1996 Windsor Workshop on

Alternative Fuels

Proceedings

June 3–5, 1996, Toronto Colony Hotel, Downtown – City Hall, Toronto, Canada

Presented by:
ORTECH Corporation

Sponsored by:
CANMET, Natural Resources Canada
US Department of Energy

Proceedings of the

1996 WINDSOR WORKSHOP

on

ALTERNATIVE FUELS

June 3-5, 1996

Toronto, Ontario

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United States Department of Energy

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DE96013100

PREFACE

Following the successful formula of past years, 1996 again saw CANMET, Natural Resources Canada, and the US Department of Energy (US DOE) team up to sponsor the Windsor Workshop on Alternative Fuels.

The 1996 Workshop attracted 172 participants from 8 countries including, Belgium, Canada, Germany, Italy, The Netherlands, Sweden, the United Kingdom and the United States; continuing to highlight the technical progress and importance of alternative transportation fuels in the World marketplace.

The '96 Workshop maintained its established approach to encourage an informal exchange of information. The message for 1996 was "**Is it time to become an industry**?" Should alternative fuel interests build coalitions and display a united front? Can they cooperate, are the OEM's committed? Is infrastructure developing, or should it focus in specific geographical areas? Are regulations helping or hurting the alternative fuels business? How are alternative fuels being developed in Europe, with oil industry cooperation.

Since inception the Windsor Workshops have proved to be an invaluable forum for this exchange, and we will endeavour to organize such timely and productive workshops in the years to come. We hope to see you all again in 1997 when the Workshop returns to Windsor, Ontario June 9-11, 1997.

We would like to express our sincere appreciation to the presenters and participants of the 1996 Windsor Workshop, and to ORTECH Corporation for coordinating this event.

Bernie James
CANMET, Natural Resources Canada

John Russell
US Department of Energy

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OPENING SESSION

Chair: **Steve Goguen, U.S. Department of Energy**

NATIONAL? CONTINENTAL? GLOBAL?

John Russell

U.S. Department of Energy

(Presentation unavailable at time of publication)

COALITION BUILDING AMONG THE ENERGY INDUSTRIES

Fred Potter, Information Resources Inc.

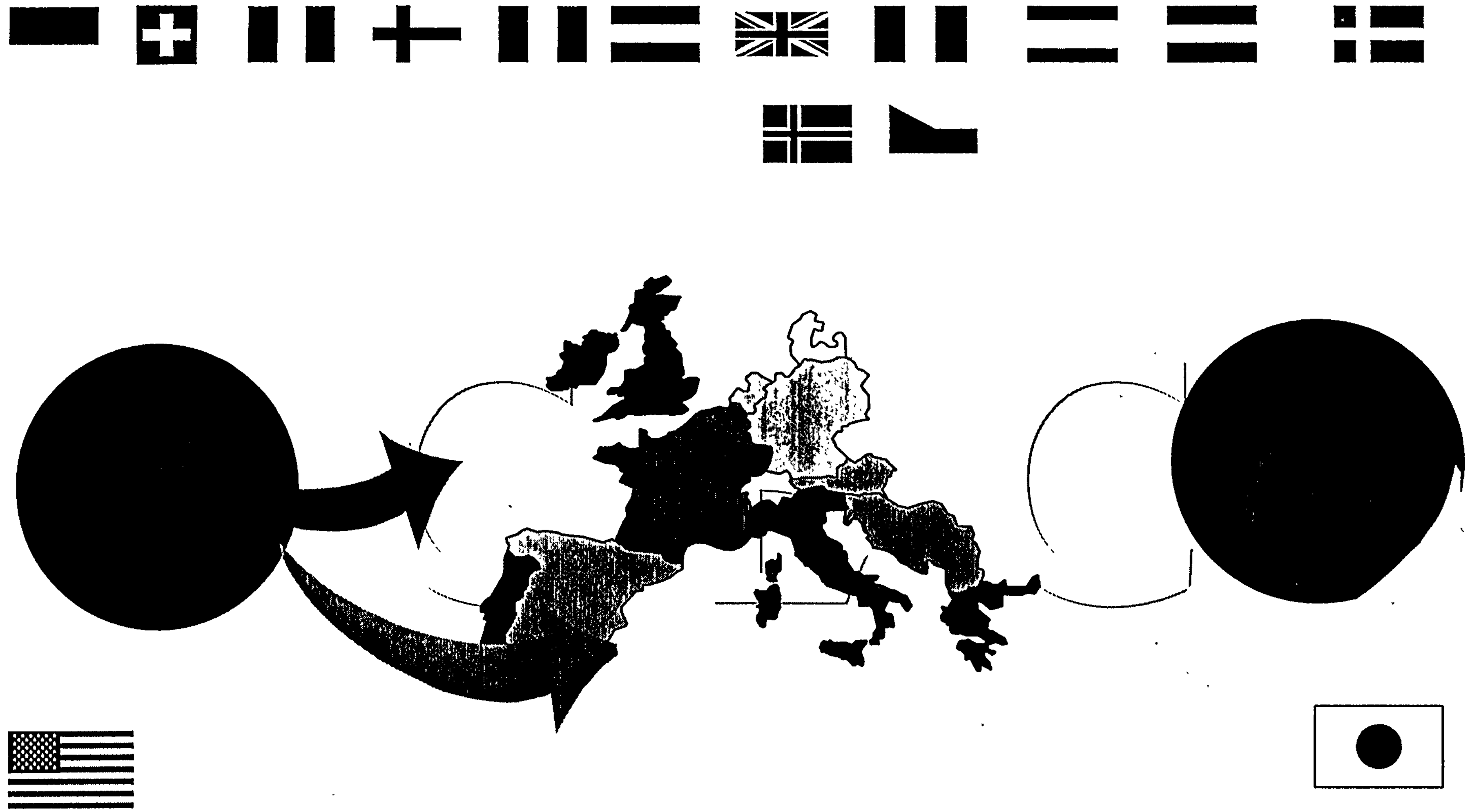
(Presentation unavailable at time of publication)

FUELLING THE ENVIRONMENTAL COLLABORATION OF THE EUROPEAN MOTOR AND OIL INDUSTRIES

FRANCIS H. PALMER

A blueprint for the way industry and government to work together on environmental issues for the benefit of the European Community and society

Performance Evaluation of Automotive Fuels & Lubricants



STRENGTHENING WORLD CONTACTS

BENEFITS OF PARTICIPATION IN CEC

- ★ Development of top quality performance tests for automotive fuels, lubricants and other fluids
- ★ Market relevance assured
- ★ Top quality assurance / accreditation provides costs-effectiveness
- ★ Underpins product specifications
- ★ Internationally recognised
- ★ Involvement means influence

BENEFITS OF PARTICIPATION IN CEC (contd)

★ Climate of trust, truth and transparency

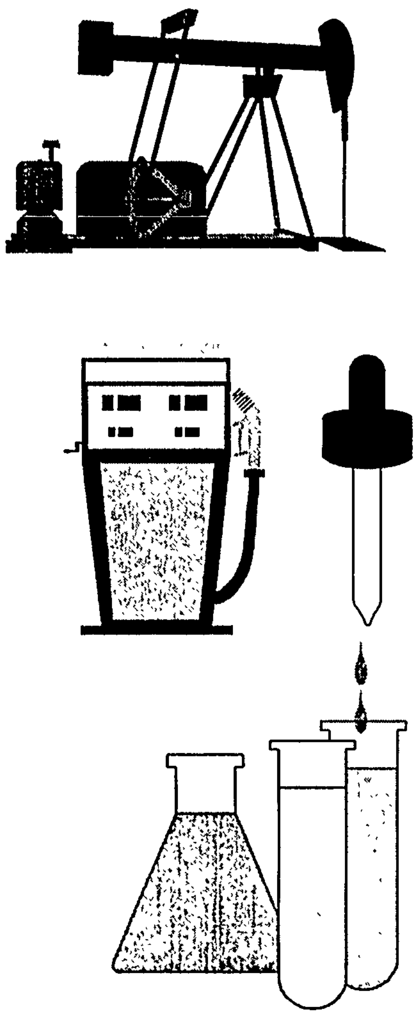
★ The only umbrella organisation in Europe representing the technical interests of motor, oil additive and allied industries in terms of product performance evaluation

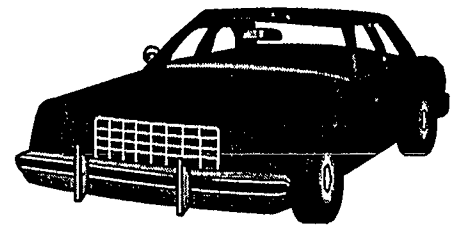
★ Involved with EU Commissions and standards bodies such as ISO, CEN, etc...

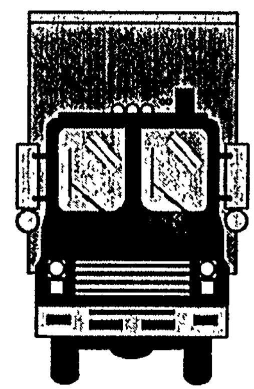
★ Involved with world-wide industry associations

★ Low cost participation-CEC operates on non-profit making principle

MAIN INDUSTRIES REPRESENTED IN CEC

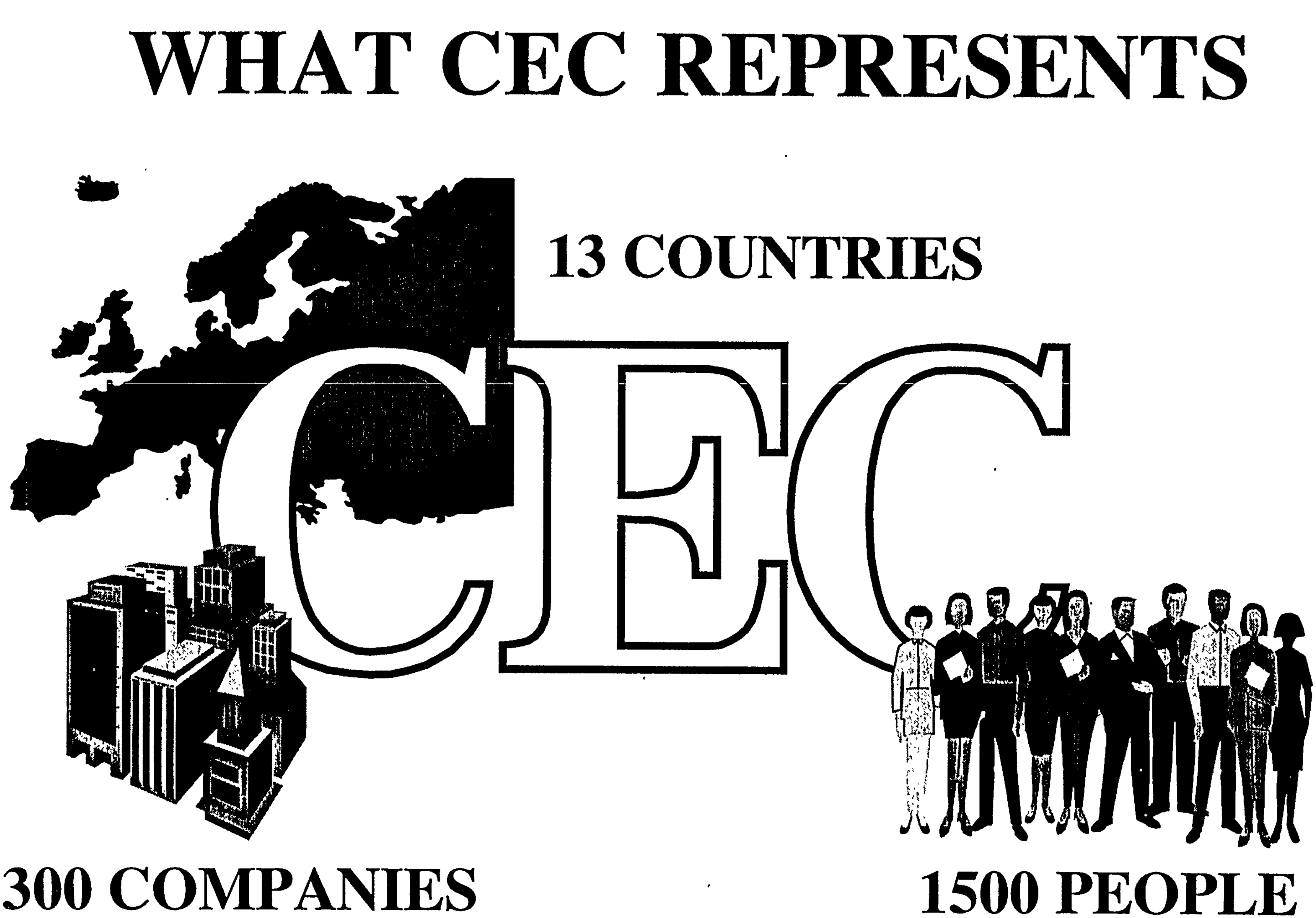


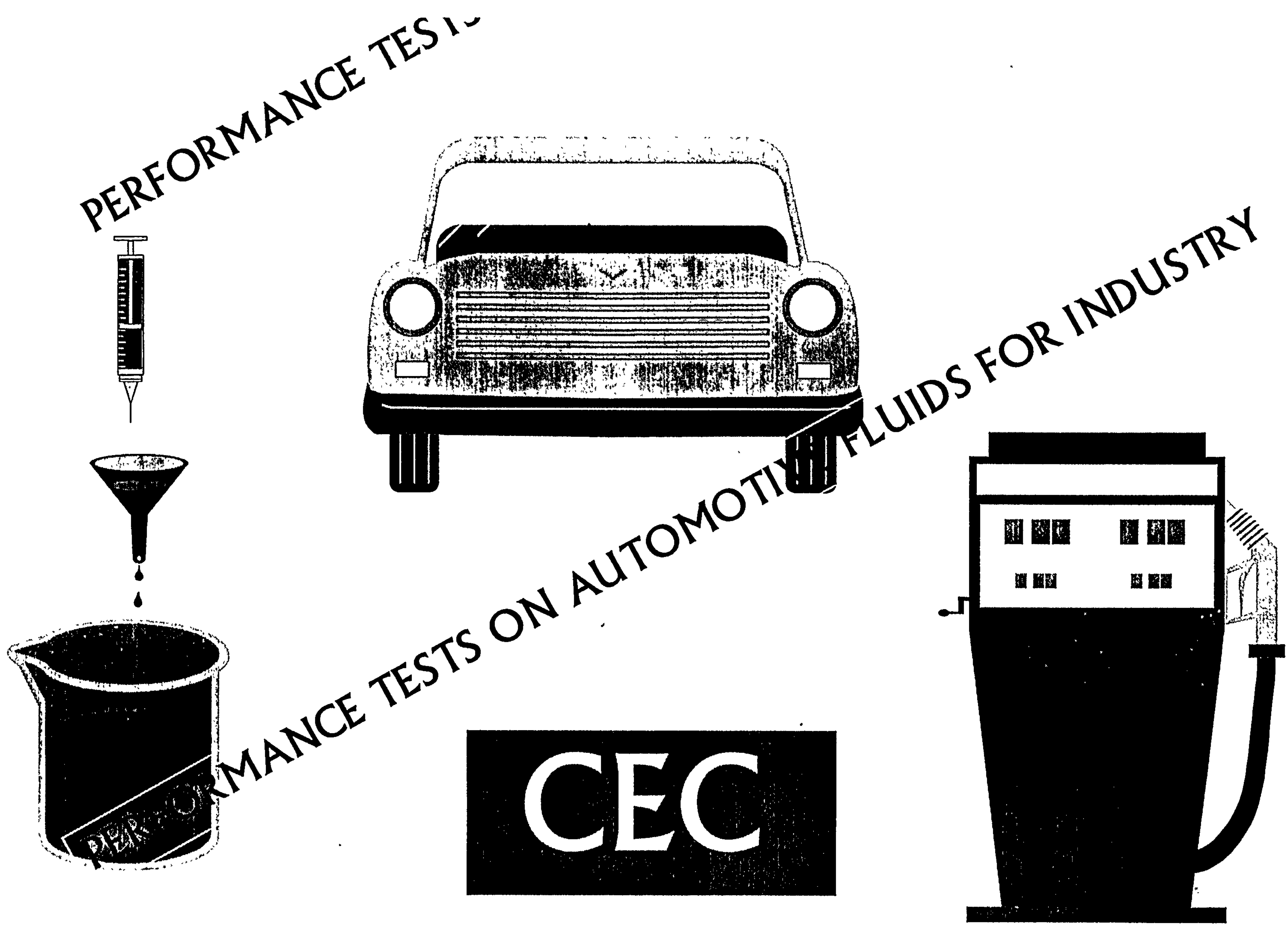




MAIN AIMS AND OBJECTIVES

- To promote joint scientific rational approach to product performance problems of the motor, oil and additive industries
- To establish performance tests that relate to the market
- To ensure test methods and thus the result derived from them meeting the highest quality standards according to ISO 9000 series, EN 29000 series and EN 45001
- To service the needs of its members and hence the industries it represents with the highest efficiency


WHAT CEC REPRESENTS
13 COUNTRIES
CEC
300 COMPANIES
1500 PEOPLE


PERFORMANCE TES
RMANCE TESTS ON AUTOMOTI FLUIDS FOR INDUSTRY
CEC

SOME QUESTIONS WHEN THINKING OF DIFFERENT FUEL OPTIONS:-

	oil	gasoline	diesel	alternatives
How much?	✹	✹	✹	✹
supply ensured?	✹			✹
from where?	✹			✹
safety?		✹		✹
pollution?	✹	✹	✹	

BIO FUELS NOT SEEN AS PART OF THE SOLUTION AT PRESENT

Questions about:-

- economics
- viability
- availability
- desirability / acceptability
- overall environmental benefits

ALTERNATIVE FUELS

ARE CONSIDERED
BY THE MOTOR AND OIL INDUSTRIES

&

THE EU

ON THE SAME SCIENTIFIC RATIONAL
COST EFFECTIVE APPROACH
AS FOR GASOLINE AND DIESEL
BASED ON AIR QUALITY NEEDS!!

ALTERNATIVE FUELS

may play a small role
in the road transportation
fuel sector but.......

Gasoline and diesel will remain
dominant in forseeable future

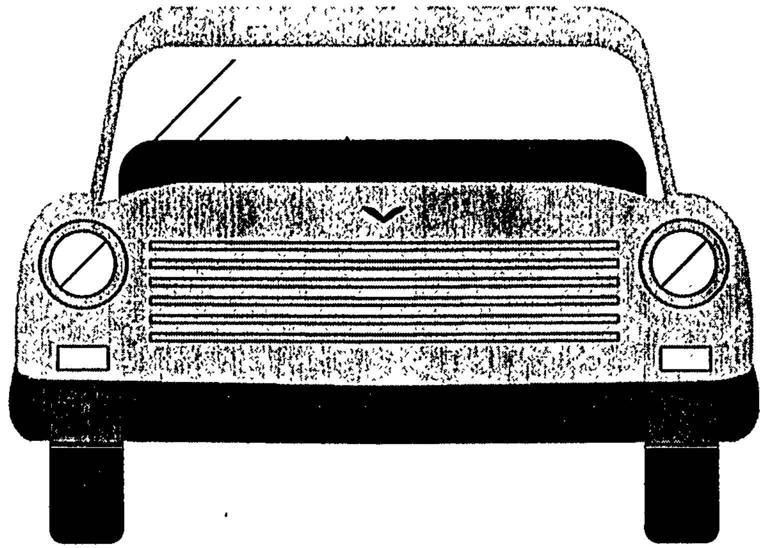
EU
ENHANCED ENVIRONMENTALLY FRIENDLY VEHICLES & ENGINES WORKING GROUP

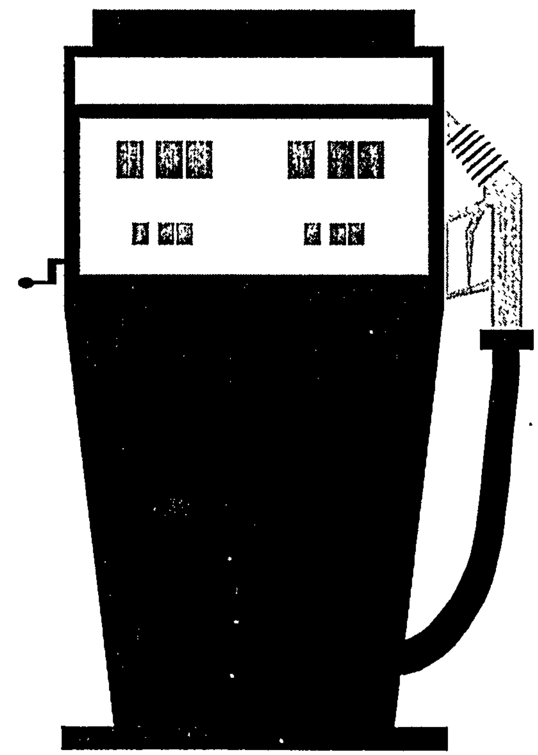
will consider use of:-

- Natural gas for city buses and trucks
- LPG for city taxis and other captive car fleets
- Other options on cost effective basis

Locations where CEC Test Methods used Inside Europe

- Austria
- Belgium
- Czech Republic
- Germany
- Finland
- France
- Italy
- Netherlands
- Norway
- Spain
- Sweden
- Switzerland
- UK
- Bulgaria
- Lithuania
- Poland
- Portugal
- Hungary
- Russia
- Yugoslavia (Serbia)
- Macedonia





CEC

C + 2T + H-P =
Harmony
= Business Sucess!!

- Rational scientific approach best for all partners and society

- Joint co-operation the only sensible way forward and an essential pre-requisite for the rational approach

The Current Situation

Leading to Win / Win / Win / Win situations:-

-Car industry Wins with fuels fit-for-purpose

-Oil industry Wins by providing fuels with specifications that are matched to future vehicle needs and with a sound rationale for investment needs

-consumer Wins by improved air quality derived on cost effectiveness basis

-Commission Wins by providing a framework for future sustainable environmental policy

The Current Situation

- Integrated approach involving all key partners
- Rational scientific approach based on:-
  - -air quality standards
  - -air quality modelling
  - -knowledge of interactions between advanced fuels with advanced vehicles / engines
  - -acceptance of cost effective rationale
  - -inclusion of other measures such as I & M-integrated approach
- Joint pioneering industry / government approach approach meeting today's complex needs

The Role of EPEFE in the Process

- Showed commitment to rational scientific approach
- Gave ACEA / Europia a seat at the table
- Provided forum for bi-lateral discussions where disagreements can be resolved and compromises reached:-

  "this lead to a better understanding of the problems faced by each partner"

- Kept pressure on the Commission to meet their commitments to the programme:-
  - -without EPEFE result air quality modelling would not have advanced or been so robust
  - -without EPEFE cost effectiveness would not have advanced

How Did We Make Progress?

- By developing trust:-

  -between Commission and Industry
  -between Oil and Vehicle Industries
  -within Oil and Vehicle Industries

- By working together:-

  -several hundreds of meetings of auto-Oil partners since 1992

- By delivering results within agreed time schedules
- By accepting the rational approach
- By agreeing to compromise rationally
- By sticking to jointly held positions between the ACEA and Europia
- By avoiding public disagreements that could be exploited

Situation Prior to 1992

Led to potential Lose / Lose / Lose / Lose situations:-

-Car Industry Lost	to technology forcing initiatives not based on air quality needs
-Oil Industry Lost	uncoordinated nature of regulations not specifically related to air quality needs
-Consumers Lost	because cost effectiveness of environment not used and transport / stationary sources regulated separately
-Commission Lost	through loss in time / energy in the piecemeal process as well as lack of sound scientific rational approach underpinning emerging legislation

Situation Prior to 1992

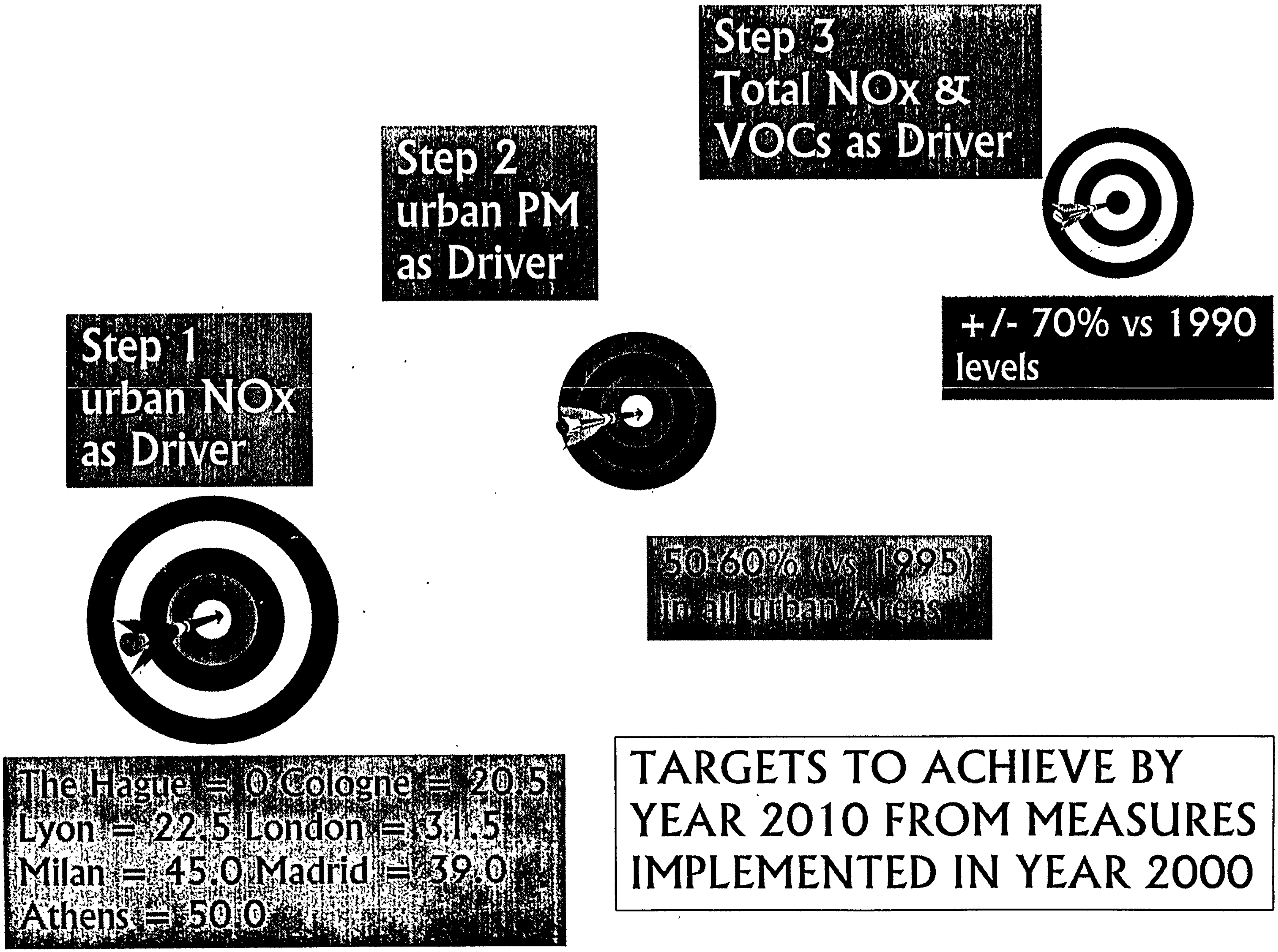
- Technology forcing best available technology at any cost
- Lack of systematic knowledge of air quality issues throughout Europe
- No air quality standards for EU
- No general acceptance of that cost effectiveness was important characteristic in environmental sustainability
- General pressure to adopt US / Californian solutions in Europe
- Uncoordinated approach to transport and environmental fuels, vehicle emissions, stationary sources, I & M, and traffic management

The Process

- Air quality of today
- Air quality in the future (2000 / 2010) versus air quality need
- EU Commission commitment to address future air quality issues / needs
- Common co-operation with industrial partners to prepare sound technical basis for legislative proposals

