Cologne: IANGV, 1998.

114. Sun, B. X., Technology Leadership- An Overview of IMPCO's New Products. Proc. Natural Gas Vehicles Conference 1999. Sydney, 12-14 April 1999. IANGV/Australasian Natural Gas Vehicles Council, 1999.

115. www.bmw.de/auto

116. www.altfuels.org

117. Information by Lars Hammarström at the 5th Annual European NGV Conference (ENGVA), Amsterdam, 18-20 May, 1999.

118. Weide, J. van der, Tiedema, P. & Ling, J. van, Alternative fuels with regard to LPG and petrol. Proc. Forth International Symposium on Automotive Propulsion Systems, Washington D.C., April 18-22, 1977.

119. Ikonen, M. et al., Taajama-ajoneuvojen uudet polttoaineet ja propulsiotekniikat. Vuosiraportti 1998. [New Fuels and Propulsion Technologies for Urban Vehicles. Annual Report 1998]. Espoo: Technical Research Centre of Finland, 1999. (ENE24/2/99). (In Finnish).

120. Emission data on Ford vehicles supplied by Alex Lawson of GFI Control Systems Inc., December 1999.

121. Webb, C. et al., Using Advanced Emission Control Systems to Demonstrate LEV II ULEV on Light-Duty Gasoline Vehicles. Warrendale: SAE International, 1999. (SAE Paper 1999-01-0774).

122. Nissan first with gasoline-fuelled SULEV. ISATA Magazine, 1999, Issue no 8, December/January 2000.

123. Kato, K. et al., Development of Engine for Natural Gas Vehicle. Warrendale: SAE International, 1999. (SAE Paper 1999-01-0574).

124. TM vertailu. Suosikkiautot pakkasen kourissa. Kylmä totuus. [Winter test of favourite passenger cars]. Tekniikan Maailma Magazine, 1999, no. 3. (In Finnish).

125. Ikonen, M. et al., Taajama-ajoneuvojen uudet polttoaineet ja propulsiotekniikat. Loppuraportti. [New Fuels and Propulsion Technologies for Urban Vehicles. Final Report]. Espoo: Technical Research Centre of Finland, 2000. (To be published in February 2000). (In Finnish).

126. 1996 Diesel & Gas Turbine Worldwide Catalog. Brookfield: Diesel & Gas Turbine Publications, 1996.

127. www.caterpillar.com

128. McLean, S., Cummins Lean Burn Technology. Proc. Natural Gas Vehicles Conference 1999. Sydney, 12-14 April 1999. IANGV/Australasian Natural Gas Vehicles Council, 1999.

129. L10 240G Engine Familiarization. Columbus : Cummins Engine Company, Inc., 1992. (Bulletin 3387920).

130. LPG Citybus Engines. The Clear Way Forward. Eindhoven: DAF Trucks N.V., 1999.

131. Knecht. W., The IVECO CNG Engine Range. Proc. Natural Gas Vehicles Conference 1999. Sydney, 12-14 April 1999. IANGV/Australasian Natural Gas Vehicles Council, 1999.

132. Bergmann, H. & Busenthur, B., Facts Concerning the Utilization of Gaseous Fuels in Heavy-Duty Engines. Proc.Gasseous Fuels for Transportation I. Vancouver, British Columbia, August 7-10, 1986. Vancouver: B.C. Research, 1987.

133. Mercedes-Benz Line-Service Buses. O 405 N/O 405 GN/O 405 NU. Natural ga low-floor buses. Stuttgart-Untertuerkekheim: Mercedes-Benz AG, 1994. (VN/MK6706.0172).

134. Wenkle, S., New developments for city buses driven by natural gas. International Workshop: "New energy-saving and environmentally friendly technolgogies for busses and trucks. Brussels, BE, 29 April 1998. Vlaamse Instellning voor Technologisch Onderzoek (VITO), 1998.

135. Titz, W.E., Development of Light-Duty Commercial CNG vehicles. In: Proc. NGV 98, The Sixth International Conference & Exhibition on Natural Gas Vehicles. Cologne: IANGV, 1998.

136. Topaloglu, T., Experience with Natural Gas Powered Buses. In: Proc. NGV 94, The Fourth International Conference & Exhibition on Natural Gas Vehicles. Toronto: IANGV,1994.

137. Keukeleere, D. de, The quest of fuel efficient and environmentally friendly bus technologies. International Workshop: "New energy-saving and environmentally friendly technolgogies for busses and trucks. Brussels, BE, 29 April 1998. Vlaamse Instellning voor Technologisch Onderzoek (VITO), 1998.

138. Millbrook Proving Ground Test Results on Buses. Data provided by Shell International, 1998.

139. Gaudio, R., Natural gas: A winning choice for environmentally friendly vehicles for the next ten years. Proc. 5th Annual European NGV Conference. Amsterdam, 18-20 May, 1999. Amsterdam: ENGVA, 1999.

140. Steen, M. van der, Seppen, J.J., Economic Assesment of Different Bus Engine Technologies and Fuels for the Future. Presented at Mostra-Convegno Internazionale GPL Auto. GPL Nuova Frontiera. Rome, 14-16.Novenber 1997. Delft: TNO Road-Vehicle Research Institute, 1997. (TNO Paper VM97004).

141. Eberwein, B., Operational experience and economic viability using natural gas buses. International Workshop: "New energy-saving and environmentally friendly technolgogies for busses and trucks. Brussels, BE, 29 April 1998. Vlaamse Instellning voor Technologisch Onderzoek (VITO), 1998.

142. Heck, E. & Schuers, A., Natural Gas Dirive- A Step Towards the Use of Hydrogen as an Automotive Fuel. Powertrain International, 1999, Volume 2, Number 4.