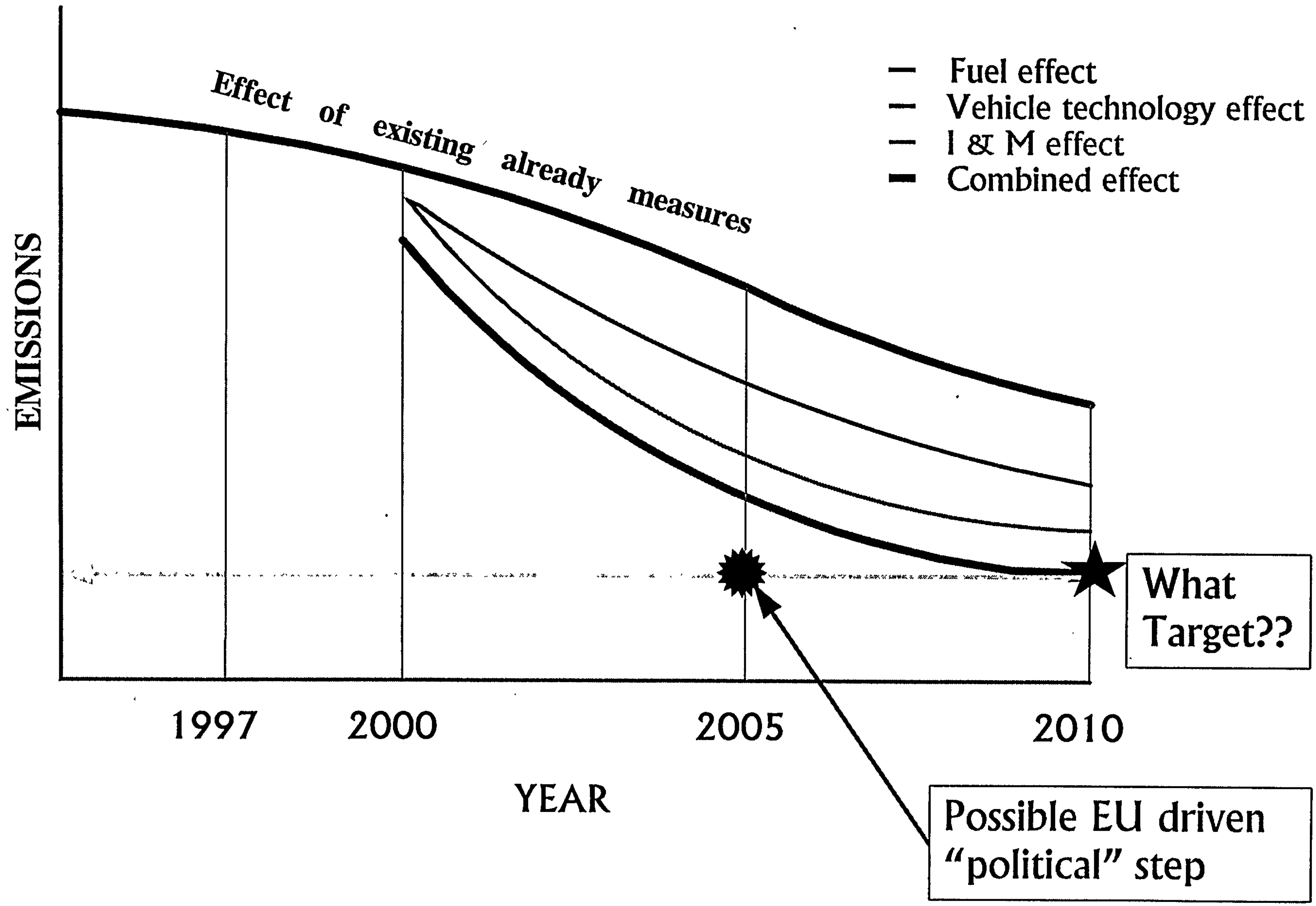
The European Auto-Oil Programme
"a win-win-win-win process"

- Situation prior to 1992
- The current position
- How did we make progress
- The role of EPEFE in the process

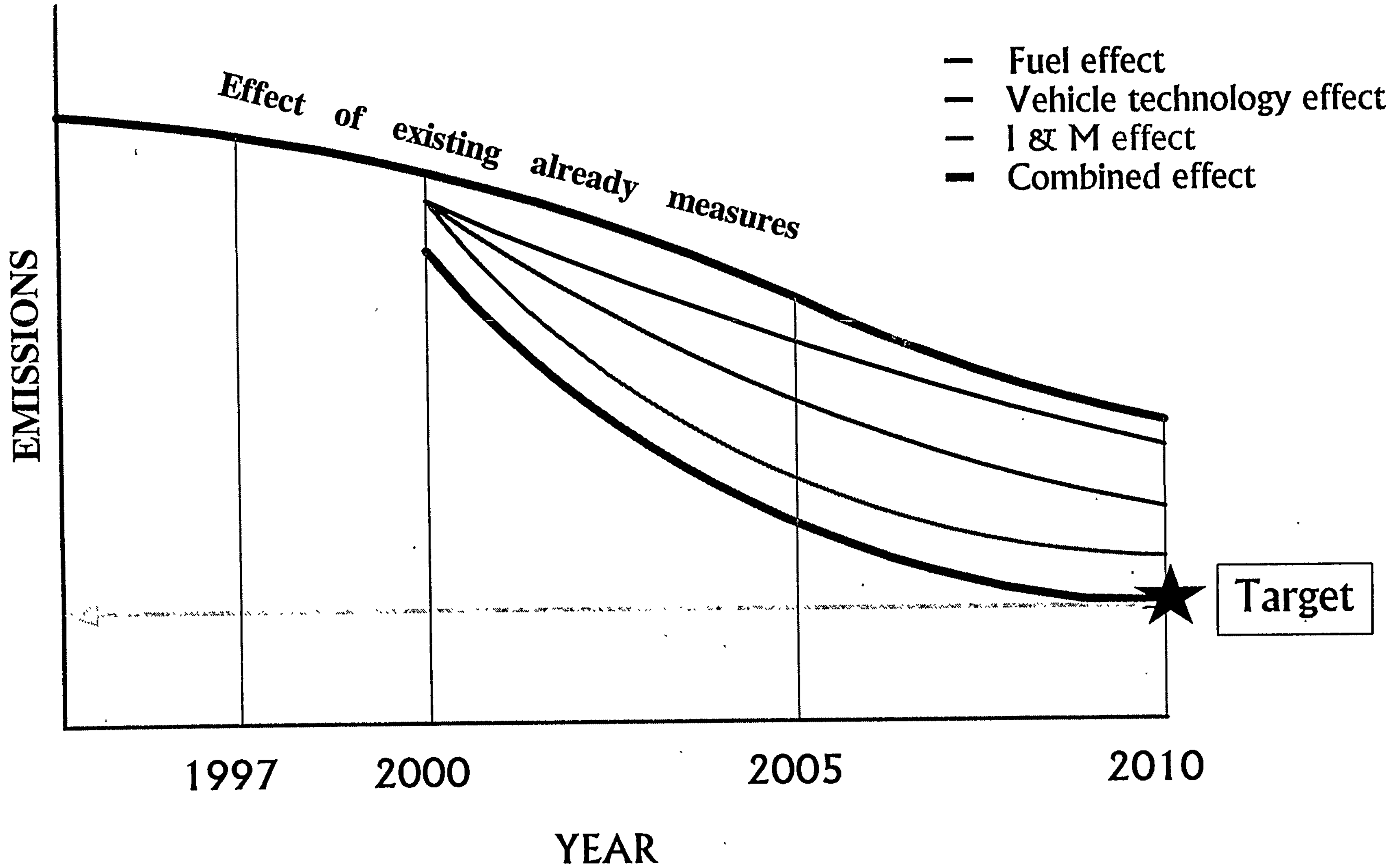


Step 1
urban NOx
as Driver
Step 2
urban PM
as Driver
Step 3
Total NOx &
VOCs as Driver
+/- 70% vs 1990
levels
50-60% (vs 1995)
in all urban Areas
The Hague = 0 Cologne = 20.5
Lyon = 22.5 London = 31.5
Milan = 45.0 Madrid = 39.0
Athens = 50.0
TARGETS TO ACHIEVE BY
YEAR 2010 FROM MEASURES
IMPLEMENTED IN YEAR 2000

Principle of implementation of year 2000 measures



Principle of implementation of year 2000 measures



COST/EFFECTIVENESS APPROACH

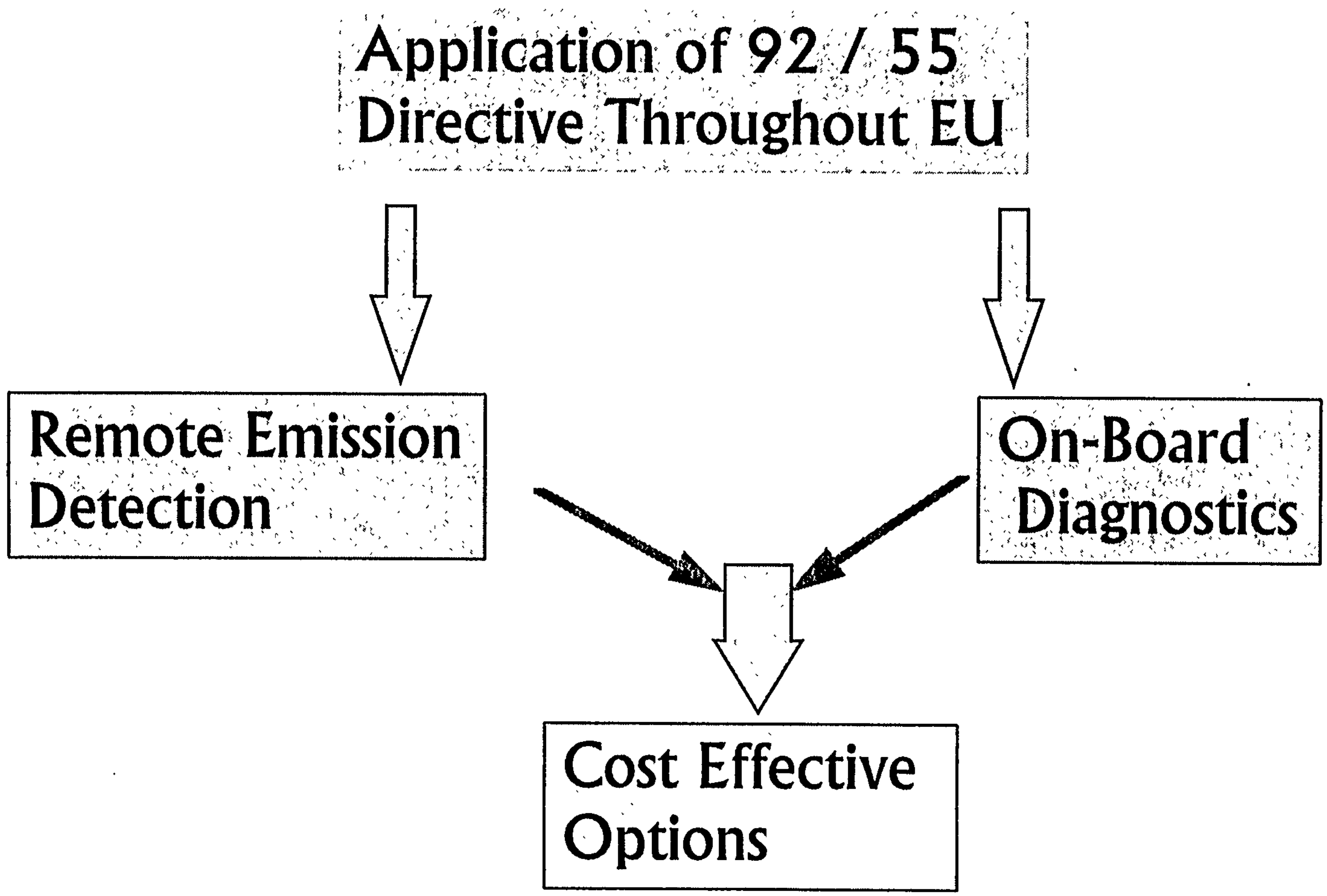
1) Automotive technology

2) Fuels technology

3) Non technical measures

4) Optimisation and measures

INSPECTION & MAINTENANCE



NON TECHNICAL MEASURES

1 - Road pricing

2 - Traffic restrictions

3 - Speed regulations

4 - Enhancements to urban public transport

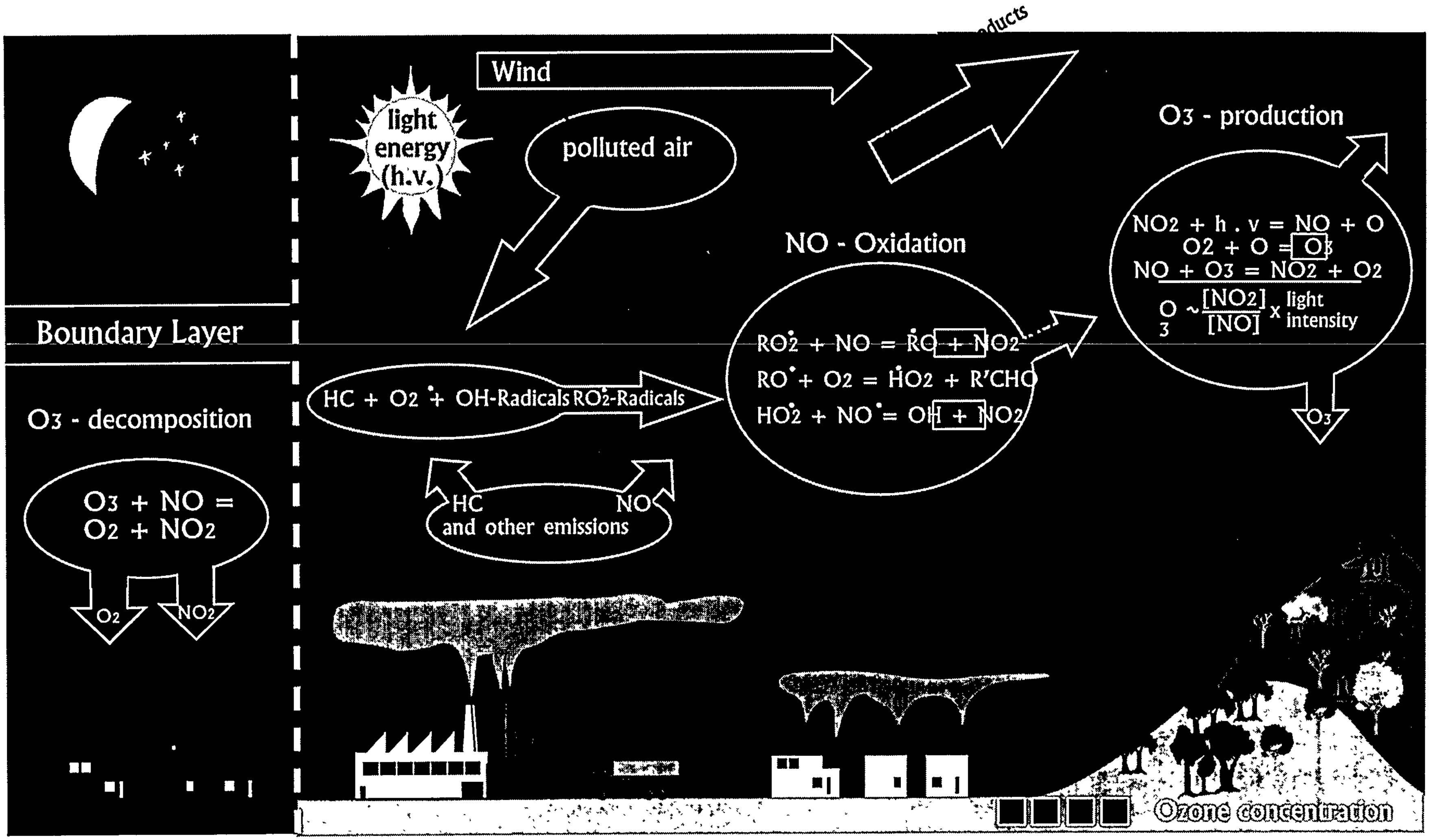
5 - Fuel tax

6a - Vehicle purchase tax
6b - Gas guzzler tax
6c - Emission vehicle tax

7 - Scrappage subsidy

8 - Freight subsidy

"SUMMER-SMOG" THROUGH OZONE ?



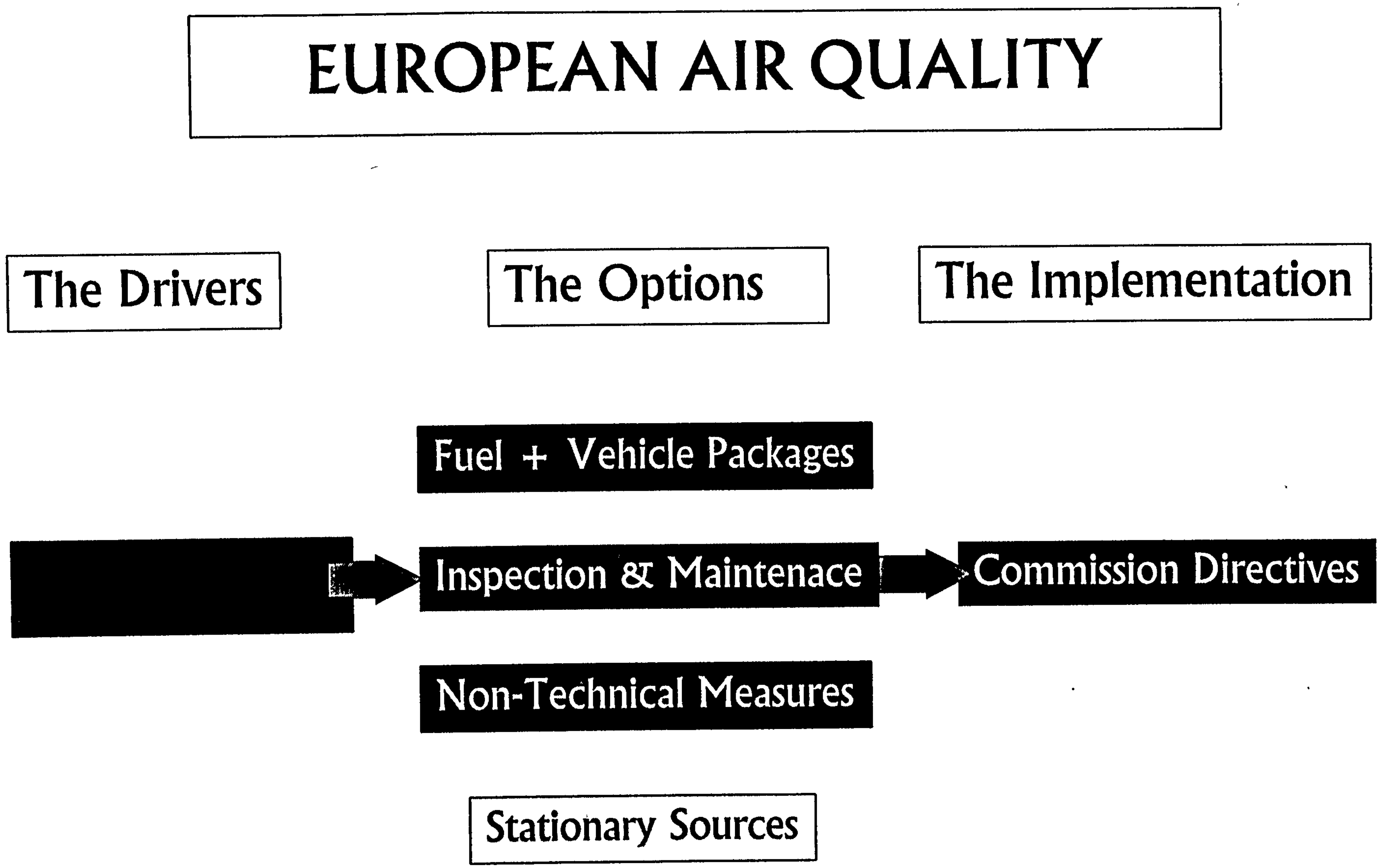
Adapted from Landesanstalt fur immissionsschutz

Non-reactive pollutants:

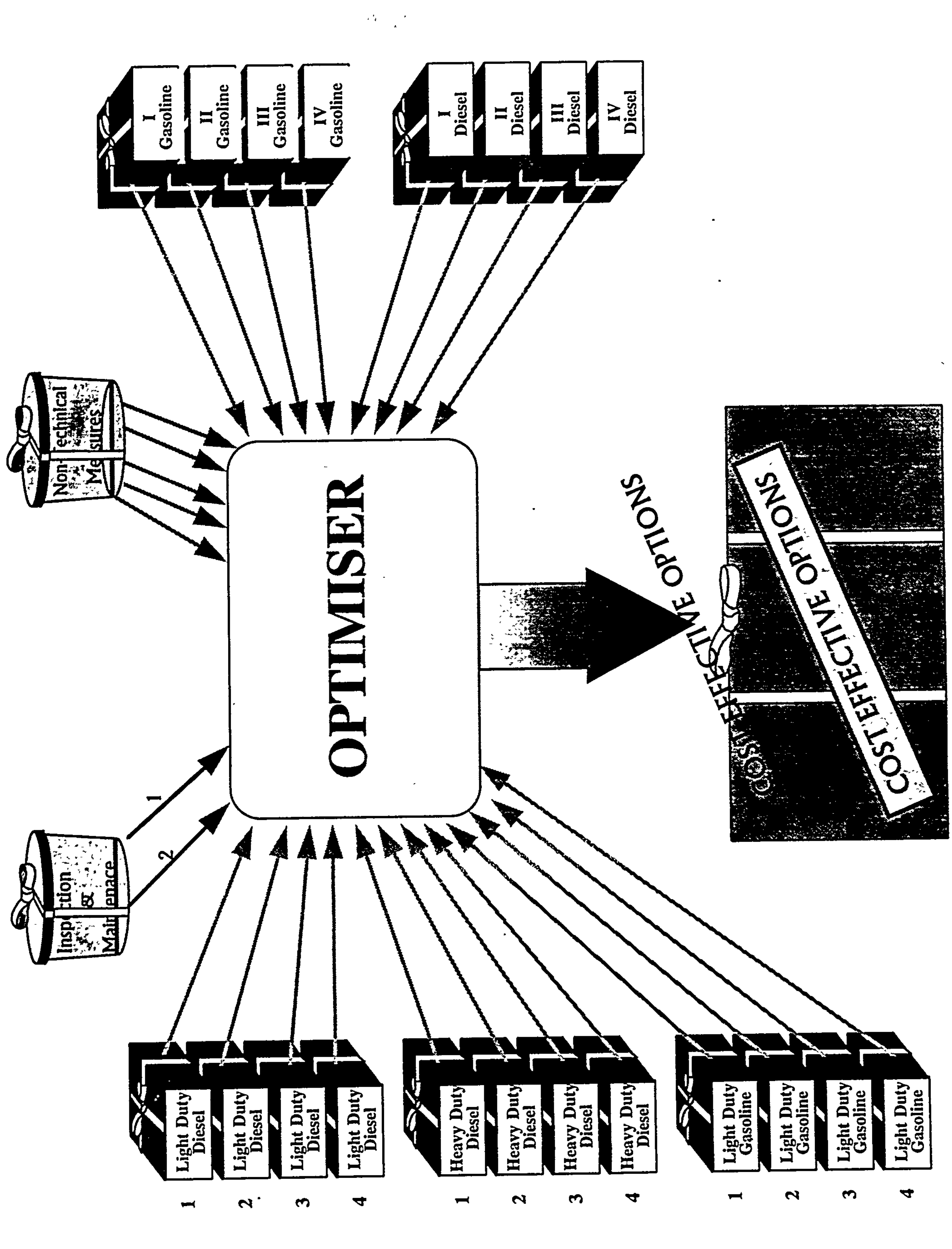
- Nitrogen oxides (nitrogen dioxide)
- Carbon monoxide
- Benzene
- (Particulates)

Reactive pollutants:

- Ozone
- (precursors: nitrogen oxides, volatile, organic compounds, carbon monoxide)



EUROPEAN AIR QUALITY
The Drivers
The Options
The Implementation
Fuel + Vehicle Packages
Inspection & Maintenace
Commission Directives
Non-Technical Measures
Stationary Sources



Possible outcome

EUROPEAN AIR QUALITY

The Drivers	The Options	The Implementation
	Fuel + Vehicle Packages	
NO_x & O_3 →	Inspection & Maintenance →	Commission Directives
	Non-Technical Measures	

EPEFE AND THE EUROPEAN AUTO-OIL PROGRAMME

by
Francis H Palmer

Background

The European Union (EU) Auto-Oil Programme is a joint activity between the EU Commission, the European oil industry (Europia) and the European motor industry (ACEA) that was established in the wake of rising public concerns about motor vehicle exhaust emissions and their effects on health and air quality.

Since 1970, when the first exhaust emission legislation for motor vehicles emerged, progressively more severe legislation has been introduced (see Figure 1), culminating with legislation in 1996 that will make emission limits directionally more severe than many USA regulations that will be in force at the time. Further directives on emissions aimed at the year 2000 and beyond are likely to emerge from the European Union Commission Directorates later in 1995. Auto / Oil is designed to provide European legislators with a rational scientific basis for the setting of future European vehicle exhaust emission limits for road transport **on a cost effective basis, linked to air quality needs, taking into account motor technology and fuels, as well as other non-technical measures such as inspection and maintenance, and traffic management systems.**

Guidelines and principles to this unique approach to cost effectiveness measures were agreed by the European Parliament and Council as laid down in Article 4 of Directive 94/12/EC. Although this Directive applies to the emissions of light duty vehicles for 1996/7, guidelines were included for the construction of future legislation that would apply in the year 2000 and beyond. (Figures 2 & 3).

Auto / Oil is an extremely large undertaking, bringing together the Commission and the automobile and oil industries for the first time at a European level in a co-operative programme. The EPEFE Research Programme into the inter-industry relationships between vehicle and fuel technologies and their impact on exhaust emissions, and which is just one part of the Auto / Oil Process, has cost more than ten million ECU (US$ eleven million), not including the cost of developing prototype technology and advanced fuels. (More detailed information may be obtained from the ACEA and Europia Secretariats based in Brussels. A draft report was formally released on 17 July at a meeting organised by the Commission to brief Member States on the status of the Auto-Oil Programme. The EPEFE Programme was designed to enhance data already available within Europe and from the USA, where relevant, to help establish the relationships between fuel composition and vehicle technology and to identify and quantify what reductions in road traffic emissions could be achieved by combining advanced fuels with advanced vehicle / engine technologies under development for the year 2000. Results from the EPEFE Programme were embodied into Tables and used to quantify complex equations that were associated with fuels and vehicle / engine technologies for inclusion into the Commission's Air Quality Modelling studies. This process facilitated the search for the optimum combination of measures to achieve the European Union's Air Quality objectives. (Figures 4, 5 & 6). **Impact of already agreed Measures**

The mandatory use of catalytic converters from the beginning of 1993 and other agreed measures that have been or will be implemented in the near future, such as the introduction of a 0.05 %m sulphur in diesel fuel and the halving of exhaust emission limits in 1996, will have a profound effect in reducing road transport derived air pollution in the coming years despite the expected growth in road traffic. Figure 7 shows the expected change in the passenger car fleet whilst Figures 8, 9 & 10 show the influence on emissions with time. Figure 11 shows the time trend for all road transportation vehicles. The effect on such emissions as NOx, CO and HC shows a significant downward trend despite vehicle population growth but, the impact of the already agreed and existing measures vary from country to country depending upon existing vehicle population and consumer buying habits. A comparison of Greece and the UK illustrates the point in Figures 12, 13 & 14). A slow turn-over of purchasing new technology in the market place in some countries will delay the beneficial impact of the already agreed and existing measures. Even on an average European basis, the passenger car life span is around 10-15 years and for commercial vehicles, the life span is somewhat longer. (Figure 15). In addition, more recent Commission ozone results has shown that existing plus already agreed measures will result in a 20% to 30% reduction in ground ozone by the year 2010. What is more, even with a total ban on city traffic, ground ozone will only be reduced by a further 10%. One of the main conclusions from this outcome was that it is important to tackle stationary sources. A flow chart identifying the already agreed measure is outlined in Figure 16.

Air Quality Needs and Results

Urban air quality will improve significantly as a consequence of the already agreed measures indicated above. Even so, the Commission still has a mandate, from the EU Directive 94/12/EC, to establish compliance of reactive and non-reactive pollutants in the urban environment. The question of whether "Summer-Smog" was responsible for respiratory and other health related problems as a result of traffic pollution causing too high ozone levels needed to be addressed. Figure 17.

Air quality target bands were identified, based largely on the World Health Organisation (W.H.O) guidelines, with upper and lower (tighter) target bands (see Figure 18). A 7 city air quality study was undertaken to assess current and future air problems associated with reactive and non-reactive pollutants. (see Figure 19). These 7 cities namely, London, The Hague, Cologne, Lyon, Milan, Madrid and Athens, were chosen to be representative across urban Europe. (Figure 20).

The main conclusions from the emissions / air quality modelling studies confirms that:-

Urban air quality in all 7 cities:-

- Improves significantly as a consequence of already agreed measures
- CO and benzene meet the lower criteria by the year 2000 / 2005
- NO2 lower criteria band determines that further emission reduction measures are needed.

- Severe NOx emission reductions are required to achieve NO2 targets in almost all of the 7 representative cities

The outcome shows clearly that NOx is the real problem for 100% compliance with the lower air quality band. Figure 21 shows an example for London for 1990-2010). As an example, NOx reductions for the year 2010 are:-

55% for Athens
40% for London

However, CO and benzene were not found to be a problem after the year 2000 / 2005 because of the benefits of the existing and agreed measures.

A full list of the required reductions for each pollutant and each of the 7 cities, for the years 2005 and 2010, is shown in Figures 22 and 23. The Commission recognises that reductions in NOx brings other benefits. For example, every 10% reduction in NOx would generate reductions of:-

-12 to 15% in CO
-9 to 13% in HC
-12 to 15% in Benzene
-10 to 11% in PM

While the existing and agreed measures, together with those measures required to meet the NOx air quality targets will significantly reduce ozone episodes, they will still not be sufficient to meet the ozone air quality target. Even the extreme measures directed at traffic will have limited effect. This clearly demonstrates that a total integrated approach aimed at reducing emissions from all sources, including those from stationary sources, is required.

Cost Effectiveness

Fuel parameter ranges studied are given in Figure 24, whilst the vehicle / engine technology assessed is shown in Figures 25 and 26.

The base average fuel qualities for gasoline and diesel fuel, used in the cost effective study are shown in Figures 27 and 28, together with increasingly severe compositional changes and the estimated potential reductions in emissions such changes bring. Also included in Figure 29, are the emission reduction targets for different levels of severity of diesel and gasoline technology changes.

Preliminary results recently released indicate that about 90% of European cities can meet the NOx targets with a set of non-extreme measures. The remaining 10% of European cities, which generally lie in southern Europe, can not meet the NOx targets even with a much more severe set of measures. Only the use of local, non-technical measures such as fleet replacement, traffic management, enhanced public transport and better vehicle maintenance, offers any hope of attaining the NOx emission reduction targets in these cities.

City diesel, once postulated as a possible solution, is not considered cost effective, although it is recognised that there may be scope for urban buses, municipal trucks and taxi fleets using CNG or LPG as a dedicated fuel.

Non-technical measures are also to be included in the analysis as indicated in Figure 30 , as are inspection and maintenance programmes, including on-board diagnostics and remote emission detection. Figure 31. However, non-technical measures do not affect emission levels directly but rather indirectly through changing driver / vehicle owner behaviour via economic instruments.(Figure 32).

A full set of the cost effectiveness results, including the contribution from non-technical and inspection and maintenance measures, should be available by the end of October.

Perhaps an easy way to explain the European Air Quality objectives and their relationships with cost effectiveness, is shown in Figures 33 & 34.

Conclusion

In summary, the EU Auto-Oil Process can be considered as a 5 step Process. This is described graphically in Figure 35. As this process approaches its "final" stages, and having identified urban NOx is a key driver, additional steps are now being considered which include the particulate mass and ozone precursors (VOC's and total NOx), in addition addition to urban NOx. Whilst the inclusion of these will increase the emission reduction severity, they will also increase the costs of the severity of the cost effective measures.

The ultimate aim is to produce cost effective options after considering all possible packages, both technical and non-technical. With most of the practical studies having been completed or very nearly completed, in line with a sound scientific rational approach, Europe stands at a cross road, with the political debate just starting.

As particulates (PM) remain the big unknown in terms of their derivation, size, life span and their impact on air quality and health, and in terms of their contribution to air pollution, (there are currently no W.H.O. standards), debates and studies on this topic will grow concomitant with the growing interest in using gaseous fuels, with potentially very low particulates, to replace the use of diesel in dedicated buses, trucks and taxis.

A draft directive is expected to emerge from the Commission soon for consideration by the EU member states and ultimately the European Parliament. Whilst politics are inevitable in legislation and law making, it is comforting to know that one of the basis on which future European legislation will be made with respect to air quality improvement, has itself been based on a unique rational scientific approach of which Europe can be justly proud.

Frank Palmer
26th February 1996

PS:- Additional slides used in the presentation are attached.
Please note that the EPEFE Report is now available and can be obtained for the ACEA and Europia Secretariats. Purchase price is 500 ECU +P & P & bank charges, etc.
ACEA:-Ph:32 2 732 5550. fax:32 2 732 6001/4267, Europia:Ph:32 2226 1911. fax:322219 9551

EVOLUTION OF THE REGULATORY EXHAUST EMISSION STANDARDS FOR PASSENGER CARS IN THE EU

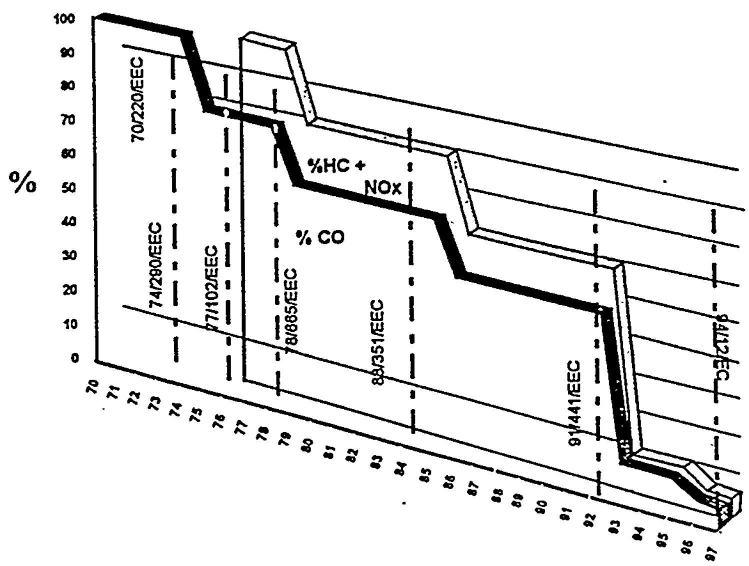


Figure 1

ARTICLE 4 OF DIRECTIVE 94/12/EC OF EUROPEAN PARLIAMENT AND THE COUNCIL

In these stage 2000 proposals the Commission shall take the following approach:

- the measures will produce effects to meet the requirements of the Community's air quality criteria
- a cost effectiveness assessment shall be taken of the potential contributions from:
  - traffic management, for example by spreading the environmental costs appropriately,
  - enhanced urban public transport,
  - new propulsion technologies (e.g. electric transmission)
  - the use of alternative fuels (e.g. biofuels)

  towards improving air quality,
- the measures shall be proportional and reasonable in the light of the intended objectives.

Figure 2

REQUIREMENTS OF DIRECTIVE 94/12

The proposals, aimed at a substantial reduction of pollutant emissions, shall comprise in particular the following elements : -

1. Further improvements in the requirements of 94/12 based on the assessment of :
   - the potential of the traditional engine and post combustion technology
   - possible improvements in the test procedures e.g.
     - cold start, starting in low or wintry temperatures
     - durability (e.g. in the conformity tests)
     - evaporative emissions.
   - measures at the level of type-approval supporting strengthened inspection and maintenance requirements, including for example, on-board diagnostic systems
   - the possibility of checking the conformity of vehicles in circulation
   - the proportional need for : -
     - specific limits for HC and NOx in addition to a cumulative limit value, and
     - measures to cover pollutants not yet regulated

2. Complementary technical measures in the framework of specific Directives, including :
   - improvements in fuel quality as far as vehicle emissions of dangerous substances (in particular benzene) are concerned,
   - strengthening of the requirements of the inspection and maintenance programme.

Figure 3

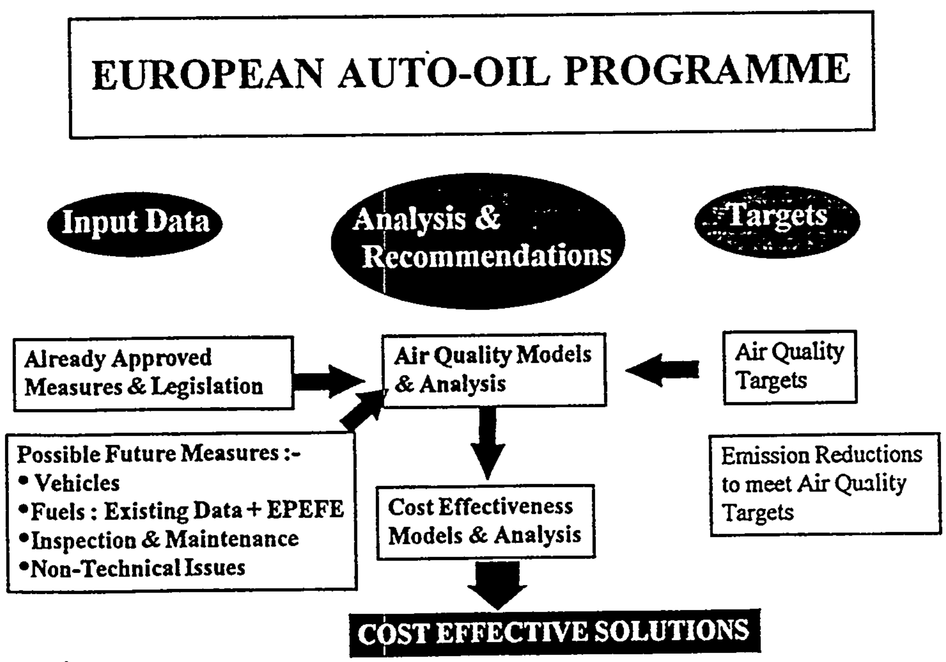


Figure 4

PERSPECTIVE ON THE EU AUTO-OIL PROGRAMME

Easy Technology Solutions already implemented

➡ New Approach needed

AUTO-OIL PROGRAMME

- **Pioneering**
- **Complex-Not perfect, designed for Today's Needs**
- **Despite Auto-Oil complexity, commitment to help find solutions for year 2000 plus**
- **Proposals for year 2000 to European Parliament & Council late 1995**

Figure 5

EVOLUTION OF ROAD TRANSPORT EMISSIONS ASSESSMENT

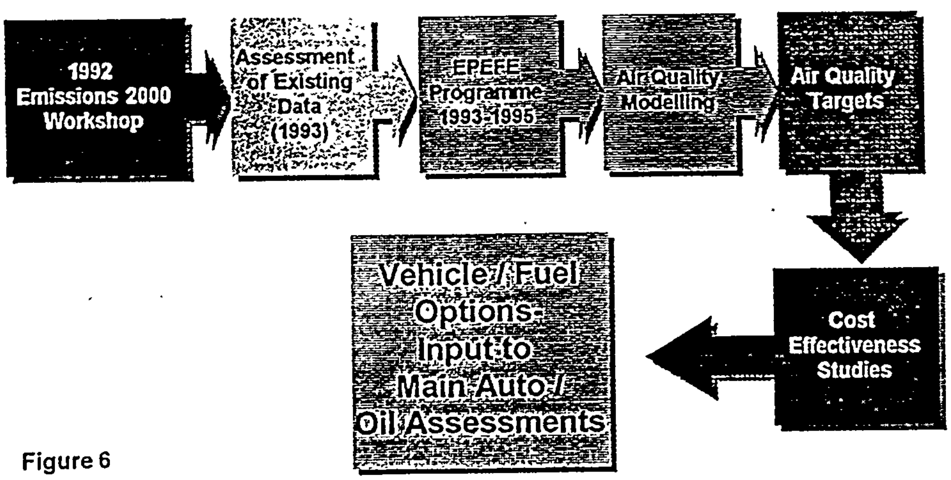


Figure 6

EU 12 PASSENGER CARS

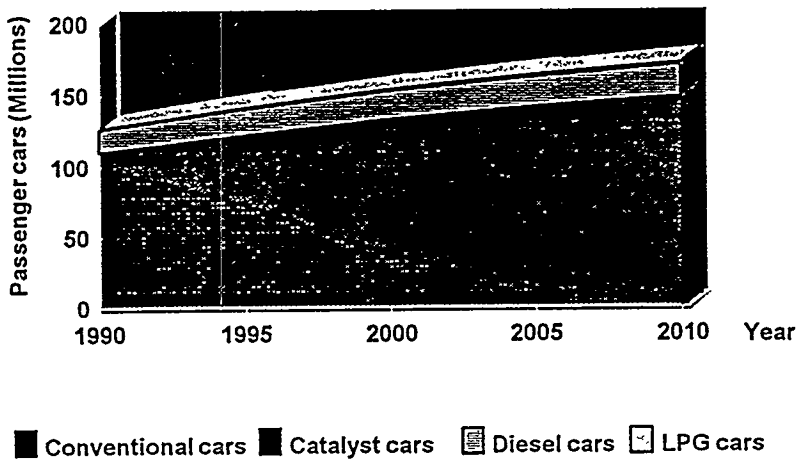


Figure 7

PREDICTED TREND IN NOx EMISSIONS FROM PASSENGER CARS AS A CONSEQUENCE OF ALREADY AGREED MEASURES (FOREMOVE)

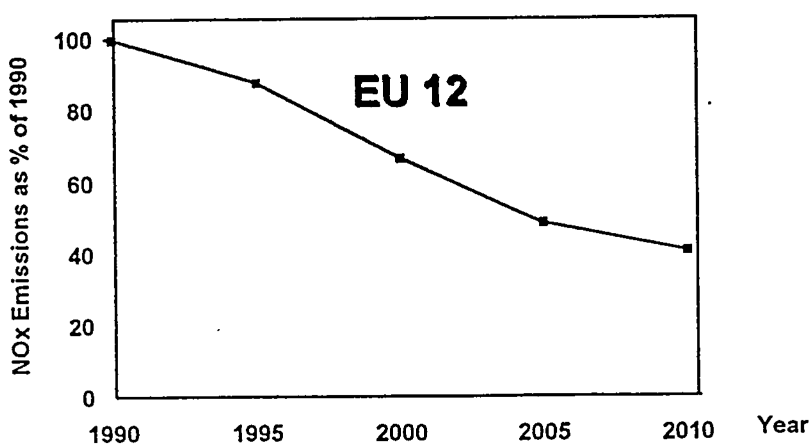


Figure 8

PREDICTED TREND IN HC EMISSIONS FROM PASSENGER CARS AS A CONSEQUENCE OF ALREADY AGREED MEASURES (FOREMOVE)

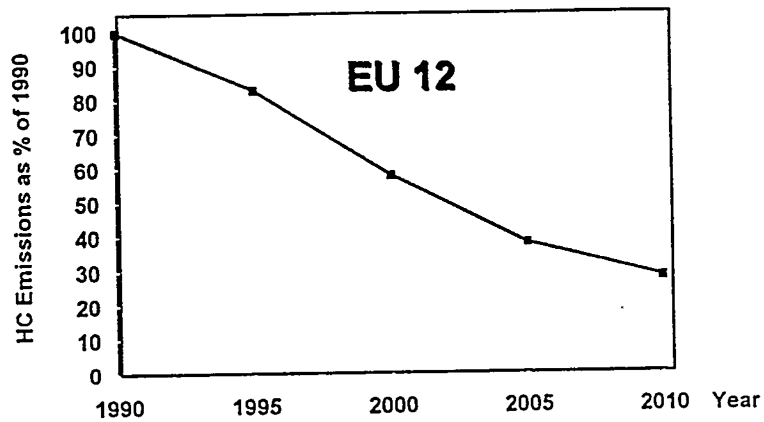


Figure 9

PREDICTED TREND IN CO EMISSIONS FROM PASSENGER CARS AS A CONSEQUENCE OF ALREADY AGREED MEASURES (FOREMOVE)

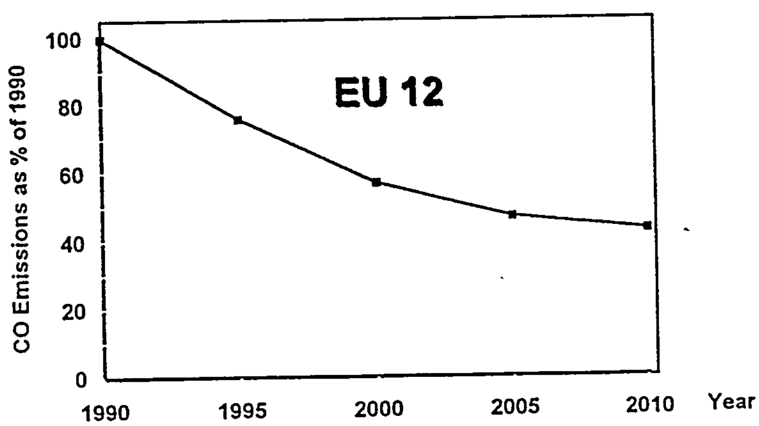


Figure 10

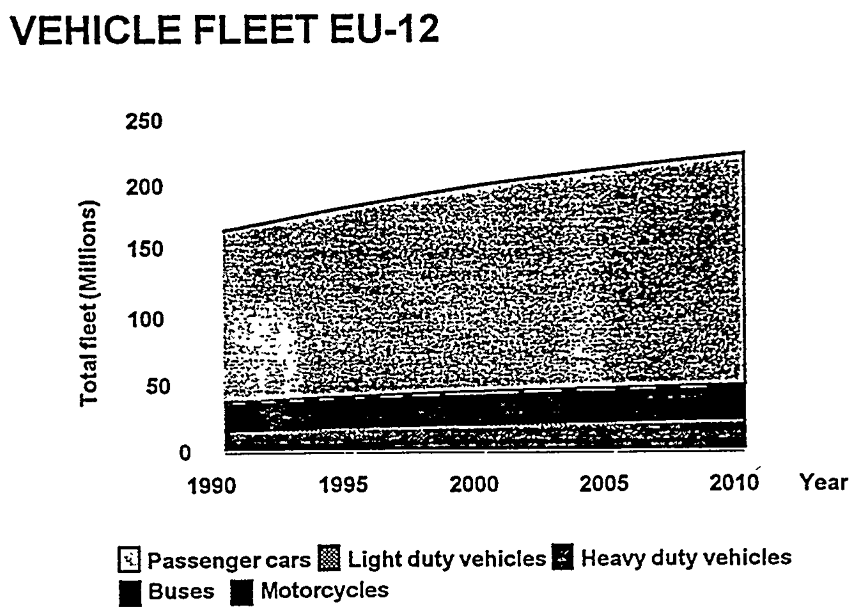


Figure 11

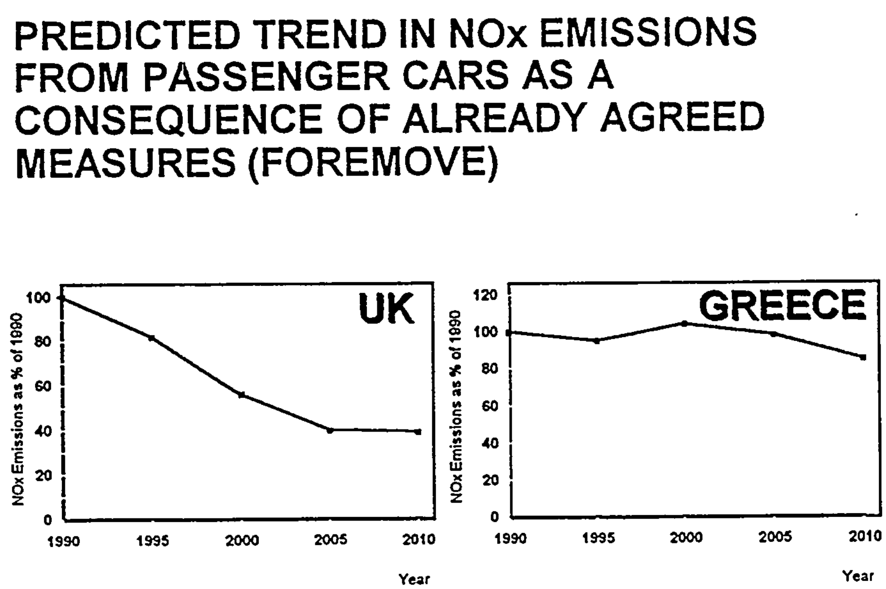


Figure 12

PREDICTED TREND IN HC EMISSIONS FROM PASSENGER CARS AS A CONSEQUENCE OF ALREADY AGREED MEASURES (FOREMOVE)

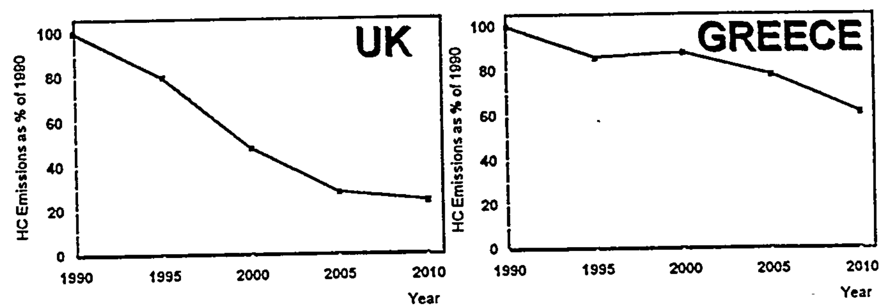


Figure 13

PREDICTED TREND IN CO EMISSIONS FROM PASSENGER CARS AS A CONSEQUENCE OF ALREADY AGREED MEASURES (FOREMOVE)

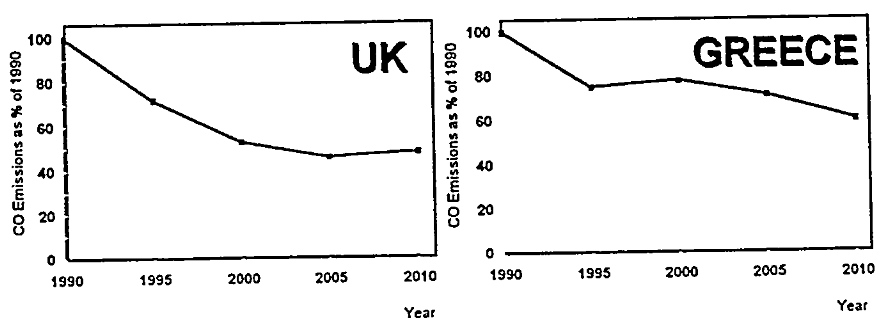


Figure 14

LIFETIME FUNCTION OF PASSENGER CARS IN THE EUROPEAN UNION

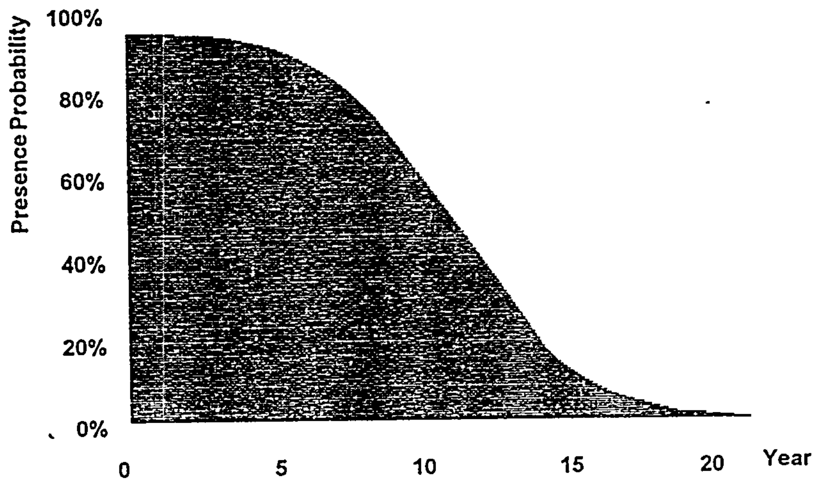


Figure 15

EVOLUTION OF AGREED TECHNICAL MEASURES

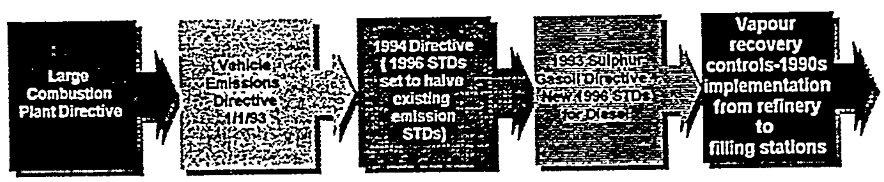


Figure 16

"SUMMER-SMOG" THROUGH OZONE ?

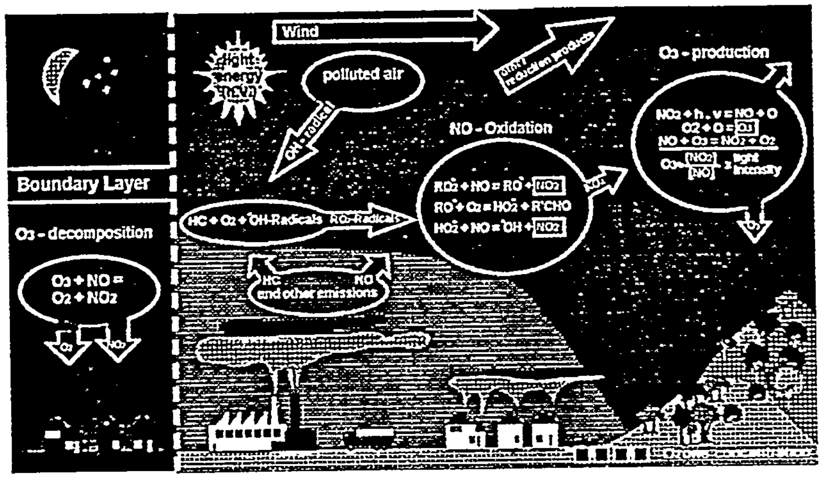


Figure 17

Adapted from Landesanstalt fur immissionsschutz

AIR QUALITY TARGET BANDS (µg/m3)

POLLUTANT	TARGET BAND VALUES UPPER	LOWER	RATIONALE	CORRESPONDING US STANDARD
NO2 (1 HOUR AVG)	200	93	EC NO2 DIRECTIVE	100 [1] (ANNUAL MEAN)
CO (8 HOUR AVG)	10	5	W.H.O	10
BENZENE (ANNUAL MEAN)	16	10 (2.5) [2]	COMPROMISE BASED ON M.S. ACTIONS	NO STANDARD
OZONE (8 HOUR AVG)	120	120	W.H.O	156
(1 HOUR AVG)	180	180	E.C. OZONE DIRECTIVE	235

[1] E.C. ANNUAL MEAN 50 µg/m3
[2] LONGER TERM TARGET VALUE

Figure 18

Non-reactive pollutants:
- Nitrogen oxides (nitrogen dioxide)
- Carbon monoxide
- Benzene
- (Particulates)

Reactive pollutants:
- Ozone
- (precursors: nitrogen oxides, volatile, organic compounds, carbon monoxide)

Figure 19

REPRESENTATIVENESS OF CITIES NO2

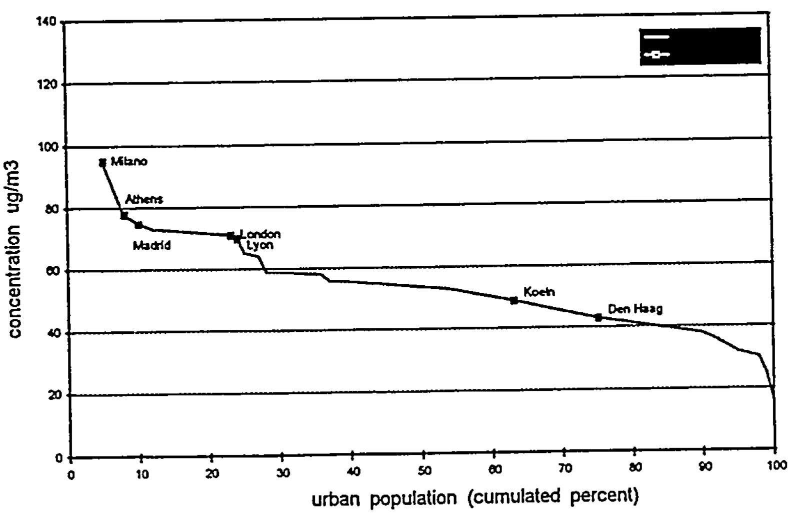


Figure 20

LONDON AQ MODEL RESULTS 1990 - 2010

NOx

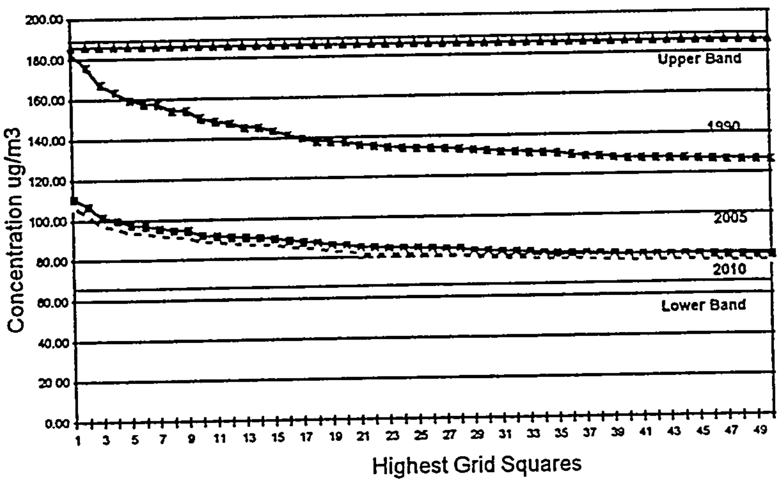


Figure 21

URBAN AIR QUALITY MODELLING - SUMMARY OF THE REQUIRED EMISSION REDUCTIONS 2005

CITY	2005								
	NOX			CO			benzene		
		emission reduction %			emission reduction %			emission reduction %	
	conc µg/m3	upper 186 µg/m3	lower 66 µg/m3	conc µg/m3	upper 3000 µg/m3	lower 1500 µg/m3	conc µg/m3	upper 16 µg/m3	lower 10 µg/m3
ATHENS	147	0	55	992	0	0	7.0	0	0
COLOGNE	103	0	35	454	0	0	3.0	0	0
DEN HAAG	69	0	5	361	0	0	2.0	0	0
LONDON	111	0	40	589	0	0	2.7	0	0
LYON	115	0	45	653	0	0	4.6	0	0
MADRID	147	0	55	0	0	0	5.6	0	0
MILAN	152	0	55	0	0	0	5.2	0	0

Figure 22

URBAN AIR QUALITY MODELLING - SUMMARY OF THE REQUIRED EMISSION REDUCTIONS 2010

CITY	2010									
	NOX			CO			benzene			
		emission reduction %			emission reduction %			emission reduction %		
	conc µg/m3	upper 186 µg/m3	lower 66 µg/m3	conc µg/m3	upper 3000 µg/m3	lower 1500 µg/m3	conc µg/m3	upper 16 µg/m3	lower 10 µg/m3	2.5 µg/m3
ATHENS	140	0	55	762	0	0	5.2	0	0	50
COLOGNE	89	0	25	386	0	0	2.1	0	0	0
DEN HAAG	68	0	5	328	0	0	1.6	0	0	0
LONDON	107	0	40	575	0	0	2.1	0	0	0
LYON	107	0	40	533	0	0	3.1	0	0	20
MADRID	135	0	50	N/A	0	0	3.9	0	0	35
MILAN	131	0	50	N/A	0	0	3.0	0	0	15

Figure 23

PARAMETER RANGES

Fuel / Parameter	Study Range
Gasoline	
Lead	0.013 - 0.005 g/l
Oxygenates	0 - 2.7% O_2
Aromatics	50 - 20%
Benzene	3 - 0.7%
Olefins	15 - 5%
Sulphur	500 - 30 ppm
RVP	80 - 60 kpa
E 100	35 - 65%
E 150	85 - 90%
Diesel	
Sulphur	500 - 50 ppm
Density	820 - 855 kg/m^3
Poly Aromatics	8 - 1%
Cetane No	50 -58
T95	370 - 330 °C

Figure 24

VEHICLE TECHNOLOGIES FOR HEAVY DUTY VEHICLE ENGINES

1. Very high pressure fuel injection
2. Electronic unit injectors
3. Electronic engine control
4. Variable pressure turbocharging
5. Controlled intercooling
6. Multi valve engines
7. Improved engine clearance volumes *
8. Exhaust gas recirculation (EGR)
9. Particulate traps
10. De-NOx catalysts
11. Alternative fuel technology **
12. *** Manufacturer other
13. *** Manufacturer other

Figure 25

VEHICLE TECHNOLOGIES BEING ASSESSED

	GASOLINE		DIESEL
1	Improved electronic engine control	1	Very high pressure injection
2	Exhaust gas recirculation (EGR)	2	Increased cylinder pressure
3	Improved & low "light off" washcoats	3	Improved clearance volumes
4	Greater catalyst loading	4	Multi valve engines
5	Dual oxygen sensors	5	Exhaust gas recirculation
6	Sequential fuel injection	6	Controlled intercooling
7	Reduced engine clearance volumes	7	Variable pressure turbo
8	Leak free exhausts	8	Electronic unit injectors
9	Cylinder disablement	9	Particulate traps
10	Electrically heated catalysts	10	De - NOx catalysts
11	Low temp stable lambda sensors	11	Manufacturer other
12	Auxiliary air injection		
13	Air assisted injectors		
14	Double wall exhaust pipes		
15	Close coupled & Under body Cats		
16	Carbon canisters - Improved charcoal		
17	Low loss systems / minimum joints		
18	Manufacturer other		

Figure 26

European Auto-Oil Programme
Average Fuel Parameter Levels for Costing

Gasoline Fuel	Base Average	I	II	III	IV
Sulphur.	300	30	30	100	100
RVP (Summer)	68	58	58	58	58
Aromatics	40	37	36	30	25
Benzene	2.3	2.1	1.8	1.0	0.7
Oxygen	0.6	≥ 1.0	≥ 1.7	~ 1.6*	~ 2.0*
Olefins	11	9	10	9	8
E100	53	55	56	62	65
E150	84	85	88	89	92
Emission Changes	HC	-5%	-8%	-8%	-12%
	NOx	-3%	-1%	+1%	+2%
	Benzene	-17%	-27%	-34%	-45%

Figure 27 * Denotes maximum of 2.7

European Auto-Oil Programme
Average Fuel Parameter Levels for Costing

Diesel Fuel	Base Average	I	II	III	IV
Cetane No.	51	53	54	55	58
Density	843	835	831	828	825
Poly-Aromatics	9	6	4.5	2.2	1
T95	355	~348	~345	~340	~340
Sulphur	450	300	200	50	30
Emission Changes	NOx	-2%	-2%	-3%	-3%
	PM	-6%	-10%	-14%	-15%

Figure 28

AVERAGE FUEL QUALITIES FOR COSTING

Mogas	Base Average	I	II	III	IV
Sulphur	300	30	30	100	100
RVP (Summer)	68	58	58	58	58
Aromatics	40	37	36	30	25
Benzene	2.3	2.1	1.8	1	0.7
O2	0.6	Š1.0	Š1.7	~1.6 *	~2 *
Olefins	11	9	10	9	8
Evaporated 100°C	53	55	56	62	65
Evaporated 150°C	84	85	88	89	92
Emission Changes	HC	-5%	-8%	-8%	-12%
	NOx	-3%	-1%	+1%	+2%

* = (Max 2.7)

Diesel Fuel	Base Average	I	II	III	IV
Cetane Numbers	51	53	54	55	58
Density	843	835	831	828	825
Poly Aromatics	9	6	4.5	2.2	1
95% Dist. Temp.	355	~348	~345	~340	~340
Sulphur	450	300	200	50	30
Emission Changes	NOx	-2%	-2%	-3%	-3%
	PM	-6%	-10%	-14%	-15%

Figure 29

NON-TECHNICAL MEASURES

Instruments Evaluated

MECHANISM	INSTRUMENT	INCLUDED IN EVALUATION Passenger cars	HGVs
Vehicle ownership	- Taxes - Scrappage subsidy	✓✓	
Vehicle use	- Fuel tax - Road pricing	✓✓	✓✓
Improved traffic management	- Traffic bans - Parking fees	✓✓	✓✓
Enhanced public/ freight transport	- Cheaper prices - Improved accessibility - Advanced telematics	✓✓✓	✓✓✓

Figure 30

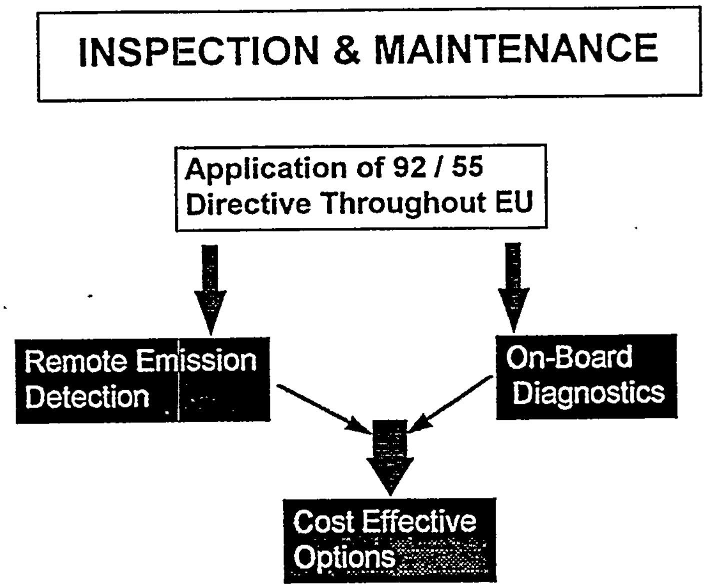


Figure 31

NON - TECHNICAL MECHANISMS CANNOT BE CHANGED DIRECTLY BUT ONLY VIA ECONOMIC INSTRUMENTS

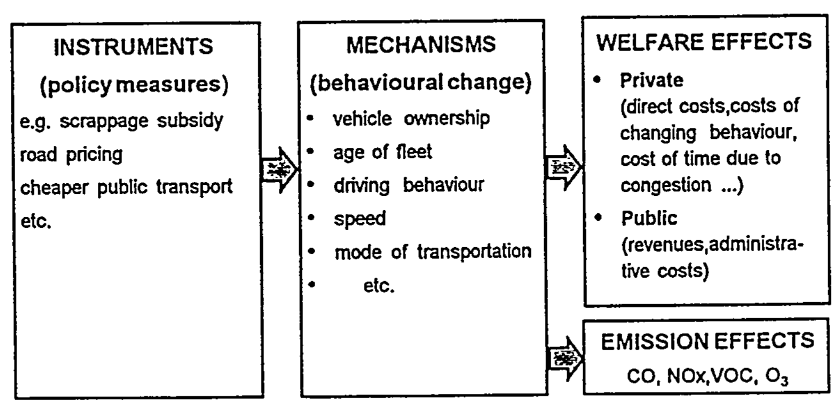


Figure 32

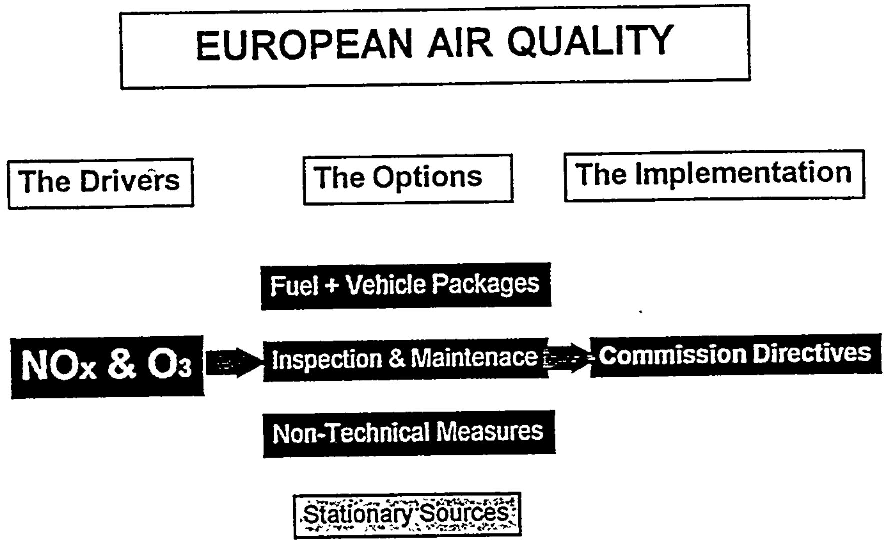


Figure 33

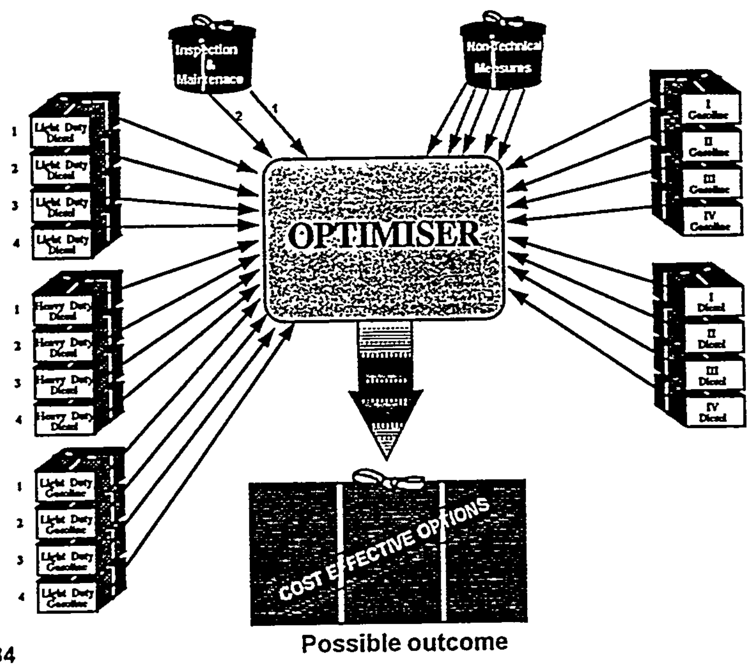


Figure 34

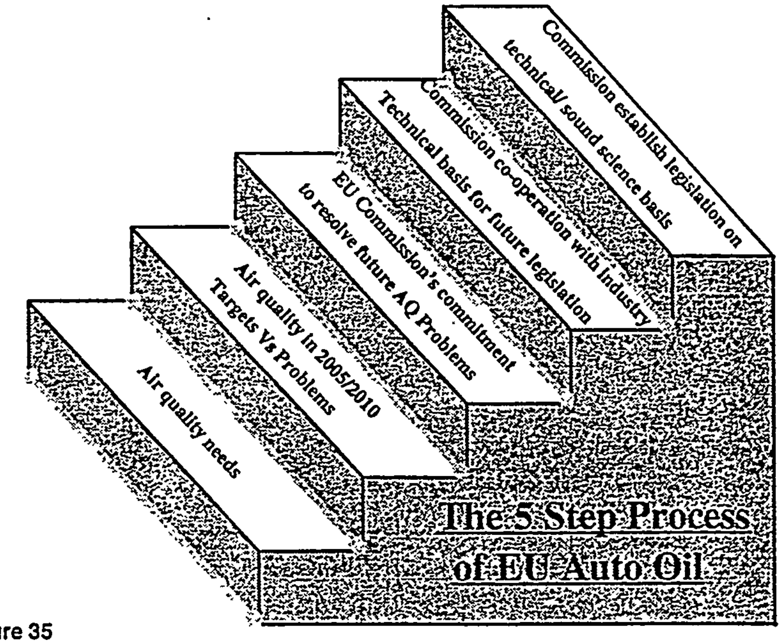
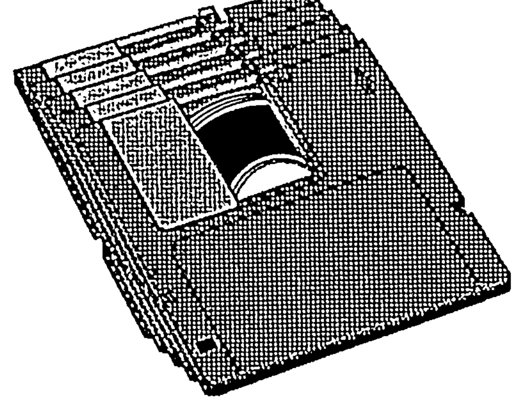
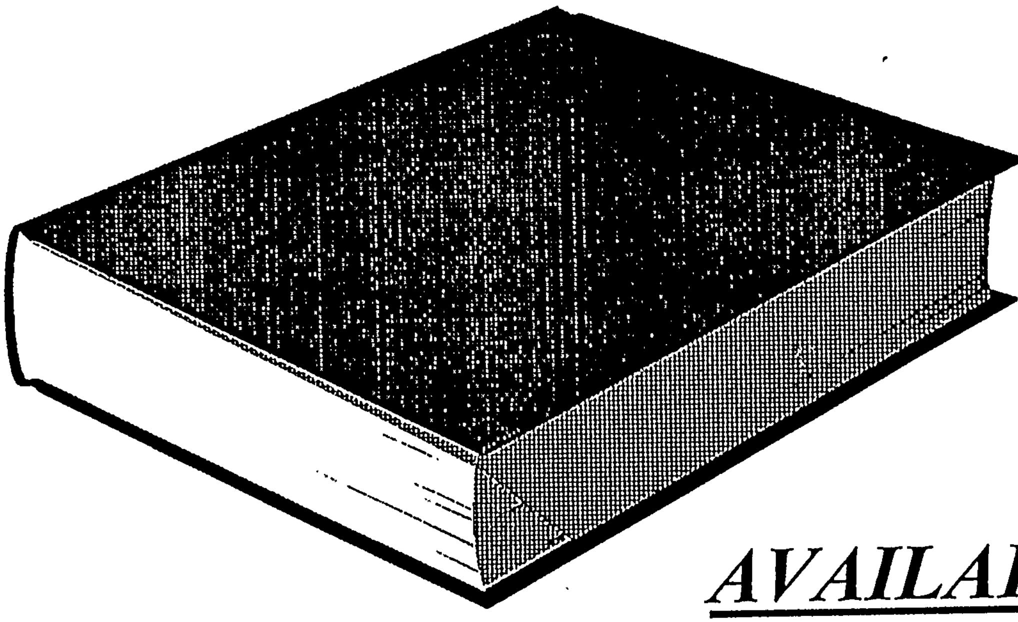

Air quality needs
Air quality in 2005/2010
Targets Vs Problems
EU Commission's commitment
to resolve future AQ Problems
Commission co-operation with industry
Technical basis for future legislation
Commission establish legislation on
technical/ sound science basis
The 5 Step Process
of EU Auto Oil

Figure 35

EPEFE REPORT



RAW DATA



AVAILABLE NOW

(via ACEA & Europia secretariats)

EPEFE EFFORT & SCOPE
(filling the knowledge gaps)

Companies
- 14 motor (ACEA)
- 32 oil (Europia)

vehicles
LD:- 16 gasoline
19 diesel
HD:- 5 engines
(all 1996+ spec)

EPEFE
11mECU ha! ha!

Fuels
- 12 gasolines (arom/E100/S)
- 11 diesel (density/T95/arom/CN)

- 500,000+ data points
- 2000+ emission tests
- 17 vehicle / engine labs
- 4 fuel blending labs
- 16000 mhs

Companies Directly Involved in EPEFE

OIL	MOTOR
SHELL	BMW
ESSO	FORD
BP	RENAULT
TOTAL	VW
STATOIL	GM / OPEL
ELF	ROVER
OeMV	PSA
MOBIL	IVECO
EURON	VOLVO
FINA	MAN
REPSOL	MB
CEPSA	FIAT
	RVI
	DAF

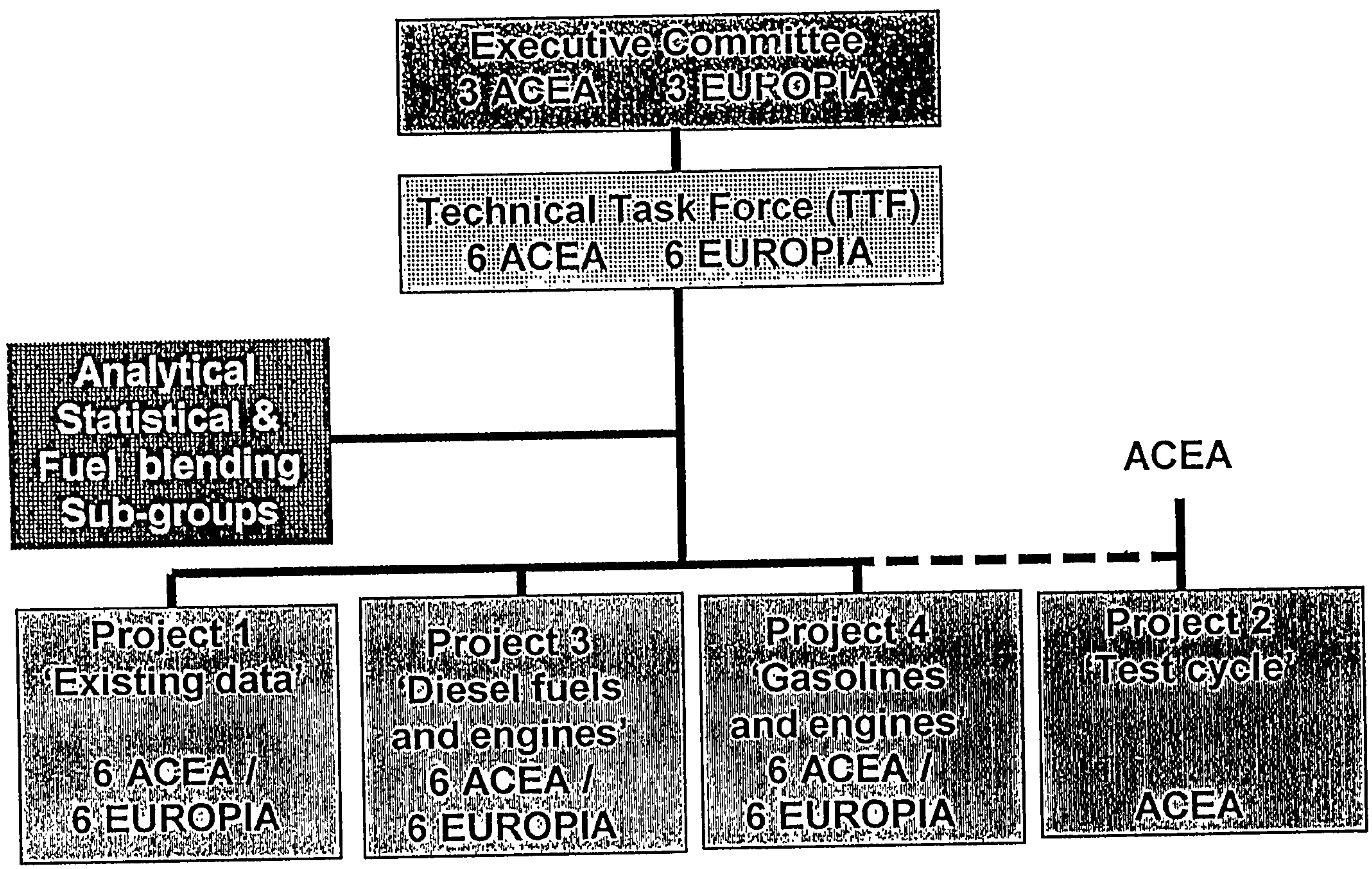
NB:- INDICATIVE LISTINGS ONLY-ALL MEMBERS OF ACEA & EUROPIA CONTRIBUTED TO THE COSTS

EPEFE HISTORY / TIMING

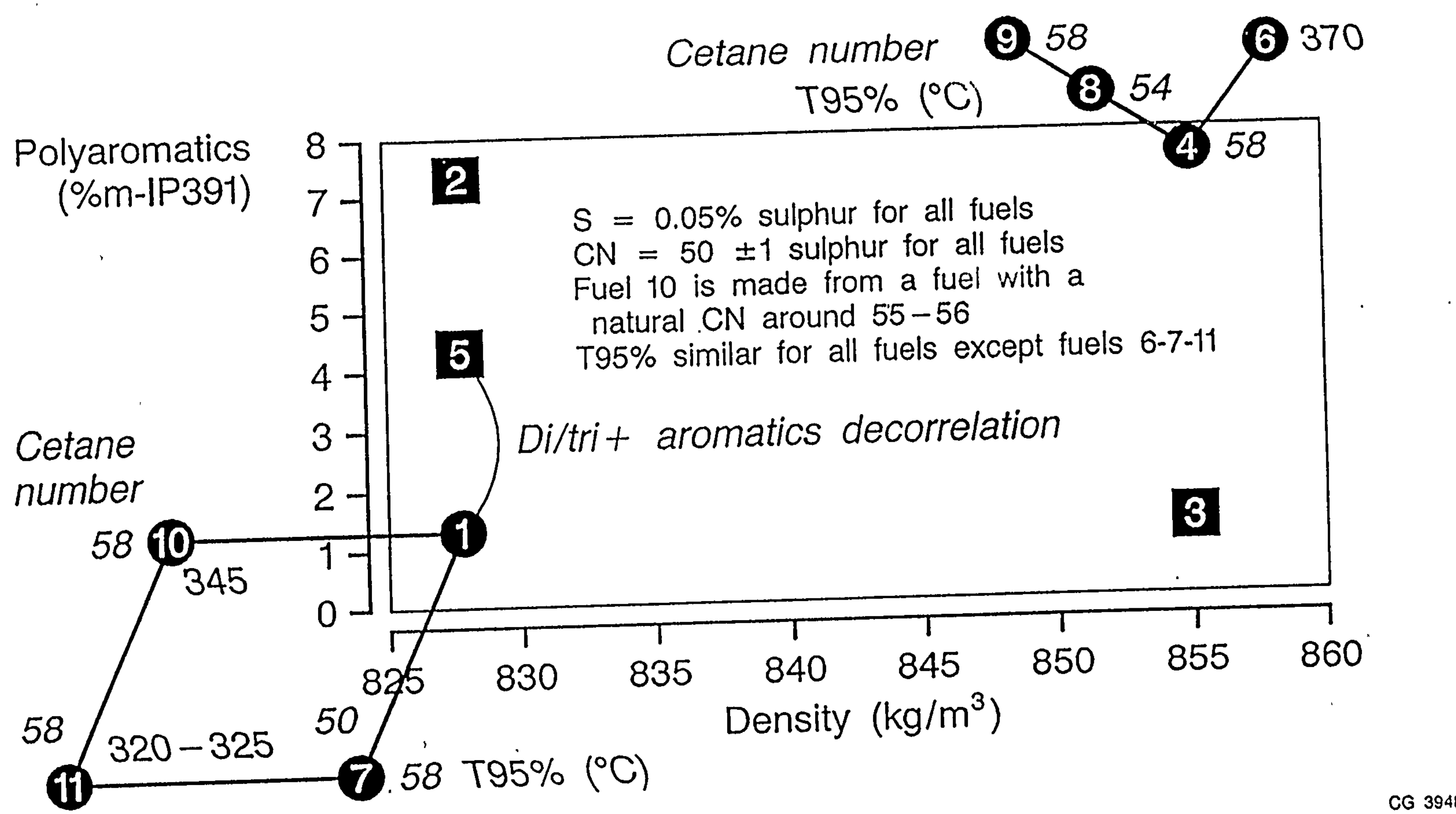
LATE '92	FRENCH/ITALIAN OIL COMPANIES INITIATIVE
Q1 '93	MAJOR OIL COMPANIES INVOLVEMENT
MID '93	ORGANISATION ESTABLISHED
LATE '93	FUELS / CARS/ ENGINE BASIS AGREED
Q2 '94	TEST PROTOCOLS/FUEL BLENDING
Q3 '94	TESTING STARTS
END Q4 '94	TESTING COMPLETE
FEB '95	AQ MODELLING INPUT
END OF 95	EPEFE REPORT

LOBBYING

The EPEFE Team Structure



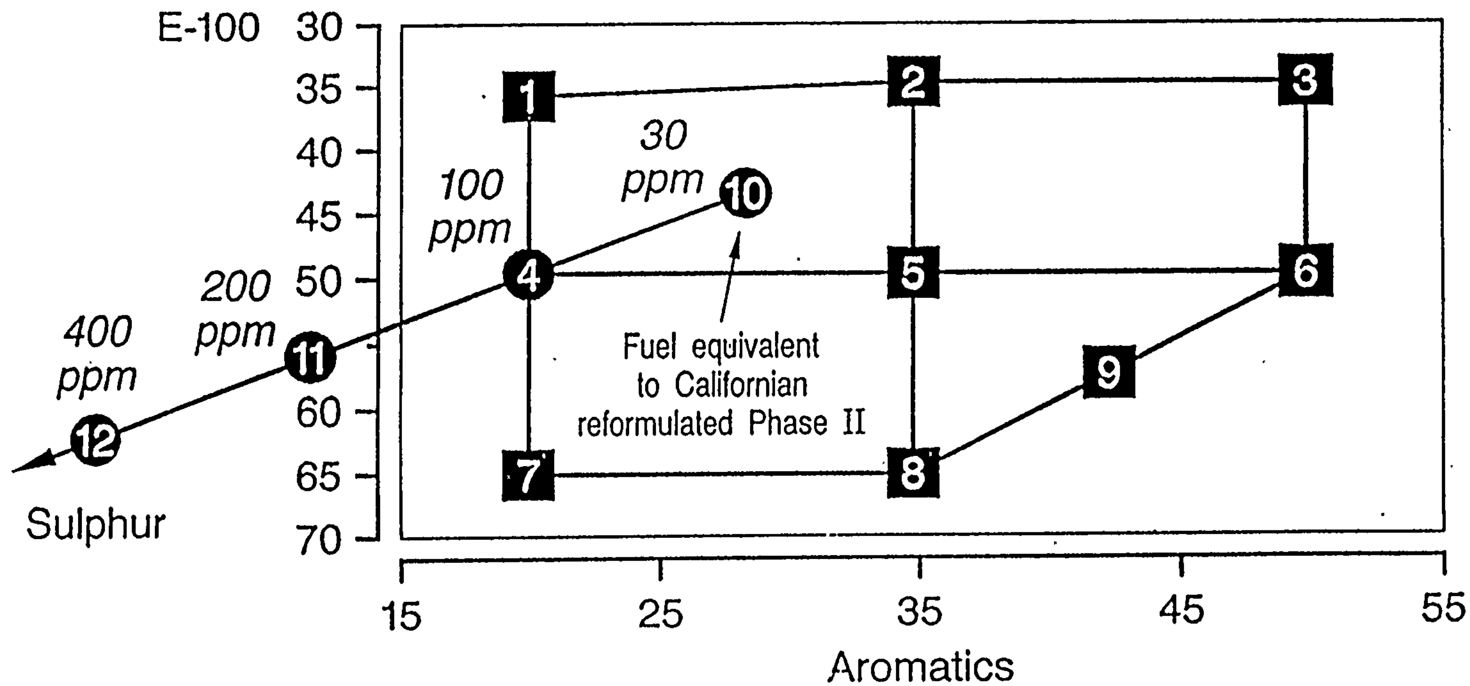
EPEFE diesel matrix

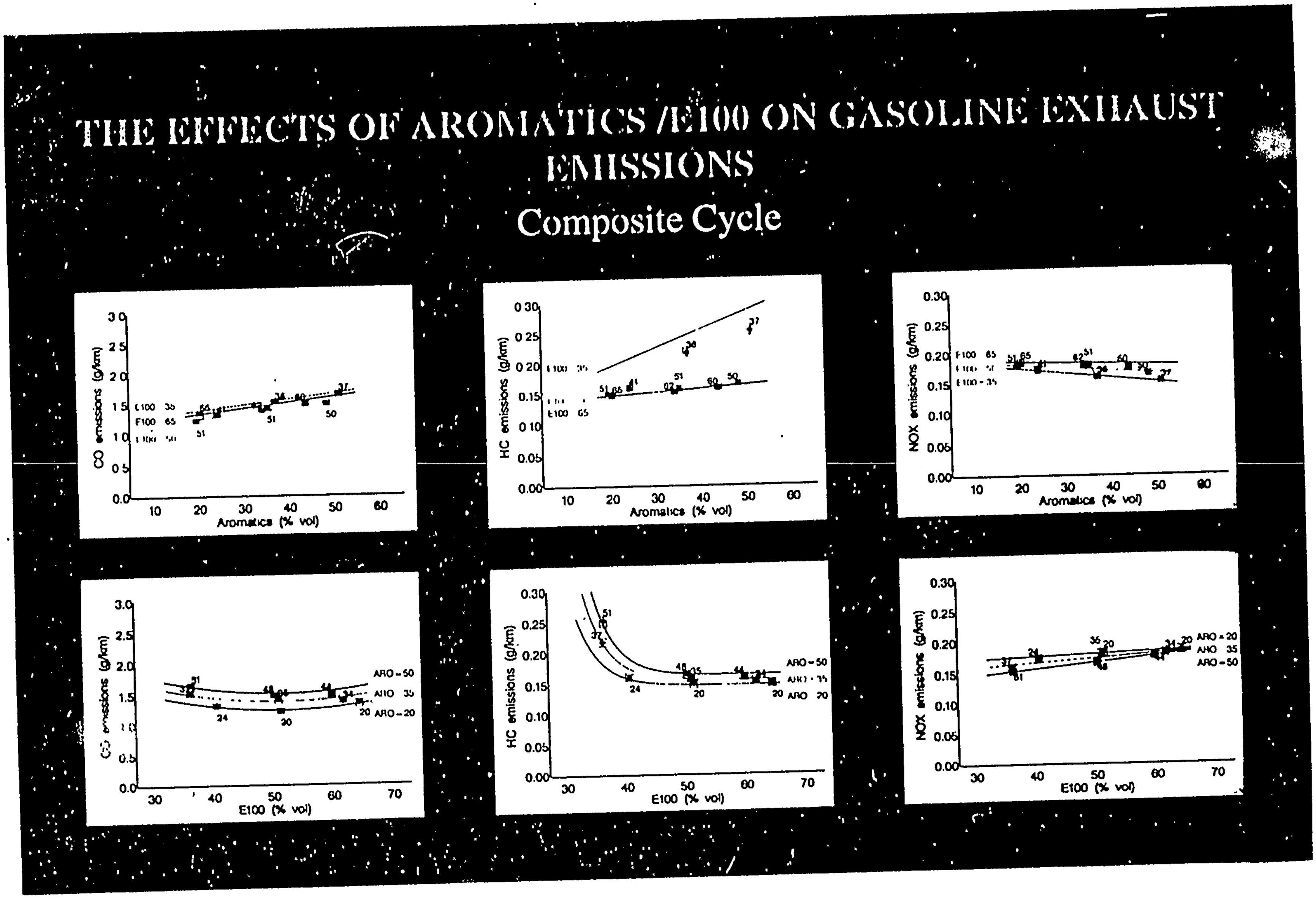


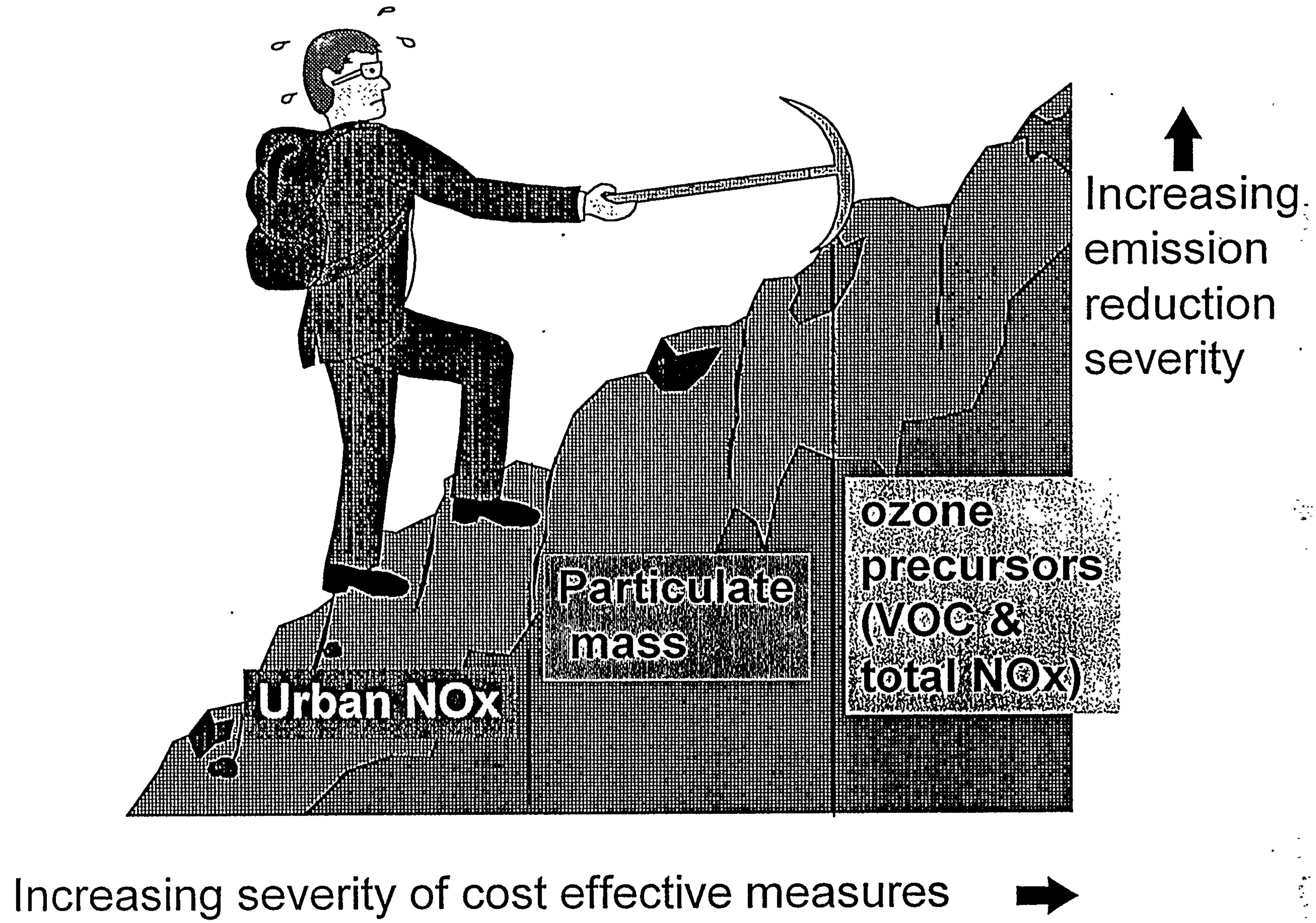
CG 39489

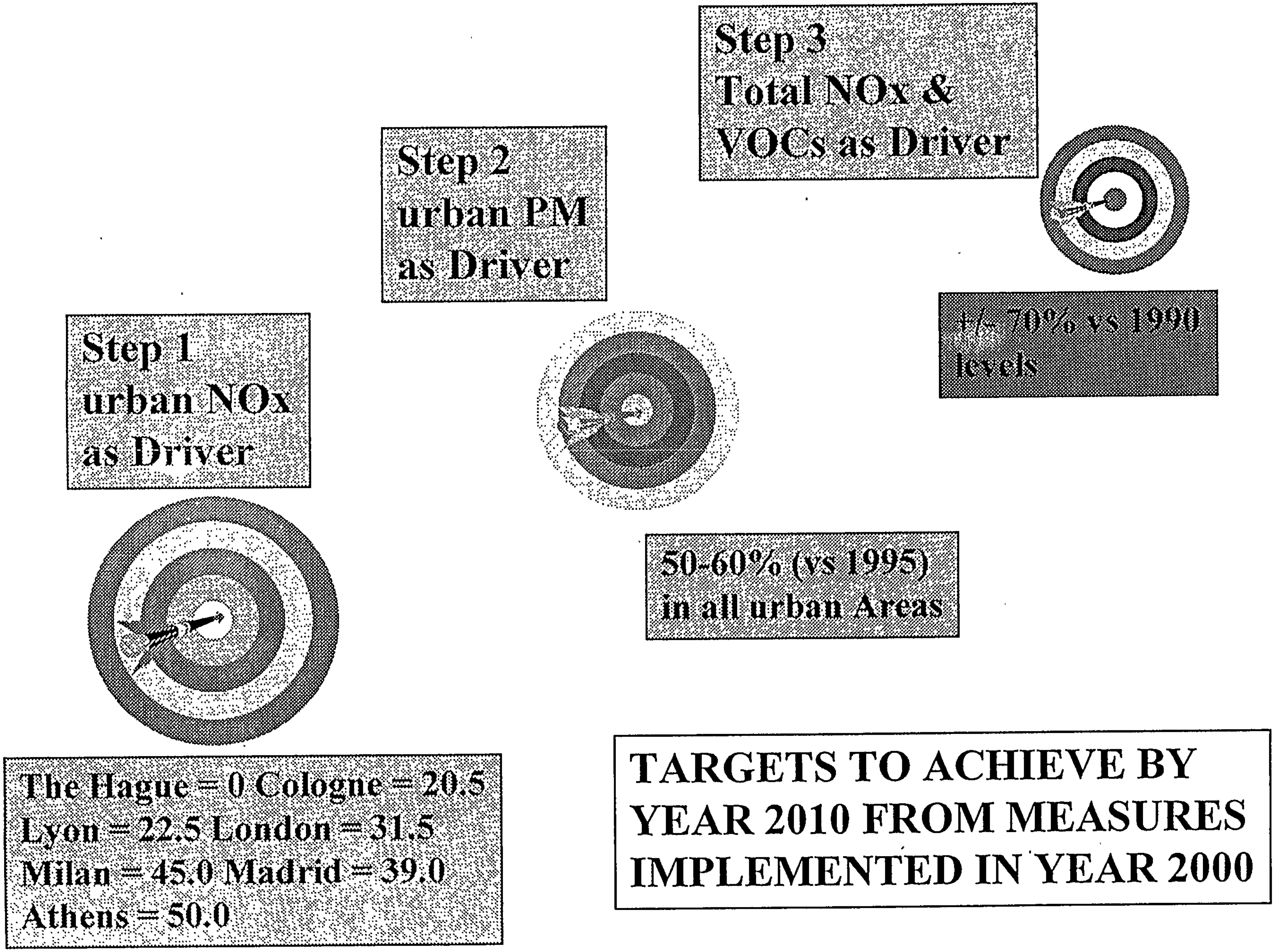
EPEFE gasoline matrix

Best option 6% vol olefins using refinery components



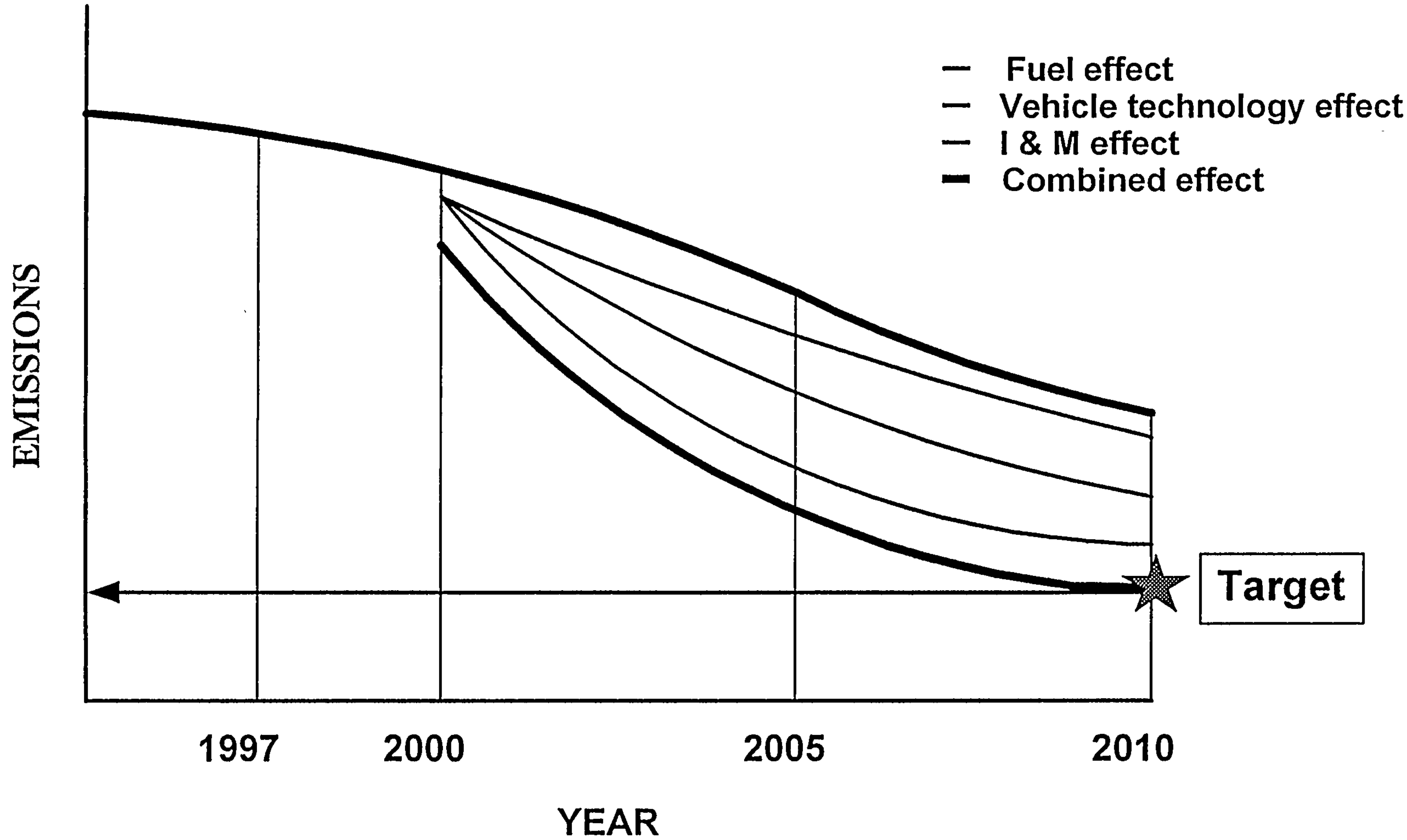

THE EFFECTS OF AROMATICS /E100 ON GASOLINE EXHAUST EMISSIONS
Composite Cycle
CO emissions (g/km)
Aromatics (% vol)
HC emissions (g/km)
Aromatics (% vol)
NOX emissions (g/km)
Aromatics (% vol)
E100 65
CO emissions (g/km)
E100 (% vol)
ARO=50
ARO=20
HC emissions (g/km)
E100 (% vol)
ARO=50
NOX emissions (g/km)
E100 (% vol)
ARO=20
ARO=50


Urban NOx
Particulate mass
ozone precursors (VOC & total NOx)
Increasing emission reduction severity
Increasing severity of cost effective measures

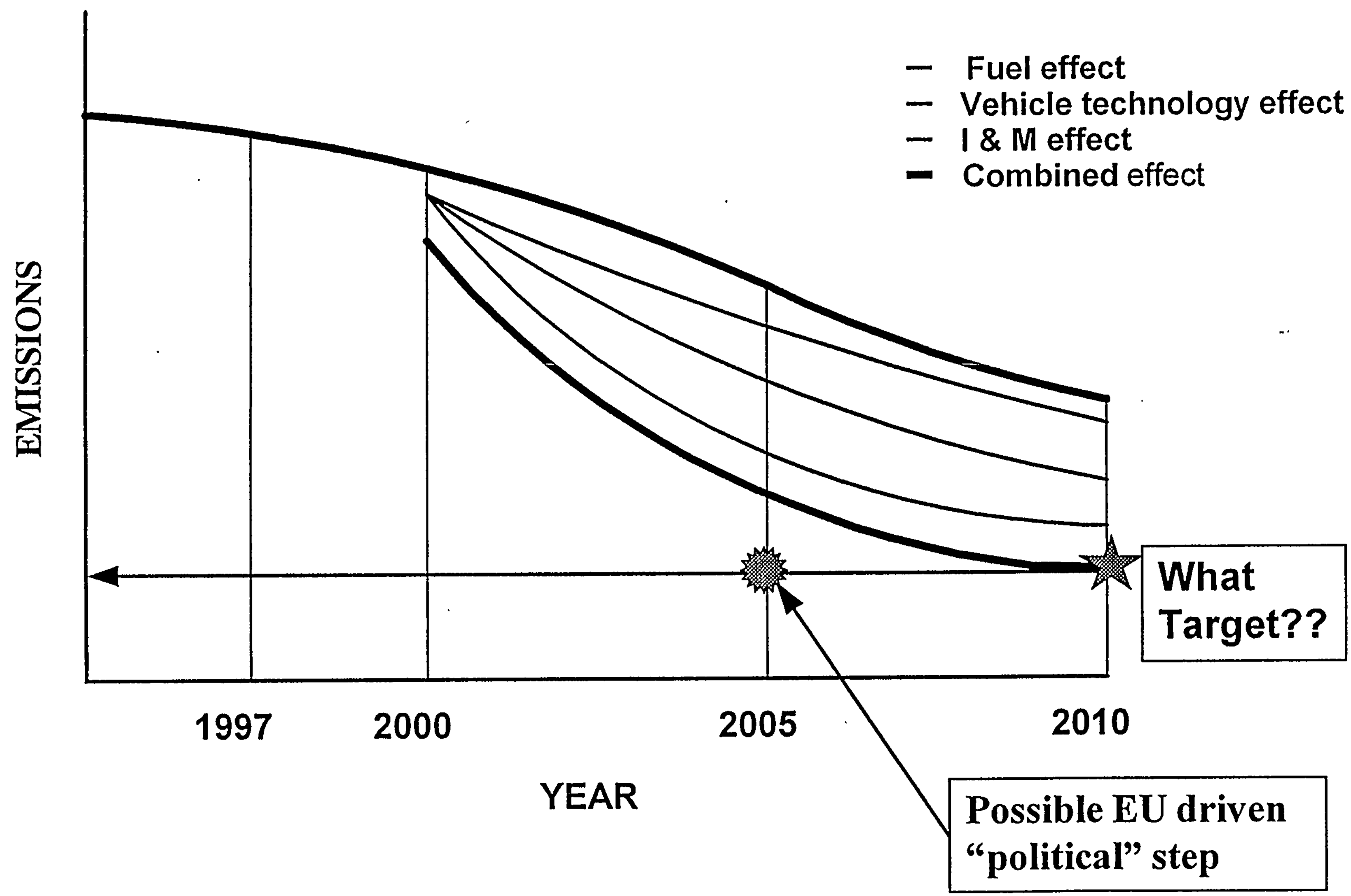


Step 1
urban NOx
as Driver
Step 2
urban PM
as Driver
Step 3
Total NOx &
VOCs as Driver
+/- 70% vs 1990
levels
50-60% (vs 1995)
in all urban Areas
The Hague = 0 Cologne = 20.5
Lyon = 22.5 London = 31.5
Milan = 45.0 Madrid = 39.0
Athens = 50.0
TARGETS TO ACHIEVE BY
YEAR 2010 FROM MEASURES
IMPLEMENTED IN YEAR 2000

Principle of implementation of year 2000 measures



Principle of implementation of year 2000 measures



POTENTIAL FOR FUTURE INDUSTRY-GOVERNMENT AGREEMENTS ON ALTERNATIVE FUELS
A PROGRESS REPORT FROM THE NAICC TRANSPORTATION GROUP

Peter Reilly-Roe, Natural Resources Canada

Tony Rockingham, Ontario Ministry of Environment and Energy

Presented at the

1996 Windsor Workshop on Alternative Fuels

June 3, 1996

CCME Recommendation #2 of Oct 1995

The Federal Government in concert with the provinces and other stakeholders through the National Air Issues Coordinating Committee (NAICC):

- **negotiate a memorandum of understanding (MOU) with the auto manufacturing and alternative fuel industries by July 1, 1996 in order to make advanced technology vehicles available for sale in a timely manner.**

- **seek to coordinate and enhance federal, provincial, and auto and fuel industry efforts to support market development of alternative fuels and advanced technology vehicles and report on these efforts to the CCME by the fall of 1996.**

NAICC formed a National Transportation Group (NTG) in December 1995.

The NTG is co-chaired by Natural Resources Canada and Ontario's Ministry of Environment and Energy

It includes broad representation from the fuels and vehicle industries, as well as federal and provincial representatives of energy and environment departments and two ENGOs.

The NTG organized a workshop to:

- **examine the barriers facing alternative transportation fuels and advanced technology vehicles and**

- **to explore areas for possible agreements or MOUs among stakeholders and between stakeholders and governments, that would be useful in overcoming the key barriers.**

The results of the workshop will be reported to the NAICC at its June 17, 1996 meeting.

Workshop Organization

The workshop was held on May 15-16, 1996 in Ottawa.

Prior to the workshop background papers were received from the following organizations:

- Motor Vehicle Manufacturers' Association
- Association of International Automobile Manufacturers of Canada
- Propane Gas Association of Canada
- Canadian Natural Gas Vehicle Alliance
- Canadian Renewable Fuels Association
- Electric Vehicle Association of Canada
- Canadian Oxygenated Fuels Association

ATF Producer Perspectives

- **Although the rationale has changed over the years, there is still a strong public policy justification for supporting the ATF industry.**
- **ATF vehicles still have significant environmental advantages over gasoline vehicles.**
- **The economic viability of the industry depends on the continued and predictable support of government, through tax concessions.**
- **Long term viability depends on the ability to overcome barriers to the marketing of ATF vehicles. Active participation of OEMs is essential.**
- **Cooperation between ATF producers and OEMs to ensure the availability of ATF vehicles.**

OEM Perspectives

- **OEMs believe in the advantages of ATFs, but also feel that there have been some unrealistic claims and expectations.**

- **OEMs have invested a lot in the development of ATVs, but results have been disappointing.**

- **Obstacles vary between fuels, but the principal common barriers are:**

    - **lack of range and refuelling infrastructure;**
    - **perceived erosion of the environmental advantages over gasoline;**
    - **inherently higher variable costs;**
    - **poor resale value;**
    - **long delivery lead times; and**
    - **lack of customer acceptance.**

- **Government resources should be focussed on the most promising opportunities.**

- **Governments must be clear and consistent in terms of policy, regulations and incentives.**

- **Fuel and vehicle standards must recognize the integrated nature of the industry and the importance of the total systems approach.**

- **All parties should constantly think of the needs and expectations of the consumer.**

Federal Government Perspectives

- The Federal Government has supported the development of ATFs for over two decades. At various times, energy policy has highlighted different benefits, including energy security, economic benefits, and environmental protection. An important current priority is Canada's commitment to stabilize greenhouse gas emissions by the year 2000.
- ATFs offer significant environmental benefits, including the reduction of greenhouse gas emissions, however, given new sophisticated emission control systems, the advantages over gasoline cannot be taken for granted.

- **The ATF market has the potential to make an important contribution to the Canadian economy.**

- **The Government understands the importance of tax waivers for the viability of ATFs but is looking for indications that ATFs will eventually be competitive on their own.**

- **Reductions in the cost of ATF vehicles are essential to the long term viability of the industry.**

- **With the exception of propane, the lack of adequate refuelling infrastructure remains an impediment to growth.**

- **The Canadian market will be guided by developments in the larger U.S. market.**

- **The continued growth of the ATF industry will require a comprehensive strategy, led by industry and competitive in the marketplace. Such a strategy should include:**

  - **continuing development of new technologies;**
  - **greater acceptance of ATFs by fleets; and**
  - **greater involvement by vehicle manufacturers.**

- **Government has played a partnership role according to the following principles:**

  - **fuel neutrality;**
  - **environmental integrity;**
  - **government leadership (use of ATVs in government fleets);**
  - **market development and awareness; and**
  - **technology development.**

Provincial Government Perspectives

- Provincial governments have provided widespread support for ATFs over the past 15 years. Programs have included R&D, procurement and tax relief.

- This support has not resulted in significant market penetration.

- Gasoline vehicles are demonstrating an increased ability to deliver emission reductions and are challenging ATF claims of environmental benefits.

- Given deficit reduction objectives and staff reductions, government's role in the marketplace has changed.

  In the future, governments will be less likely to intervene directly and may act more frequently as facilitators.

- **The ATF industry will have to identify the issues and the opportunities and develop appropriate strategies.**

Framing Statements for Breakout Groups

1. Improving the economic viability of new or "current" alternative fuels and vehicles

2. Transition from "aftermarket" or demonstration activity to OEM vehicle production

3. Enhancing the contribution of alternative transportation fuels and vehicles to sustainable development

Final Plenary Areas of Agreement

- **The success of ATF market development in the short term is critical for the viability of the ATF industry in the longer term.**

- **Collaboration by all stakeholders is a prerequisite for success.**

There is a need:

- **to investigate and clarify the environmental benefits of ATFs.**

- **to better publicize the benefits of ATFs.**

- **for more effective market research and planning.**

- **to reexamine the effectiveness of current government and industry incentives for ATFs.**

- **to review the effectiveness of government policies in relation to ATFs.**

Key Workshop Outcomes: Specific Commitments

1. It was agreed that four ATF industry associations (NGVA, COFA, CRFA, PGAC) would form a partnership (MOU to be in place by June 30, 1996).

2. It was agreed that the ATF partnership will explore the development of an umbrella MOU (to be in place by August 1996) with OEMs with the following provisions:

   - government was asked to facilitate the process (perhaps the Co-Chairs of the NAICC Transportation Group);
   - the initial focus will be on marketing; and
   - there may be a need to form sub-groups aimed at specific fuels.

3. **It was agreed that governments be requested to clarify ATF policy through a consultative process aimed at defining the policy rationale for ATFs and integrating ATFs into the broader government policy agendas (energy, environment, industry).**

4. **It was agreed that an industry/government working group be formed to investigate the development of uniform emission and safety standards for aftermarket conversions of gaseous fuel vehicles.**

SESSION 1

PANEL DISCUSSION: ARE THE OEM'S COMMITTED, AND IS THE TECHNOLOGY READY?

Moderator: Bernie James
CANMET, Natural Resources Canada

(Presentations unavailable at time of publication)

SESSION 2

PANEL DISCUSSION: INFRASTRUCTURE ISSUES

Moderator: Peter Ward
California Energy Commission

Presentation - Thomas J. Timbario, EA Engineering Science and Technology, Inc.
Presentation - Zoher Meratla, CDS Research Ltd.

(Other presentations unavailable at time of publication)

Panel Discussion

LEARNING FROM EXPERIENCE:

WHAT HAVE ACTIVITIES UNDER AMFA, EPACT, AND OTHER PROGRAMS TAUGHT US?

Prepared for presentation at

The Windsor Workshop
June 3, 1996

by

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WORLDWIDE PUBLIC POLICY DRIVING FORCES UNDERLYING REGULATION OF FUELS AND VEHICLES

- URBAN AIR QUALITY
- OIL IMPORT DEPENDENCE
- GLOBAL CLIMATE CHANGE
- DOMESTIC JOB CREATION
- RENEWABLE ENERGY DEVELOPMENT
- URBAN CONGESTION

OF THESE, URBAN CONGESTION IS NOT RELATED TO ALTERNATIVE FUELS, WHILE ALL THE OTHER DRIVERS HAVE PLAYED ROLES IN ALTERNATIVE FUEL POLICY DEVELOPMENT.

EXPERIENCE TELLS US

FOR VEHICLES/FUELS:

AFVs COST MORE THAN CONVENTIONAL VEHICLES; MANY COST SUBSTANTIALLY MORE.

FUEL COSTS ARE SOMETIMES LESS AND SOMETIMES MORE THAN CONVENTIONAL FUELS.

EVEN WHEN FUEL COSTS ARE LESS THAN CONVENTIONAL FUELS, THE SAVINGS ARE OFTEN NOT ENOUGH TO GET LIFE CYCLE COSTS TO PARITY.

EXPERIENCE TELLS US (CONT.)

<u>FOR INFRASTRUCTURE</u>:

REFUELING INFRASTRUCTURE REQUIRES ADDITIONAL COSTS, WHICH ARE SUBSTANTIAL UNLESS SHARED BY MANY USERS.

MOST FLEETS IMPLEMENTING AFVs ARE LOOKING TO LOWEST SHORT TERM COST FOR REFUELING THEIR OWN VEHICLES, NOT TO ACCESS FOR HIGH VOLUMES OF FLEETS OR PERSONAL AFVs.

VEHICLE STORAGE AND MAINTENANCE FACILITY MODIFICATIONS ARE ALSO OFTEN REQUIRED (FOR SAFETY PURPOSES).

CASE STUDY - CNG TRANSIT BUSES

- INCREMENTAL VEHICLE COSTS HIGH BUT ACCEPTABLE (AND FUNDABLE)
- FUEL COSTS COMPETITIVE
- REFUELING FACILITY COSTS SUPPORTED BY UTILITIES
- MAINTENANCE AND STORAGE FACILITY MODIFICATION COSTS BECOME THE DETERMINANT FACTOR

AFV MANDATES

BY 2010
HOW MANY VEHICLES?
HOW MUCH INFRASTRUCTURE?

Mandate	Likely Range of Vehicles	Estimated No. of Fuel Dispensers Req'd.
Fuel Provider	100,000 to 216,000	1,100
State Fleets	100,000 to 285,000	1,500
Private and Local Government Fleets	450,000 to 1,800,000	9,000
CARB and OTC	2,400,000 (ZEVs) 400,000 (Others)	NA Mostly RFG (?)

FACTORS AFFECTING INFRASTRUCTURE DEVELOPMENTS FROM MANDATES

- FUEL PROVIDERS MUST USE AFs, AND WILL MOST LIKELY ESTABLISH PRIVATE REFUELING FACILITIES.
- STATE FLEETS DO NOT HAVE TO USE AFs, THUS, WILL NOT ADD SIGNIFICANTLY TO DEMAND FOR AF REFUELING FACILITIES.
- PRIVATE AND LOCAL GOVERNMENT FLEETS, IF MANDATED BY DOE RULEMAKING TO ACQUIRE AFs, MAY GENERATE SUFFICIENT DEMAND TO CATALYZE ESTABLISHMENT OF SIGNIFICANT NUMBERS OF PUBLIC AF REFUELING FACILITIES, BUT PROBABLY AFTER 2001.
- CARB AND OTC ZEV IMPLEMENTATION RATE AND DEPTH ARE UNCERTAIN, AND MOST NON-ZEVs WILL PROBABLY USE CLEAN GASOLINE OR DIESEL FUEL

NON-PRICE BENEFITS OF AFV USE

ACCRUING TO SOCIETY: VARIOUS SOCIAL BENEFITS AS MANIFESTED BY "DRIVING FORCES" (SLIDE ONE).

- TO DATE, NOT REFLECTED IN MARKETS OR INCENTIVES.
- UNLIKE LEADED GASOLINE, CATALYTIC CONVERTERS, CLEAN DIESEL, RFG, POLICY BURDENS UNLIKELY EVER TO BE EVENLY SPREAD.

POSSIBLE INDIVIDUAL BENEFITS TO AFV USERS:

- ACCESS TO TRANSPORTATION FUEL IN EVENT OF OIL SHORTAGE. APPARENTLY INSUFFICIENT TO EFFECT SUBSTANTIAL AFV USE.

WHERE ARE WE TODAY?

CURRENT PRINCIPAL POLICY INSTRUMENT IN U.S. IS FLEET MANDATES.

COSTS ARE THE SAME WHETHER MANDATES OR INCENTIVES ARE USED.

COSTS COULD BE REDUCED IF VOLUME THRESHOLDS ARE REACHED FOR SOME FUELS.

CURRENT FLEET MANDATES ARE UNLIKELY TO REACH THE NECESSARY VOLUMES FOR COST REDUCTION FOR FORESEEABLE FUTURE.

WHAT DO WE NEED?

EXISTING POLICY DRIVERS INSUFFICIENT TO OVERCOME COST REDUCTION THRESHOLDS OR ACHIEVE SUBSTANTIAL AFV USE.

WHAT CAN CHANGE THIS PICTURE???

- MORE MANDATES? - HIGHLY UNLIKELY IN SHORT TO MID TERM
- SUBSIDIES/TAX INCENTIVES? - POSSIBLE VIA HIGHWAY TAX
- MARKETS FOR ENVIRONMENTAL BENEFITS/CREDITS? - A REAL STRUGGLE
- MARKET CHANGES IN RELATIVE FUEL PRICES? - UNLIKELY
- SPECTER OF PETROLEUM SHORTAGES? - NO PRESENT VALUE
- CHANGES IN PERCEPTIONS OF INDIVIDUAL BENEFITS? - WOULD TAKE GENERATIONS

LNG FUELING FOR TRANSPORTATION: THE NEXT GENERATION OF LNG FUELING STATIONS

Zoher Meratla, CDS Research Ltd, North Vancouver, Canada
Norman Trusler, BC Gas Utility Ltd, Vancouver, Canada

Abstract

The current state of the art has been reviewed. On the whole, the assessment criteria leading to the selection of liquefied natural gas (LNG) as an alternate fuel have been fairly well developed. However, the technology needs have not been adequately addressed in many instances resulting in demonstration projects less successful than anticipated. Because LNG technology is more complex than that of conventional fuels, such as gasoline and diesel, and because LNG as a transportation fuel is in the early stages of development, the technology needs must be very carefully addressed. The paper presents an overview of a new philosophy for designing LNG fueling stations using a systems approach covering all aspects of an LNG fueling system.

1.0 INTRODUCTION

For the past twenty years, LNG has seen an increasing and broad level of interest as an alternative fuel driven largely by its environmental benefits and other specific attributes including a mileage range comparable to diesel. However, LNG has to compete with other alternate fuels such as, propane, methanol, ethanol, compressed natural gas, gaseous and liquid hydrogen, and other fuels at an early stage of introduction. Based on typical selection criteria, such as, environmental emissions, safety, availability, operating costs, efficiency, ease of developing the infrastructure, weight penalty, mileage range, refueling time and effect on vehicle maximum load carrying capacity, LNG has often come out as the best option in comparison to both conventional and other alternative fuels for many heavy vehicle fleet demonstration projects. The current trend towards high purity liquefied methane together with the inherent clean-up during liquefaction makes LNG the cleanest hydrocarbon fuel.

A review of the experience reported on a large number of LNG fueling projects implemented to date shows that most of these projects have not met all the expectations of the facility operators. Some of the problems encountered include: leaks at nozzles, excessive filling time, icing and difficulty in disengaging the fill nozzle, high boil-off losses, uncontrolled state conditions at the LNG fueling station and on-board the vehicle, unreliable fuel delivery to the vehicle, inadequate metering, lack of proper material balance, uncontrolled emissions to atmosphere, inadequate safety provisions and uncontrolled cooldowns.

Because the LNG industry serving the international trade and the peak shaving facilities is a mature one, with considerable experience in all facets of LNG operations, a close examination of the projects experiencing difficulties indicates that these fueling projects have not been implemented as total systems with a single responsibility from a qualified contractor. The most common omission in the list of evaluation criteria is adequate assessment of technology requirements. Thus, it is not uncommon for fleet operators with no previous experience in LNG to start improvising solutions to problems encountered in the field. This is not considered acceptable. Given the pressure to maintain services, some operators have either slowed the introduction of

LNG or opted for dual fuels or deferred the introduction of LNG in order to avoid these difficulties.

There is another drawback to the current practice. Fleet operating personnel who have to deal with serious teething problems will justifiably develop a perception that LNG is a problem fuel. If this perception is allowed to develop unchecked, the result will be a credibility problem that will make the continued introduction of LNG as a vehicle fuel very difficult.

Thus, a system approach designed by qualified contractors is considered a must if LNG is to play the role it deserves as an alternate fuel.

Most of the issues identified above have been addressed by CDS Research Ltd in a project initiated by the government of Canada through its PERD program.

2.0 ADDITIONAL CONSIDERATIONS FOR SELECTING LNG

In addition to well established evaluation criteria, it is desirable that consideration be given to the following:

1. objective of the project: demonstration only or full conversion
2. given the number of demonstration projects already completed or being implementated, establish the need for another demonstration project, particularly under operating conditions
3. for a large scale conversion effort, develop a total system and identify the potential problem areas so that these are fully addressed and resolved at the design stage. Establish specific performance criteria that have to be met by the design/construction contractor
4. at the outset, insure that safety is given the highest rating. This is not to be construed that LNG is not safe. It simply means that it requires proper design and handling
5. in addressing the economics of LNG fueling, in common with any other industry, scale is an important factor. The conversion cost per vehicle is generally highest for a small fleet. There is a need to consider a central liquefaction facility serving many users, thus permitting certain costs to be spread and creating the volume of vehicles needed to improve the economics of the project. Future LNG fueling growth needs to be assessed and taken into consideration
6. standardization of equipment, such as fuel transfer pumps, fuel nozzles, vapor return, fittings, fuel injection, etc., can improve reliability, safety and costs.

3.0 DESIGN PHILOSOPHY

The implementation of a successful LNG fueling project requires the development of suitable terms of reference. In particular, the following are considered important:

1. sizing the LNG production and/or supply needed for the various phases of the project
2. product specification. For consistency of heating value and to eliminate weathering problems, 99.5% + methane content should be targeted
3. suitable OEM equipment should be available to permit conversion of the targeted vehicles
4. because most of the users, such as transit operators, trucking companies, etc., have little or no experience with LNG, the entire fueling station should be designed for ease of operation and inherent safety

5. it is important to design a coherent LNG supply system. The state conditions of the fuel delivered to the fueling station should meet specific conditions so that when combined with its design residence time, no venting will occur under normal operating conditions. To meet these targets, the insulation system of the delivery tanker and the fueling station need to be selected accordingly. Delivery time should also be taken into consideration
6. the state conditions of LNG loaded into a vehicle should meet specific limits to give the expected residence time and meet the operating requirements. Again the insulation of the vehicle fuel tank must be properly selected
7. given that small LNG plants, of the type needed for LNG fueling, have a high fuel auto-consumption, it is necessary to impose strict limits on the permissible boil-off generated throughout the distribution chain so as to reduce operating costs
8. safety should cover the entire LNG fuel handling chain, including delivery, fueling station facility and vehicle equipment. The siting of the LNG fueling station should take into consideration the local conditions of the site and an assessment of the impact of the design spill
9. security requirements should be carefully assessed
10. the project should comply with existing requirements in the LNG industry for commissioning, operating, maintenance, training and emergency procedures. The fire department having jurisdiction over the fueling station and supply route should have suitable training to mitigate small LNG spill vapor dispersion and radiant heat flux from LNG spill fires
11. all the equipment used in the project should be suitably designed and should comply with the applicable codes and standards
12. the business implications of outages should be carefully assessed to ensure the overall LNG supply system has adequate reliability
13. depending on the location of the facility, a basic public communication program may be necessary to ensure any safety related questions can be quickly and adequately answered.

4.0 SAMPLE LNG FUELING SYSTEM

The following items illustrate some of the features incorporated into the design of an advanced fueling station. (These have all been recently assessed by CDS as part of the PERD program project).

4.1 Control Philosophy

The station is designed to meet the requirements of operators with no previous LNG experience. Under computer control, it integrates a full material balance, continuous monitoring and indication of state conditions, overfill protection, record of LNG transactions, inspection schedule and procedures, maintenance aids and procedures, spare parts lists, operating aids and procedures including troubleshooting diagnostics, safety procedures, training procedures, inhibition of vehicle engine start before fill nozzle disengagement, hands-off filling sequence once the nozzle is properly engaged, automatic correction for the LNG state conditions inside the fuel tank to permit billing where required, multi level custody transfer calculation and checks, interface with vehicle to check on-board instrumentation and effect refueling shutdown at the preset fill level, fill nozzle de-icing sequence, conditioning of the fuel, automatic cooldown of fill line, submerged pump start/stop and condition monitoring, records of venting to atmosphere, enable/disable operation of fueling station, secondary automatic shutdown of transfer operations under confirmed leak or fire event detection, etc.,

4.2 Insulation

Proper specification, design and installation of the insulation on equipment used in an LNG fueling project are very important for controlling operating costs and providing reliable service. In general, conventional insulation systems, including powdered insulation in conjunction with a vacuum space, are well understood and developed. However, superinsulation which provides the longest holding time is still at an early stage of industrial scale application. Within the project referred to herein, the following superinsulation tasks were completed:

1. survey of the current state of the art and short listing of materials approved for LNG service
2. development of detailed specifications and quality control procedures for sourcing both the reflector and separator and for fabrication of the blanket of multi layer insulation
3. development of a computer program written in C++ to compute the required number of layers for a specific design heat flux
4. development of a computer program written in C++ to compute the holding time for any insulation system. The program lends itself to different state conditions in the LNG supply chain. Computed state conditions for a 400 litre fuel tank insulated with superinsulation are illustrated in Figures 1 to 3. The design heat flux is 1 W/m^2 augmented by 15% for the supports. The program allows for the effect of sloshing
5. development of procedures and quality control for packaging superinsulation blankets
6. development of installation procedures including anchoring of the blankets onto the vessel.

Validation of the superinsulation design and installation described above was performed on a substantial liquid hydrogen project.

4.3 LNG Storage

Field erected storage tanks covered by API 620, Appendix Q have benefited from over 30 years of experience and know-how accumulation. The same is true of shop fabricated cryogenic vessels in stationary services.

High frequency service LNG delivery tankers will benefit from additional attention to the design of the supports of the inner vessel and the means to maintain the integrity of the insulation. It is desirable to carry out suitable dynamic proving tests, well established in the automotive industry, on the storage vessel of delivery vehicles and fuel tanks. Apart from assessing the overall structural integrity of LNG containers, the performance of the inner vessel supports, instrumentation and insulation should also be targeted.

The location of the penetrations on a storage vessel or fuel tank will determine the design spill and therefore the safety needs of the equipment or facility.

4.4 Refueling Pumps

External centrifugal pumps require a bottom penetration on the LNG storage vessel at the fueling station. This adversely affects the design spill of the facility since in the event of failure of the bottom penetration the entire contents of the vessel may be discharged. For priming considerations, the external pump will need to be provided with continuous automatic cooldown.

Because of the potential cost penalty associated with the foot print of an LNG fueling station using storage with bottom penetrations, only submerged pumps connected to top penetrations are considered for all tanks and vessels.

Submerged centrifugal pumps have benefited from extensive development work over the past 20 years. When properly specified, a service life in the order of 8,000 hours can be achieved or exceeded. This operating configuration allows the pump to be permanently cooled down and ready for operation.

4.5 Safety

In common with other alternative fuels and technologies, it will take only one serious incident to develop a public perception that LNG is a hazardous fuel. It is this fear that motivated the international LNG trade to treat safety very seriously. The vast quantities of LNG transported between continents over the past thirty years without serious incidents proves that this is a safe fuel when the equipment is designed and handled properly. There is no reason why LNG refueling stations, which are very small in size in comparison to grassroots LNG plants, cannot be designed to the same standards of safety.

Within the design work completed, safety has been addressed for the entire system, from LNG production to the vehicle, including the following specific features:

1. a review of incidents in the transportation of refrigerated products indicates that driving away with the fill nozzle still connected is the most common source of accidents. Thus, the refueling system has been designed so the vehicle cannot drive away with the fill nozzle connected
2. based on previous experience in the cryogenic industry, bellows and flexible piping are generally the weakest link in any piping system. To prevent personnel injury in case of failure of a flexible fill line, the refueling sequence is designed for hands-off operation
3. for top penetrations into the LNG storage of refueling station, the design spill is determined by the quantity of LNG that can be discharged whilst the submerged pump is operating. Advanced fast response LNG spill and fire detection systems have been integrated into the automatic emergency shutdown system to minimize the spill size and therefore the secondary safety provisions required. LNG design spill hazard mitigation has been addressed
4. a small design spill requires minimal costs to manage it. There is extensive experimental data for LNG spills on land and water including spills in impoundment systems of the size expected for refueling stations. Therefore, LNG spill vapor downwind travel distance can be readily assessed. Most vapor dispersion modeling tools have been validated over the range of spills expected on refueling stations
5. below an LNG spill pool diameter of 6 m, the mass burning rate of LNG decreases rapidly as the pool diameter is reduced. This feature has been included in the design spill and impoundment system so that radiant heat flux is substantially mitigated by design. Small LNG pool fires can also be extinguished or controlled using readily available technology
6. the means to annunciate when the pre-venting to atmosphere level is reached have been addressed
7. provisions have been made to prevent uncontrolled venting during indoor parking over night in cold climates or during indoor maintenance

8. On and off board vehicle leak detection has been included
9. redundancy has been provided on all critical instrumentation and controls
10. incident specific emergency procedures have been developed.

5.0 CONCLUSIONS

The vast knowledge accumulated in the LNG industry over the past thirty years does not appear to have been fully utilized in LNG fueling for ground transportation. The absence of a system approach based on clearly pre-defined deliverables has hampered the large scale introduction of this fuel. Some aspects of an advanced refueling system are described herein and address a number of issues not fully addressed for on previous projects.

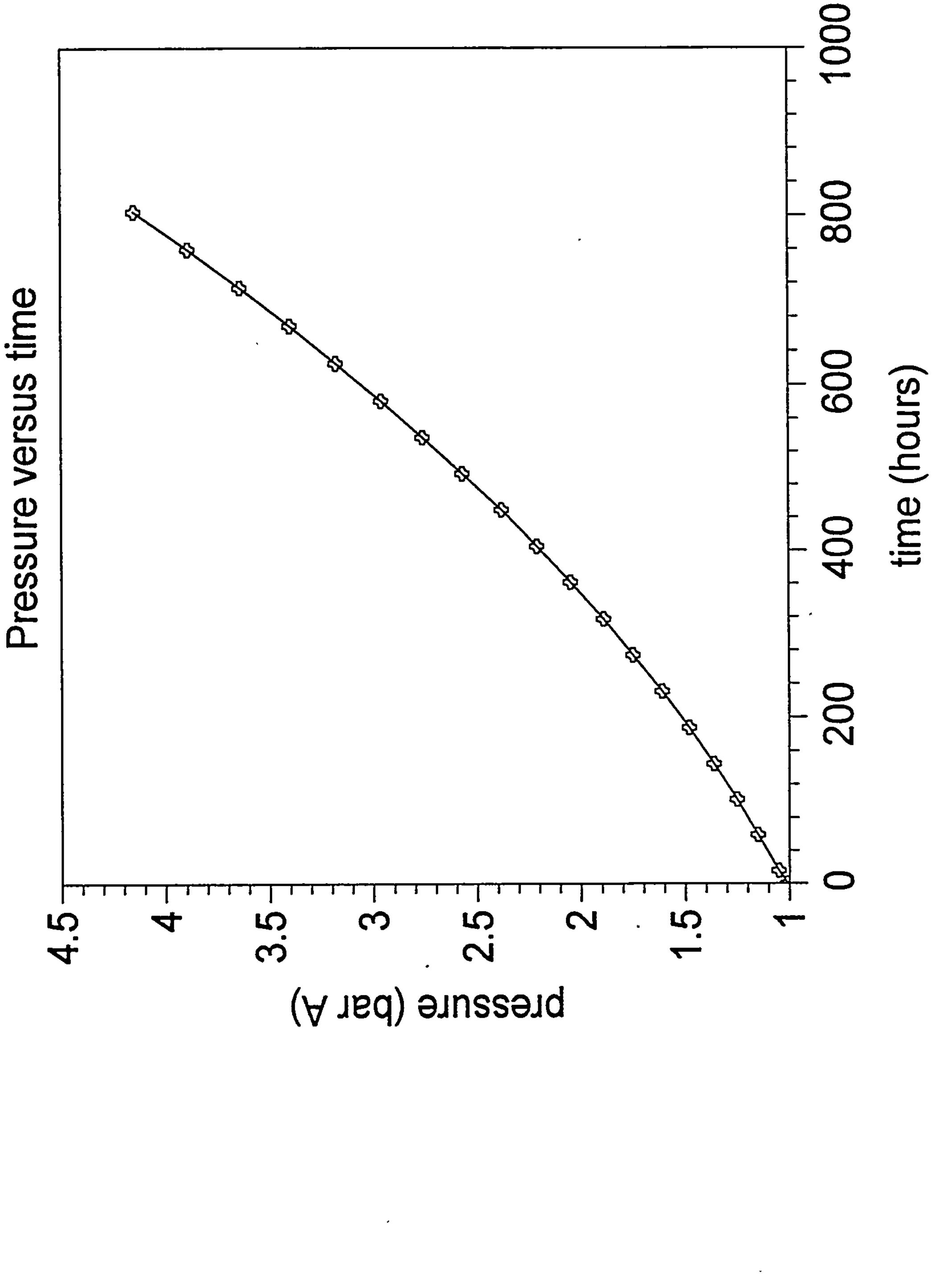


Figure 1 - 400 Litre LNG Fuel Tank

Figure 2 - 400 Litre LNG Fuel Tank

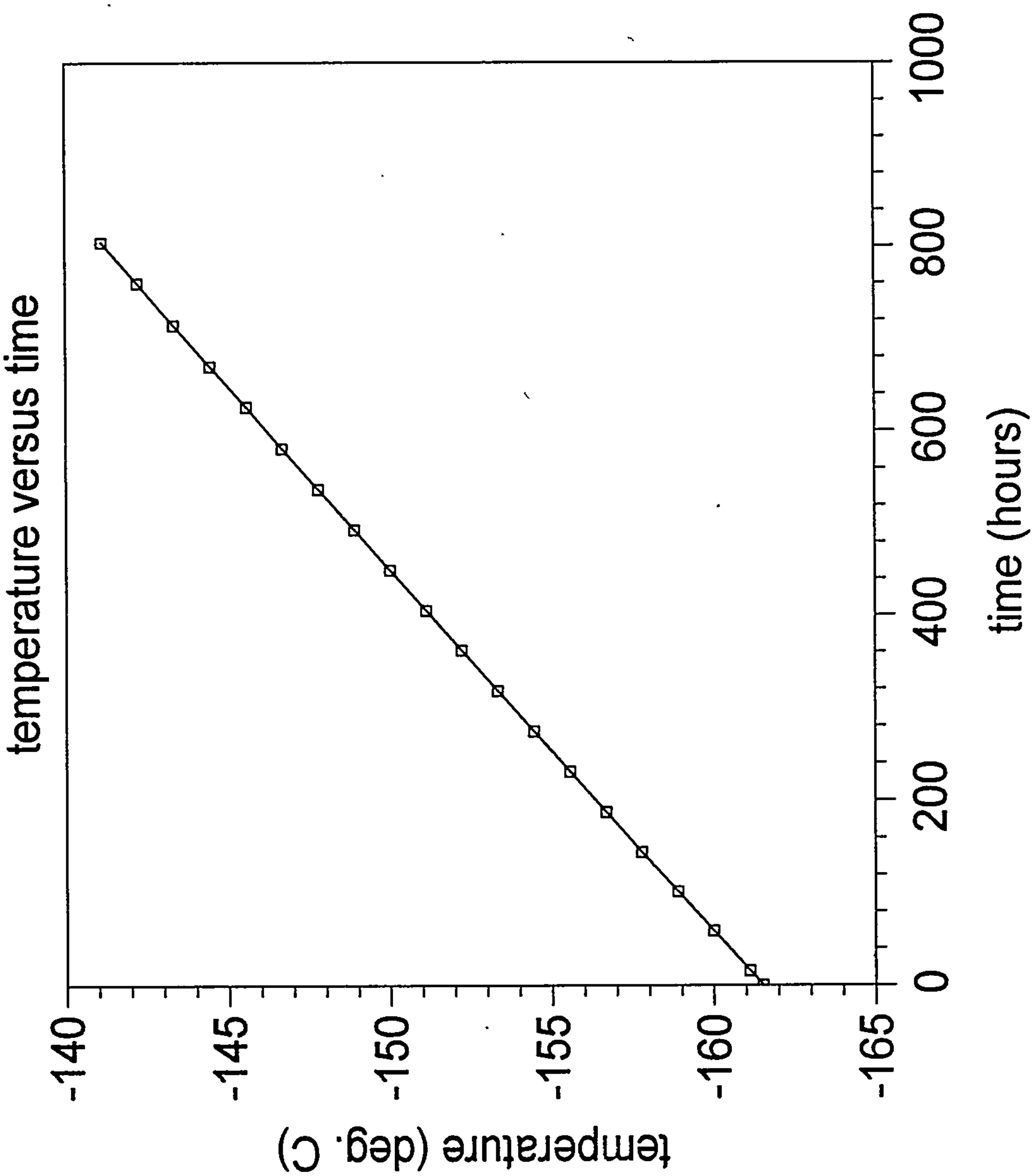
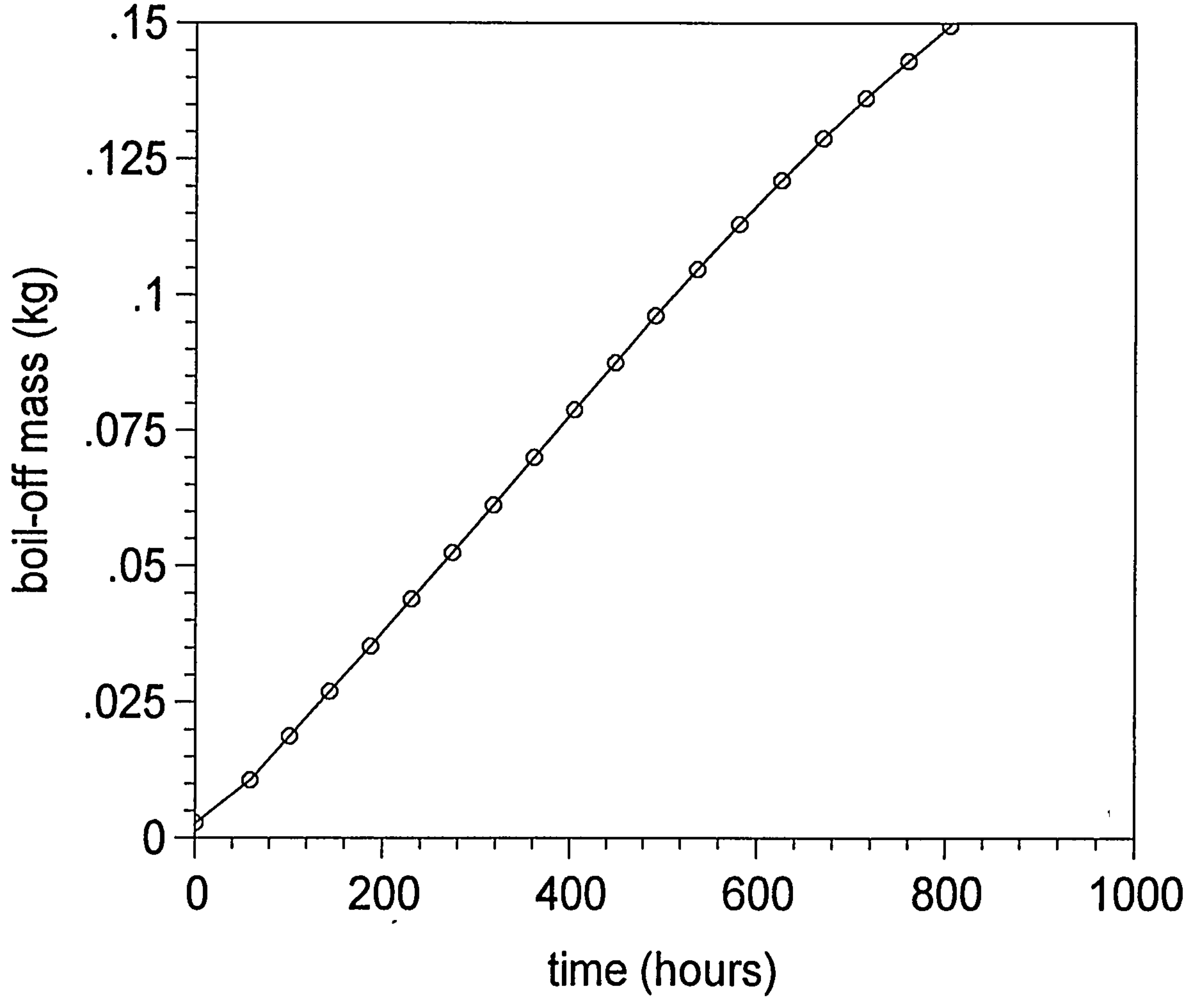


Figure 3 - 400 Litre LNG Fuel Tank

boil-off mass versus time



SESSION 3

INTERNATIONAL LINKS

Chair: John Convey, ORTECH Corporation

GFI Control Systems Inc

MEETING THE EUROPEAN EMISSIONS CHALLENGE

Brett Nelson, GFI Control Systems, Inc.
Glynn Thomas, British Gas PLC
George Tilley, Business Gas

1996 WINDSOR WORKSHOP

SLD520

1996 WINDSOR WORKSHOP

Meeting The European Emissions Challenge

Prepared by

Brett w. Nelson, P.Eng., GFI Control Systems, Inc.

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George Tilley, Business Gas
Paul Weall, Business Gas

April 1996

The concern for our environment has never been greater. As a global community, we recognize the importance of providing a clean, safe environment, and as an industry, the automotive sector has a large role to play. Providing alternate fuel powered vehicles is a practical direction for countries throughout the world, but not yet an effortless one.

Industry representatives in North America would agree that the business of converting commercial fleet vehicles to natural gas is fraught with challenges. New vehicle technology creates new hurdles, and understanding, let alone meeting current US legislation can be a difficult process. What we may not realize, from our North American perspective, is that we may have it easy compared to Europe.

By working with European automotive manufacturers, Utilities, and alternative fuel vehicle converters, GFI Control Systems has become an active player in the goal to reduce exhaust emissions in Europe, and understands the extra challenges faced by our European partners. This presentation demonstrates these challenges as they relate to vehicle emissions, describes the strategies used to meet these challenges, and provides a score card of our partner's successes in providing a cleaner global environment.

THE CHALLENGE

GFI Control Systems Inc

SLD526

THE CHALLENGE

THE EUROPEAN EMISSIONS CHALLENGE

- Challenging Vehicles
- Challenging Emissions Cycle
- Challenging Emissions Standards
- Expectations Go Beyond The Standards

To provide Natural Gas powered vehicles as an alternative to petrol or diesel, the European alternate fuels converter must meet and overcome several new challenges, not found in North America. To begin with, the vehicles used by fleets and converted to Natural Gas in Europe are very different than the typical fleet vehicle of North America, and in many cases, these differences create an additional burden on the converter. Secondly, as any student will tell you, some tests are easy, some are hard, and the difference is often reflected in the test results. The test cycle used to measure vehicle emissions also influences the results, and there are key differences between the European emissions test cycle and the American test cycle which make the European test more difficult for Natural Gas powered vehicles. In addition, the legislated emissions standards are quite different for Europe and provide a unique challenge for Natural Gas. Of course, consumer demand does not stop at legislated standards, and expectations placed on alternative fuel vehicles is rightfully high.

THE VEHICLE CHALLENGE
Unique European Opportunities
- Small Displacement Engines
- Electronic Distributorless Ignition System
- Exhaust Gas Ignition

We have been taught that problems should be regarded as opportunities. There are many opportunities for alternative fueled vehicle converters in Europe based on the fact that European vehicles are very different from their American counterparts. To begin with, the typical engine for a European vehicle has a much smaller displacement. Vehicles in the range of 1.3 to 2.0L are the norm for fleet use in Europe, while fleets in North America may start at 2.0L, but are more typically powered by 3, 4, or 5L engines. The smaller displacement engine provides a tougher challenge because conversion to Natural Gas generally results in a small loss in power, which would be instantly felt on the typically inclined roads of Europe.

While engines up to 7.5L have been converted from gasoline to Natural Gas here at home, European trucks with larger displacement engines are most often diesel powered, requiring an added element of complexity to the conversion to Natural Gas.

The technology used in modern European vehicles has also produced some surprises for the vehicle converter. Even on vehicles with manufacturers in both the US and Europe, there are differences in under bonnet equipment. The Ford ignition control system called EDIS was found only on one common engine in North America (the Ford Ranger) in 1992 but was quite prevalent in Europe, being used on a variety of platforms from Escorts to Scorpio's. This ignition system required a completely different approach to timing advance not found on any other vehicle.

There are also variations in electronics and emissions controls which are not likely to be found anywhere in North America. Although extra oxygen sensors in the exhaust are becoming the norm in North America, we are unlikely to see an extra spark plug between two catalysts, which one European manufacturer is calling Exhaust Gas Ignition (Ford Galaxy). Catalysts themselves are newer introductions on European vehicles, and their placement, as well as the placement of the oxygen sensor with respect to the exhaust ports is more variable on European vehicles.

THE EMISSIONS CYCLE CHALLENGE
European Drive Cycle vs Federal Test Procedure
- ECE R15.04 + EUDC
- FTP 75

It can be readily argued that a vehicle's exhaust emissions are strongly dependent on its owner's driving style. Five minutes of high speed, stops and starts would produce very different emissions than a five minute low speed cruise in the same car or truck. For this reason, emissions tests must be performed under tightly controlled and repeatable driving conditions. Unfortunately, North America and Europe have defined two completely different emissions drive cycles to measure vehicle exhaust emissions.

In North America, a light or medium duty vehicle's emissions are measured during a Federal Test Procedure, or FTP, as defined by the US Environmental Protection Agency. The drive cycle used in this procedure is the EPA Urban Dynamometer Driving Schedule or UDDS. The drive cycle itself was developed from the replication of a typical drive in Los Angeles, and as such contains three phases of stops and starts, accelerations, decelerations, and cruise portions, none of which follow a predictable pattern. In fact, the first two phases of the test are commonly known as an LA4. The full FTP test is an LA4, followed by a repeat of the first 505 seconds.

In Europe, vehicles emissions are measured over a very different drive cycle. The European cycle designed for light duty petrol vehicles consists of four repetitions of a basic pattern, called the elementary urban cycle, plus a high speed portion at the end, called an Extra Urban Drive Cycle.

FIGURE 1: Cycle Comparison; ECE Urban Cycle vs FTP 505 Cycle

A comparison of the European cycle over the first 505 second phase of an FTP show the significant differences in driving. Here, vehicle speed in km per hour is plotted vs time in seconds.

Unfortunately, my slide is actually plotted with the FTP cycle in miles per hour, so with my apologies, would you please note that the FTP trace should be 1.6 time higher than illustrated. The top speed of the first FTP hill is 50km/h, and the second hill reaches 90 km/h. I should know better being Canadian, but American road speed always seems slower to me.

One might conclude that the highly variable Los Angeles trip would generate higher emissions than the simple first, second, third gear hills of the European cycle. While this may be true of engine out emissions, it is not the case for tailpipe emissions, which are the critical measured product of the test. Consider for a moment that the best cure for high emissions is a hot catalyst. Note that the Federal cycle starts early with a sustained acceleration, while the European cycle starts much later with short 1st gear and second gear accelerations. The sustained acceleration will provide an early source of high heat into the exhaust, effectively warming the catalyst, while the European cycle waits a full minute before any sustained acceleration takes place. The first hill of the Federal test also reaches a higher speed of 50km/h (or 31 mph as shown in the graph) while the urban cycle does not reach this speed for the first 3 minutes.

Also note that the higher speed cruise is not sustained in the European test, as it is in the second hill of the FTP. Rather, the elementary urban cycle ends at 235 seconds, returning to idle for the next 3 hill cycle to start.

FIGURE 2: Catalyst Temperature During ECE Urban Cycle

- CNG, 2.0L German Ford Transit
- Pre-Catalyst temperature

This repeated return to idle creates a very real problem for controlling emissions on a Natural Gas powered vehicle. As shown by this pre-catalyst temperature plot of a German Transit van, taken over 2 elementary urban cycles, or half of the ECE test, the catalyst temperature drops significantly during each of the idle periods. The impact of the lower speeds is also evident, where the catalyst temperature reaches only 300C in the first hill, 400C in the second hill, and only breaks through 450C in the higher speed, 3rd gear hill. Even after the 50km/h cruise in 3rd, the catalyst temperature drops again to 350C at each idle.

Note that all accelerations are started with a catalyst temperature at or below 350C, and the majority of the test is run with a catalyst temperature below 400C.

Meeting the European Chanllenge

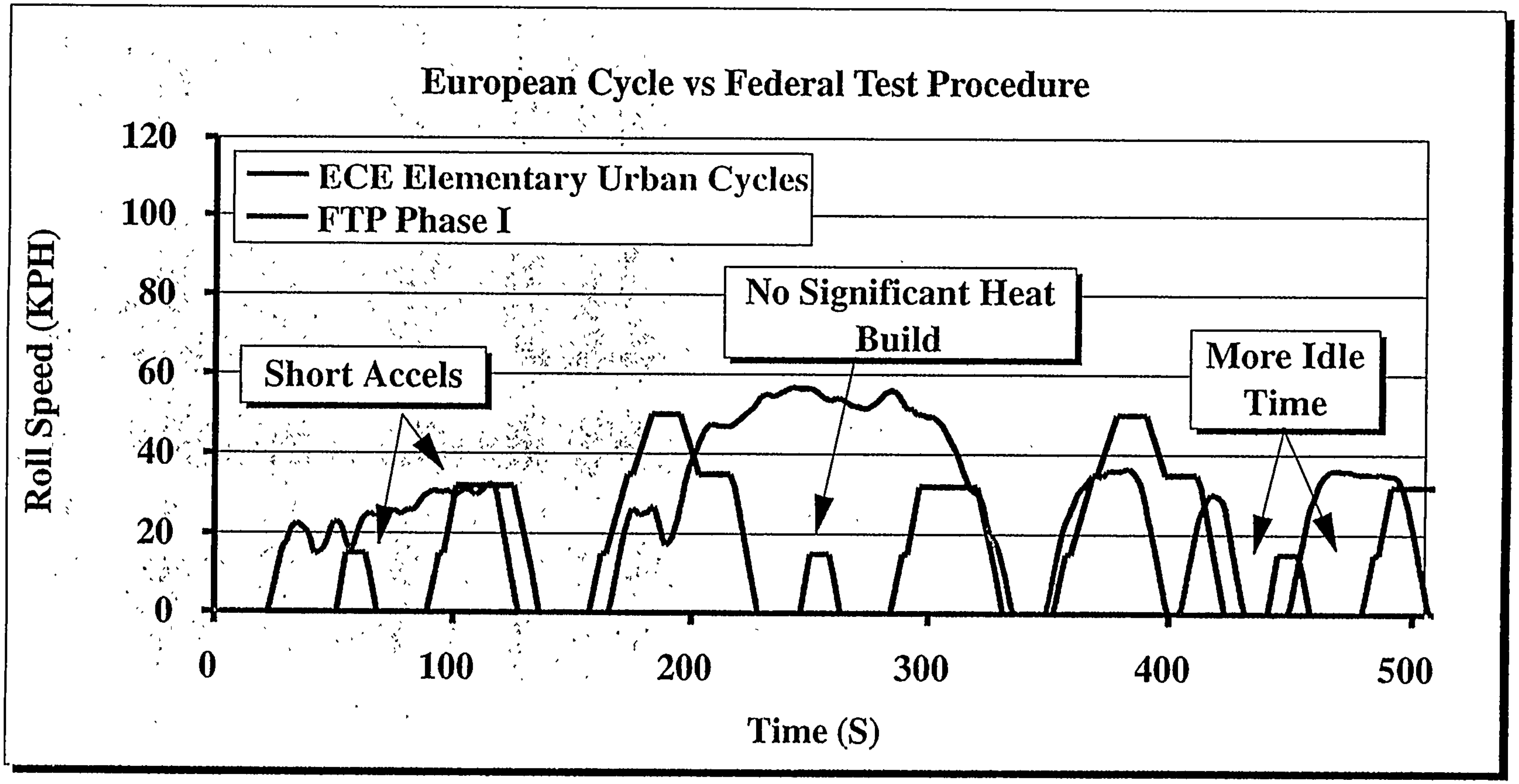

Figure 1

SLD546

Meeting the European Chanllenge

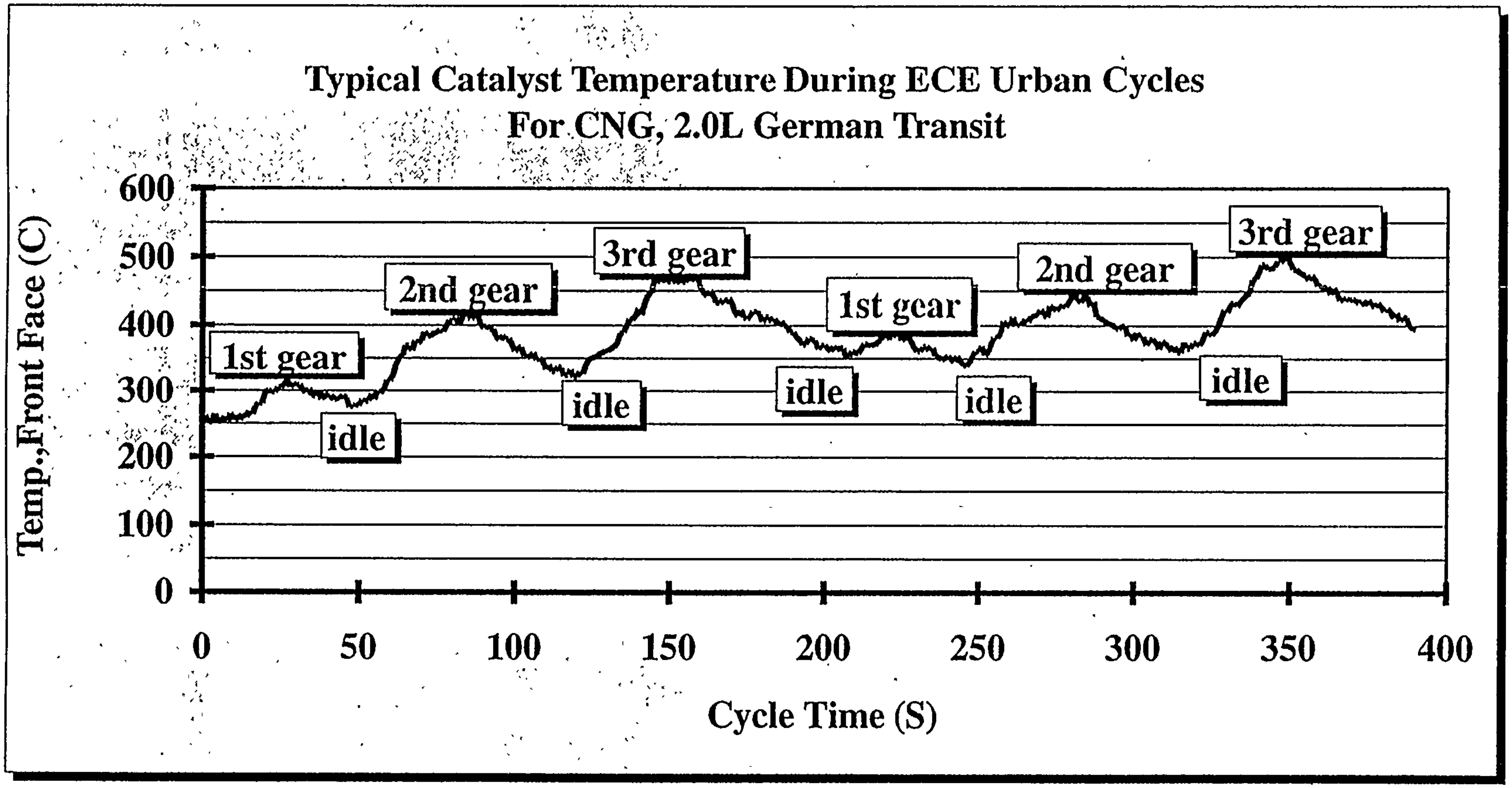

Fig. 2.

SLD548

FIGURE 3: Aged Catalyst Efficiency vs Temperature

These temperatures are significant, as shown by this next illustration. The findings of Usmen and McCabe of Ford Motor Company, show the catalyst conversion efficiency for a typical aged automotive catalyst. (Vehicle aging of 50,000 miles.) As demonstrated by their testing, conversion efficiency for CO falls off rapidly below 350C, while HC and NO conversion require temperatures over 500C for effective catalytic reaction. Note the dip in NO converter efficiency around the 400C mark, right where our previous example spent most of its time. This dropout in NO conversion is the result of precious metal sintering common to aged catalysts, and demonstrated by Ford in both Palladium/Rhodium and Platinum/Rhodium beds, typical of commercial vehicle catalysts (Samples from Thunderbird and Crown Victoria.) (4)

FIGURE 4: Cycle Comparison; Full ECE+EUDC vs FTP

Here, a complete European cycle is shown against the same time from an FTP. Note the higher speed portion of the FTP takes place early in the test, providing good light-off heat to the catalyst, while the European cycle places the high speed drive at the end of the cycle, where it can do no good for the rest of the cycle.

9:1 Pd/Rh Vehicle Aged Light Off

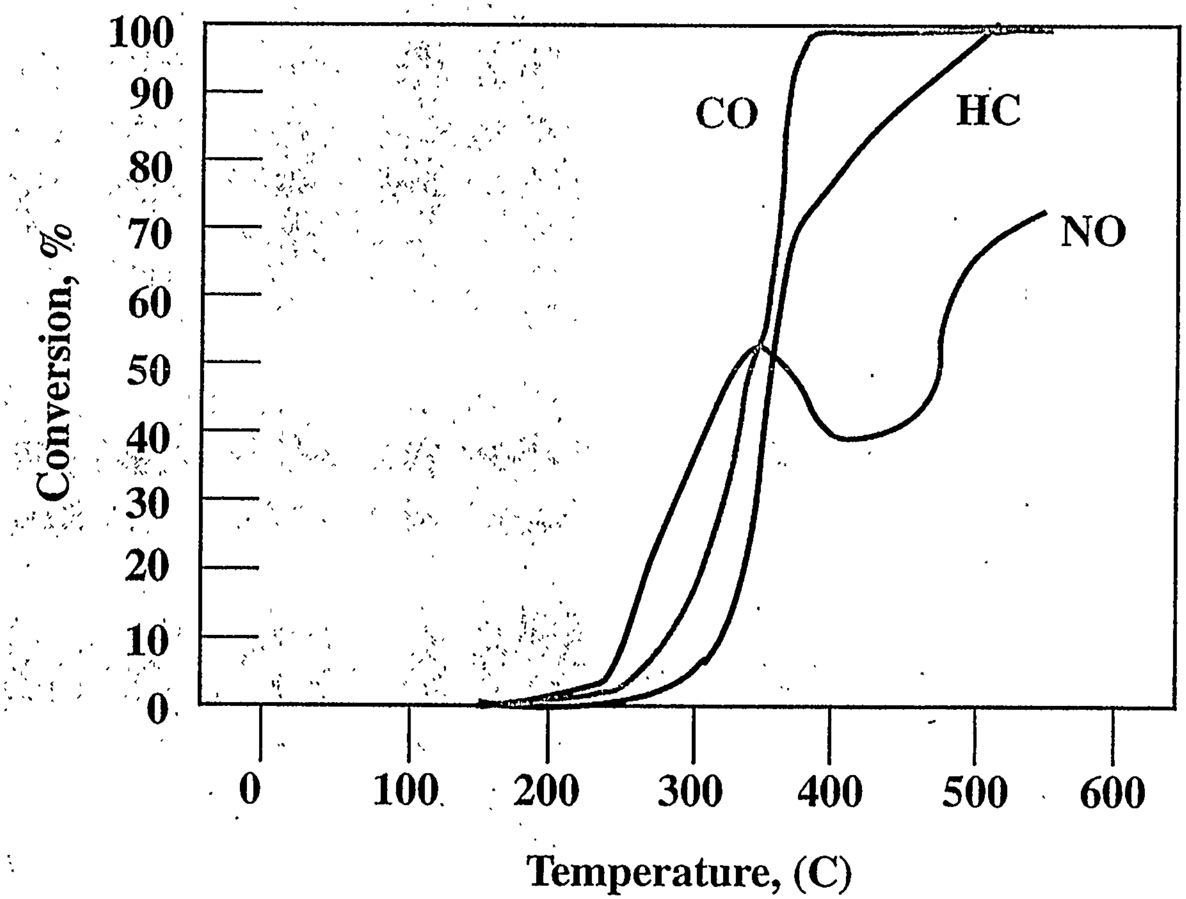

Fig 3.

Meeting the European Chanllenge

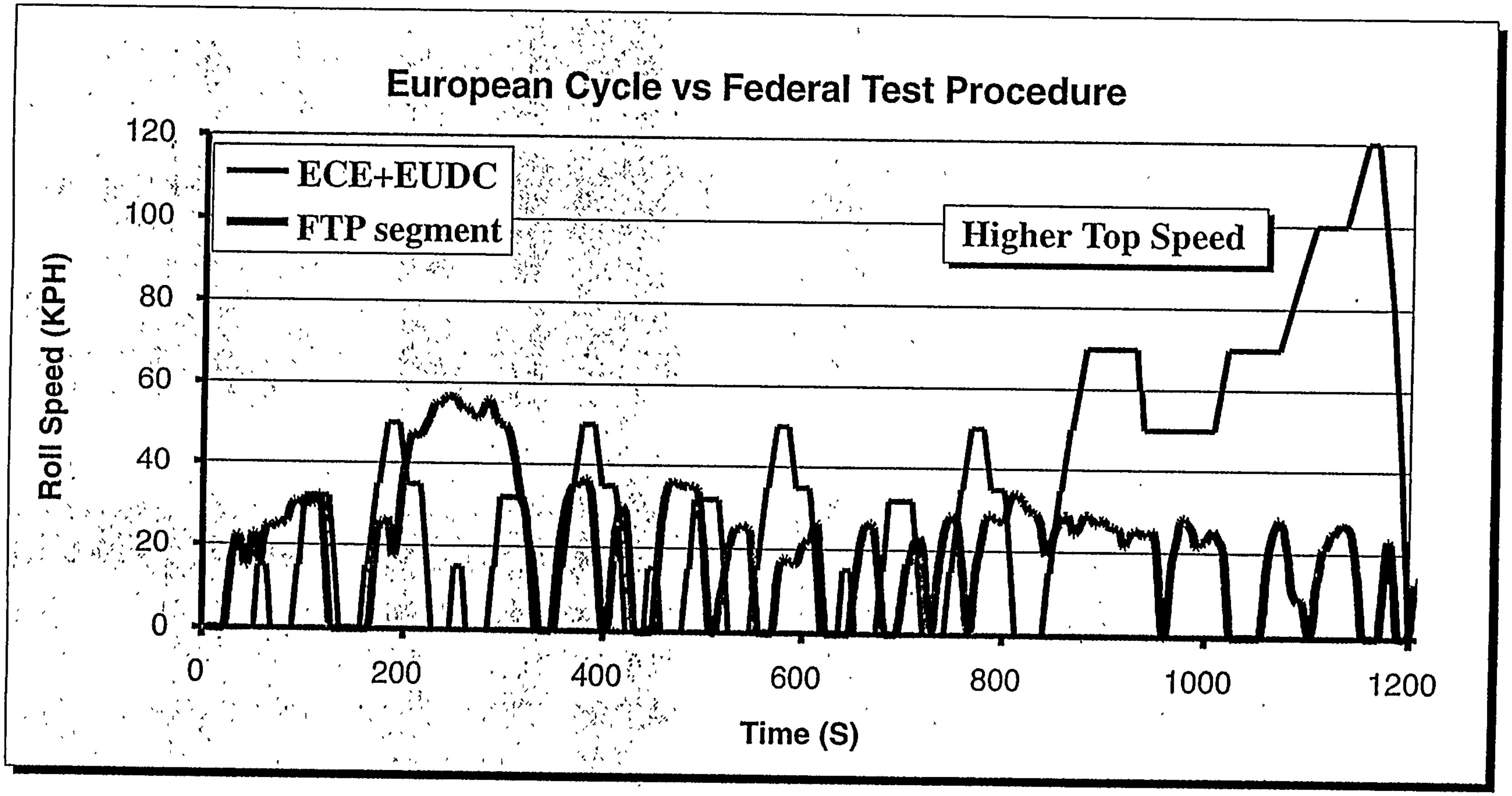

Fig 4

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FIGURE 5: Catalyst Temperature, ECE+EUDC vs FTP
- Lower Exhaust Temperature Demonstrated While Running Natural Gas
- Up To 150C Cooler During AMA Cycle

The end result of a European cycle versus the American FTP is shown by this next plot. Here, pre-catalyst temperatures are once again plotted against time. Both plots are for the same vehicle, a typical small displacement Van converted to run CNG. The early, high speed hills of the FTP are clearly effective at raising the catalyst temperature to over 500C, where the maximum converter efficiency is found. Contrast this with the slow climb in converter temperature under the European ECE cycle. Here, catalyst temperature reluctantly climbs to 500C after 10 minutes of driving. These are 10 painfully long minutes for a European emissions calibrator.

The real heat is finally generated in the Extra Urban Drive Cycle, placed at the end of the test.

Overall, the front face catalyst temperature averages 497 degrees C during the FTP, which places it just on top of the catalyst efficiency curve, whereas the ECE+EUDC cycle average catalyst temperature for the same vehicle is well down the curve, at 427 degrees C.

Why is this question of temperature so important? Surely any test is fair as long as it is consistent. The problem with the European test when used to measure Natural Gas emissions is not shown here, but has been demonstrated by repeated tests with our Bi-Fuel vehicles. Catalyst temperature traces during European emissions cycles, Federal cycles, and AMA mileage accumulation tests have shown that a vehicle running Compressed Natural Gas has a lower catalyst temperature than the same vehicle running gasoline. In fact, temperature drops of 100 to 150C are not uncommon.

Re-examine the FTP and European cycle temperatures shown here and imagine a shift upwards of 100 to 150 degrees. This shift would take the FTP temperatures to 600C, and more importantly, move the ECE+EUDC temperatures safely over the 500C high catalyst efficiency band. Under these circumstances, the European cycle becomes more evenly matched to the Federal test; but, unfortunately for Natural Gas conversion suppliers in Europe, this European emissions cycle remains a challenge.

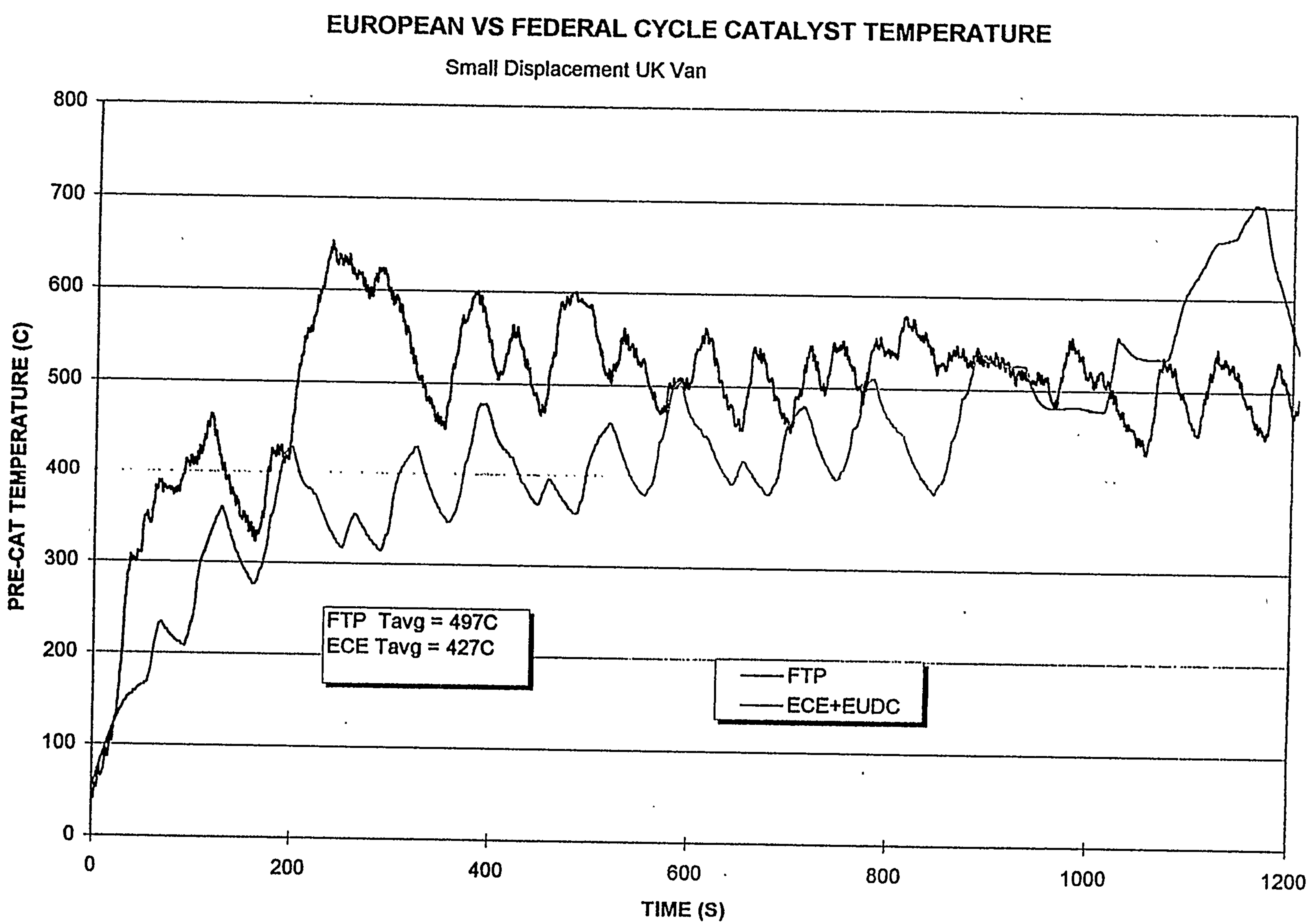

EUROPEAN VS FEDERAL CYCLE CATALYST TEMPERATURE
Small Displacement UK Van
PRE-CAT TEMPERATURE (C)
800
700
600
500
400
300
200
100
0
TIME (S)
0
200
400
600
800
1000
1200
FTP Tavg = 497C
ECE Tavg = 427C
FTP
ECE+EUDC

Fig 5

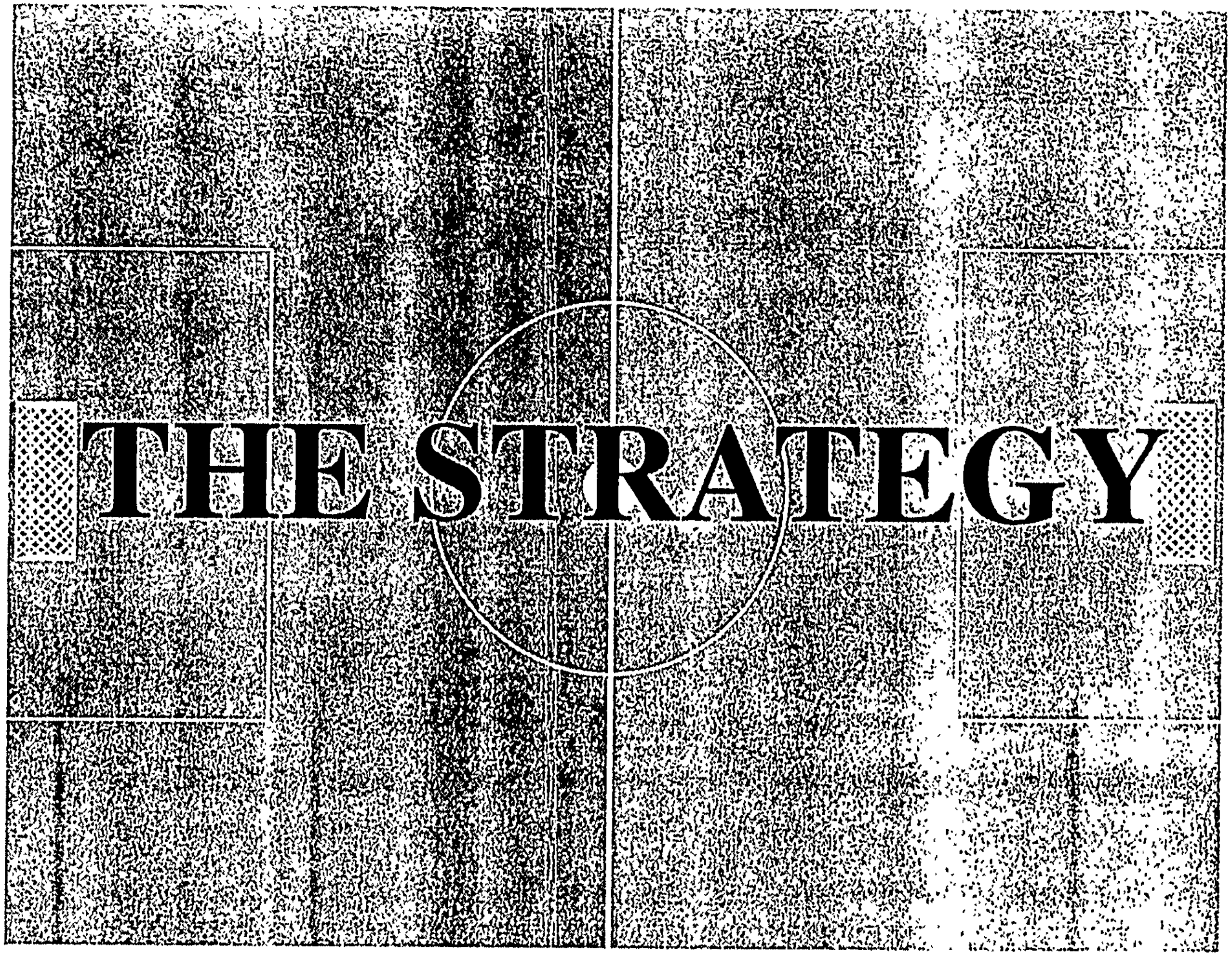
THE EMISSIONS STANDARDS CHALLENGE
- Federal (North American) Regulated Emissions
- *CO, NOx, NMHC*
- European Regulated Emissions
- *CO, THC+NOx*

On top of the European cycle, the European emissions standard provides an additional challenge for CNG conversions. The two most difficult Natural Gas emissions compounds to reduce through standard catalytic conversion are combined into one legislated number.

Catalytic converters on today's automobiles are designed for petrol exhaust. It is now widely recognized that methane, the principal component of CNG, is harder to oxidize than the longer chain molecules of petrol. Because of its higher bond strength, unburned natural gas travels through a standard automotive catalytic converter relatively unscathed, whereas the unburned hydrocarbons in petrol exhaust with their longer chain, higher carbon molecules, are more readily oxidized. This results in a higher total hydrocarbon emission from a vehicle running natural gas through a standard catalytic converter. The hydrocarbons emitted from a natural gas powered vehicle are generally at least 85% methane, but the European legislation does not differentiate between methane and non-methane hydrocarbons as the newer American standard does, in recognition of the fact that methane has a considerably lower environmental impact than the higher carbon compounds.

To magnify the problem in the Europe standards, Oxides of Nitrogen are added to the Total Hydrocarbons count to produce one legislated number. For petrol based emissions, this is not as big an issue, but with Natural gas conversions, NOx emissions can be difficult to control. NOx is typically produced any time the air fuel ratio in the combustion chamber goes lean. This occurs most often during accelerations, where the air flow into the engine rises sharply, and the fuel system must react quickly to provide the matching fuel. For a modern petrol fuel injection system, this task is made easier with a combination of sensors tied into the fuel control system, which may detect the extra air intake directly, or indirectly through a throttle position change or speed density change. Once detected, the petrol fuel system also has an advantage over an aftermarket conversion in that it has been provided with the best position for fuel injection, at the inlet ports, whereas an alternate fuel conversion must typically inject fuel further upstream.

To minimize NOx emissions, especially when combined with Total Hydrocarbons as it is in Europe, it is important for the alternate fuel converter to carefully chose a conversion system which can react quickly to these accelerations, and maintain accurate fuel control throughout the emissions cycle.



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THE STRATEGY

VEHICLE CONVERSION STRATEGY
CNG Conversion System

- Gaseous Fuel Injection (GFI) System
- Commercially Available and Proven
- Electronically Controlled
- Single Point Fuel Injection
- Closed Loop Stoichiometric
- Interfaces with OEM Electronic I/O
- Provides Electronic Spark Advance and Dwell Control

GFI's business partners in Europe have chosen the GFI fuel system for several reasons. As an electronically controlled single point fuel injection system, GFI can make rapid adjustments to fuel delivery, and provides precise metering of fuel under all conditions. The GFI system interfaces with OEM electronic signals, allowing rapid detection of transients, and long term stability of air fuel ratio. In addition, GFI provides the ability to intercept and control spark advance and dwell, an important factor in successful European conversions.

VEHICLE CONVERSION STRATEGY
Diesel Conversions

- Converted to CNG by Modifying Engine
- Pistons Machined to Reduce CR to 12.3:1
- Injector Holes Drilled for Spark Plugs
- Valve and Valve Seats Replaced
- Ignition System Fitted
- Throttle Body Fitted
- GFI Fuel Injection System Fitted

As noted earlier, it is much more common in Europe to encounter medium to heavy duty truck fleet vehicles running diesel instead of petrol. This list shows the extra work involved in converting a Leyland DAF Roadrunner to CNG, as performed by British Gas for their UK market. As seen here, this effort is fairly significant, and fairly rare for North American converters given the common availability of large displacement gasoline powered engines here.

EMISSIONS CYCLE STRATEGY
Calibration Tuning
- Engine Mapping Allows Precise Fuel Control
- Transport Delays Programmed
- Lambda Targets and Biases Used For Optimization

For all engines, the critical step in providing a successful conversion, is the matching of the conversion system to the vehicle. The GFI system provides a full suite of calibration parameters which enable a qualified calibrator to map out the fuel demand of the engine over its entire range of loads and speeds. This allows precise fuel control over the full operating range of the vehicle. To provide the best overall fuel control, including THC minimization, the transport delays of the system are also measured and fine tuned. This provide the best transient control, especially important for the frequent stopping and starting experienced during a European emissions cycle. Two key transport periods measured are the fuel delivery time from injection point to intake, and the exhaust port to oxygen sensor feedback. For NOx control, it is important to maintain stoichiometric or slightly rich operation under accelerations. The GFI system provides lambda target tables and fueling biases to allow the system calibrator to enrich or reduce the amount of fuel under many different sets of conditions, including accelerations, cruises, and decelerations.

The best combination of rich, lean, and stoichiometric fueling is dependent on the base vehicle design, so no one strategy is best for all cases.

Once programmed, the GFI fuel system will provide repeatable and accurate fuel delivery, allowing the calibrator a greater degree of confidence that performance and emissions results will be consistent from test to test, over the life of the vehicle.

EMISSIONS CYCLE STRATEGY
Calibration Tuning
- Spark Timing Advanced
- Selected for Best Catalyst Efficiency
- Selected for Best Performance

A key feature of the GFI control system, unique for NGV conversion systems, is its programmable spark advance system. In North America, this feature is used most commonly to recover power lost by conversion to the less energy dense natural gas. Given the catalyst temperature problems encountered in the European emissions cycle, spark advance and even some spark retard, provides an additional strategy for conversion suppliers to meet their emissions challenge. By providing a limited degree of spark retard on start-up, it is possible to generate some additional exhaust heat to promote early catalyst light-off. This strategy is used sparingly, to avoid performance problems or wasted energy in the combustion process.

THE SCORE

SLD528

THE SCORE: VEHICLES
European Conversions

Italy	290 000
Germany	1 100
France	603
The Netherlands	600
Great Britain	370
Belgium	116
Sweden	108
Ireland	34
Austria	18
Spain	11
Denmark	9
Total	292 969

Approximate, As of August 1995

The conversion to natural gas is a difficult one, nonetheless, over a quarter of a million vehicles have been converted to this clean fuel. British Gas, working closely with GFI Control Systems, has successfully converted over 400 vehicles since 1991 in the UK. Given the challenges faced by European natural gas vehicle converters, these are impressive statistics.

THE SCORE: VEHICLES

- Both Petrol and Diesel Converted
- CNG a Commercially Viable Alternative
- Minimal Power Loss From Petrol
- Excellent Driveability
- Bi-Fuel Operation Maintained

Both petrol and diesel vehicles have been converted, proving that CNG is a commercially viable alternative to these fuels. Testing at the British Gas Research Centre has shown that power loss is minimized with conversions to Natural Gas using the GFI fuel control system. Driveability is maintained, as well as the vehicle's gradeability, or ability to restart on a hill, an important measure in the UK. In all cases of single point gaseous fuel injection, petrol operation is maintained with no impact on torque or power, a common demand by consumers of Natural gas powered vehicles.

7.5L Diesel Conversion Results

	Original Diesel	Gen 1 CNG Conversion	GFI CNG Conversion
Max Power (kW)	86	84	92
Max Torque (n.m)	370	371	427

NOx	11.64	11.69	2.75
CO	5.44	2.33	2.33
HC	1.75	1.63	1.84
Pm	0.42	0.05	n/a
CO2	762	713	484

Emissions measured over ECE49 (13 mode) test

Power and Torque corrected to ISO 1585

British Gas has also demonstrated their ability to successfully meet the challenge of converting diesel equipped vehicles. Using a generation 1 style system, power and torque were maintained at 86kw and 370 newton.metres respectively, while reductions in CO, particulate matter, and CO2 emissions were obtained. By implementing the more sophisticated strategies available with the GFI system, power was actually increased to 91 kw, and torque increased to 427 newton metres. Original CO reductions were maintained, while NOx was brought down by an impressive 76%. Additionally, CO2 emissions are 36% lower on the alternate fuel

European Emissions Summary

	THC+NOx Reduction	NOx Reduction	CO Reduction
1.4l Ford Escort Van	56%	85%	40%
2.3l Mercedes 210 Van	37%	63%	50%
1.3l Ford Escort Van	14%	33%	68%
2.0l Peugot Boxer	6%	25%	74%
2.2l Renault Trafic	0%	0%	0%

Values show percent reductions in emissions from CNG conversion as compared to petrol

Emissions measured over ECE+EUDC Cycle

In the case of petrol vehicle conversions, using GFI for natural gas fuel injection, British Gas has shown that the emissions challenge, which is very real in Europe, can be met by the right combination of skill and strategy. This chart not only shows that European emissions legislation can be met, but further reductions in emissions over petrol can be realized. Even the challenge of THC+NOx can be overcome on these commercial applications, without compromising Carbon monoxide emissions. Even with the Renault Trafic, which represents an optimized engine build for petrol can be successfully converted and the emissions held well below EU limits, within 0.01 grams per km of the original petrol emissions.

THE NEXT MATCH

THE NEXT MATCH
Leveling The Playing Field

- NEW VEHICLES
  - *Designed For CNG*
  - *Methane Tuned Catalysts*
  - *Appropriate Emissions Controls*
- NEW EMISSIONS CYCLE
- NEW EMISSIONS STANDARD
  - *Non-Methane Organic Gases*

In any fair contest, teams compete both at home and in "away" games. Gasoline has had a long standing "home team" advantage, with natural gas as the consistent "visiting team." The playing field; the vehicle, is designed for gasoline combustion, and reduction of gasoline combustion byproducts. Emissions cycles provide unique challenges for natural gas, and emissions standards weigh against the methane based gaseous fuel. Natural Gas can and does meet these challenges, but the next match may be played on a more level playing field. Vehicles can be optimized for natural gas combustion, using higher compression ratio engines, and emissions controls designed for the gaseous fuel. Use of methane tuned catalysts alone will significantly reduce the challenges faced by natural gas powered vehicles, allowing new demonstrations of the potential of this clean future fuel.

Figure 6: ULEV Results from Small Displacement Passenger Car

The possibilities have already been demonstrated by this small displacement vehicle manufacturer, using the GFI fuel system, and a natural gas friendly catalyst. The ultimate goal of Ultra Low Emissions is achieved here, with room to spare, on Natural Gas. The ULEV challenge, not enforced until 1997, and phased in over several years, can already be met with natural gas, on nothing more complicated than a level playing field.

Can the challenge be met? Yes! It is being met today, by strategists all over the world, using the fuel of the future, natural gas, and the GFI gaseous fuel injection system.

THE NEXT MATCH

GFI

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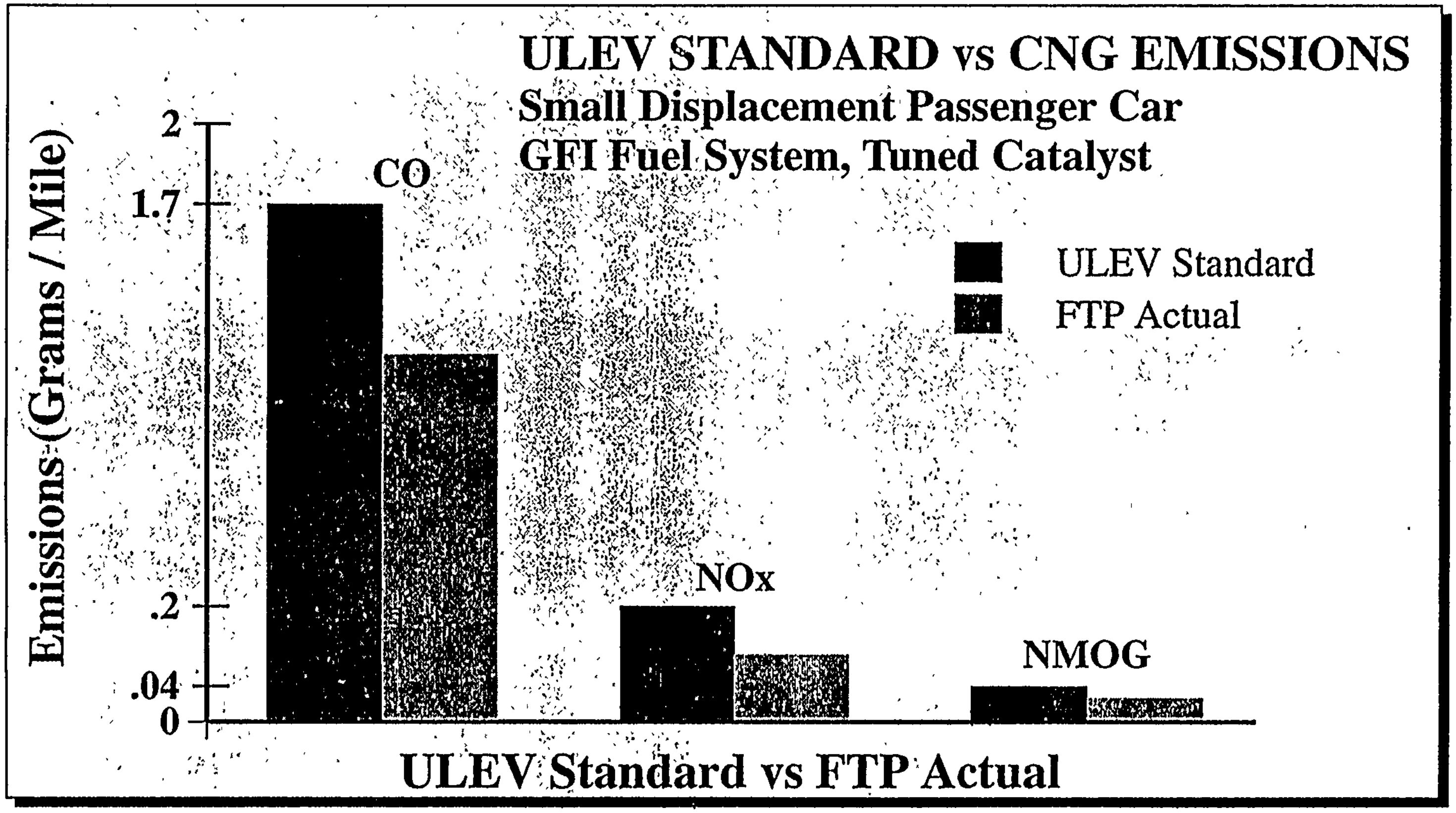
Meeting the European Emissions Challenge



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TNO-paper
VM9605

Stoichiometric and Lean Burn Heavy-Duty Gas Engines - A Dilemma between Exhaust Emissions and Fuel Consumption?

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Introduction

The main objective for today's engine development is to comply with the more and more stringent emission legislation. Already for a very long time, research has been carried out in the field of alternative fuels. Emission legislation is one of the main reasons for the fact that alternative fuel engines are a viable product on today's market. The technology is being developed reapidly to meet with the legislative measures for cities or the so-called *non-attainment areas.*

An engine and vehicle manufacturer has many options to consider when making clean engines (figure 1). Of course, the conventional diesel engine and clean exhaust gas technology (EGR, deNOx-catalysts) developed for this engine type will remain an interesting option for the future. Liquid alternative fuels (methanol, ethanol, etc.) have been tested and a number of demonstration projects all over the world have demonstrated that this could be a feasible option. Most of the current development work both in Europe and North-America, however, is directed towards the use of gaseous fuels (natural gas and propane/LPG). Furthermore, in Europe, an increasing number of Original Equipment Manufacturers of light-duty and heavy-duty engines are putting alternative fuelled engines on the market. Besides, although in a quite early stage, the rather new fuel DME looks, at least from a technical point of view, a promising alternative for diesel engines.

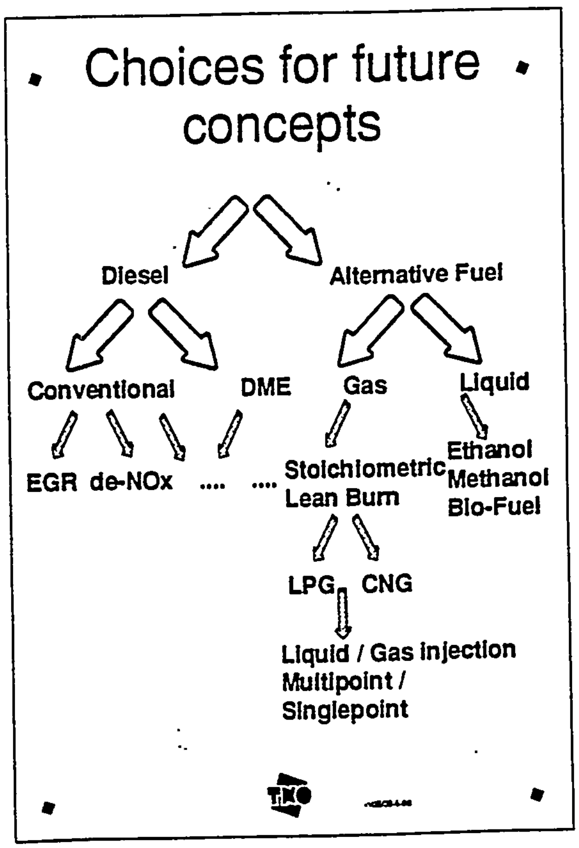

Figure 1

Gas engines can be divided into two major groups. One the one hand, OEMs direct their research into stoichiometric engine technology. The main reason for this is the extremely clean exhaust gases that can be achieved by using a closed-loop controlled three-way catalyst. On the other hand, engine manufacturers opt for lean burn technology, as these engines have a lower fuel consumption with respect to their $\lambda=1$ counterparts.

This paper compares stoichiometric with lean burn technology for heavy-duty gas engines (natural gas and LPG) and demonstrates that there is a future for both engine concepts on the multilateral global market. Emission limits in Europe as expected in the near future will facilitate both engine concepts. Which of the two concepts is the most viable depends on a number of factors.

Emission standards

Due to the introduction of the three-way catalyst the emission production of light-duty vehicles has been reduced considerably. The contribution of heavy-duty vehicles into the total emission production has, therefore, increased. This has resulted in considerable political pressure to reduce the pollution from these vehicles. Figure 2 shows, as an example, the situation in the Netherlands with respect to NO_x-productions. Without any measures the NO_x emission from heavy-duty vehicles would soon be extremely high. The legislator has imposed stringent emission limits for the coming years, mainly focused on the further reduction of NO_x and, to a lesser extent, of particulate matter (figure 3) [1]. Depending on the technology an engine has to be tested in the future according to a 13-mode like steady-state test or a transient test (EURO III). Gas engines will have to be tested according to a fully transient cycle (FIGE test) as well as the steady-state test.

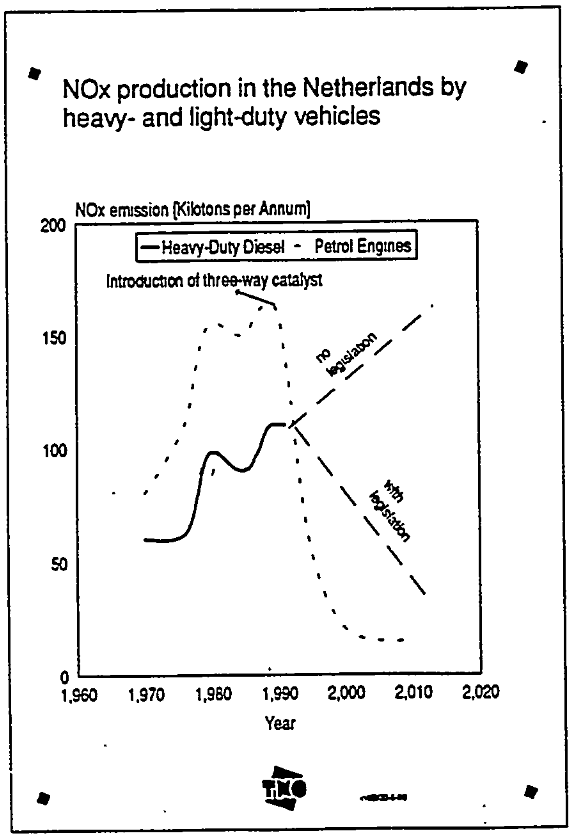

Figure 2

European Emission Limits in g/kWh

Heavy-Duty Engines
European 13-mode test

	EURO-I 1992	EURO-II 1995	EURO-III 1999	EURO-IV 2004
NOx	8	7	<5	<3
CO	4.5	4	2.5	1
HC	1.1	1.1	0.7	0.5
PM˙	0.36	0.15	<0.10	<0.10

Euro-III and Euro-IV: expected introduction date
Possible change in weighting factors and/or test procedure

Figure 3

Improvement of air quality is one of the major issues within the European Union (EU). The EU is convinced that a substantial improvement is only possible and economically feasible with clear and uniform measures throughout all its member states. This awareness has resulted in a cooperative study by the automobile industry (ACEA), the oil industry (Europia) and the EU-commission. A project was started to predict the air quality situation in urban agglomerations in the year 2010 under different scenarios. Preliminary results demonstrate that there are big differences in the reduction necessary for the different regions (cities) in Europe. In the different scenarios the influence of improved technology, different fuels and different composition of the vehicle fleets is simulated. In some cities the air quality required can never be achieved by technical measures alone, while in other cities this can be achieved by relatively simple measures [2].

In the Netherlands there is already a long history of alternative fuels. CNG but mainly LPG is a well accepted fuel. About 12% of all the kilometres driven in the Netherlands is on LPG. A study carried out by TNO has revealed that a proper fuel-mix (one-third diesel, one-third gasoline and one-third LPG) has overall the biggest positive effect on the regional and global environment [3]. The Dutch government has made clear its intention to reduce also the CO_2
emission. The objective is to reduce this greenhouse gas by 3% in the year 2000 with regard to the emission level of 1990. The Dutch Ministry of Environment has announced its policy to decrease the emission of CO_2 in different sectors (traffic, transport, industry etc.) by aiming at the use of 10% renewable energy and a 33% reduction in energy consumption in 2020 [4].

Equipped with the latest technology and properly adjusted, natural gas and LPG engines are able to produce very little emissions. In that respect, the stoichiometric engine with a three-way catalyst has the clear advantage over the lean burn engine. The latter, however, potentially has a better fuel consumption. The reason for buyers has mainly to do with these aspects. Although rather similar from the outside, there is a clear difference in the development efforts of both engines.

The above clearly shows that under these circumstances there will be a good potential for alternative fuelled vehicles. Many countries in Europe (the Netherlands, France, England, Germany etc.) have decided or are considering to stimulate the use of alternative fuels by adopting tax incentives.

Development targets

As already stated, the single most important issue is the emission legislation. In 1999 the EEV-emission limits will come into effect in Europe. EEV stands for Enhanced Emission Vehicles and the adopted limits concern heavy-duty city-vehicles. The EEV-limits are:

Component	Limit [g/kWh] ([g/bhph])
NOx	2.5 (1.87)
HC	0.6 (0.45)
NMHC	0.25 (0.19)

The EEV-emission limits still leave enough room for the lean burn heavy-duty gas engine to come onto the market. Moreover, it is possible that locally more stringent emission legislation will come into force, based on the best available technology (NO_x < 1g/kWh). Apart from this boundary condition, the ability of the engine to meet the emission legislation, there are other important factors which decide which engine type is the most viable.

In Europe, where some of the public transport companies are state-companies, the decision is sometimes made in favour of the stoichiometric engine for public image reasons. One of the motives for most of the European manufacturers to produce closed-loop three-way catalyst λ=1 engines.

First of all, the manufacturer will decide on the basis of production and development costs which engine type is the most attractive to produce and sell. As gas engines are still built in rather small volumes, the development costs play a considerable role in the sales price of an engine. Of course, as production volumes increase this factor will loose importance.

Apart from the above, at the end of the day the user of the engine (client) decides which engine is bought. The main motive for commercial users is without any doubt the costs in use. An urban transport company will never buy any vehicle running on alternative fuel that is economically less attractive than a vehicle with a conventional diesel engine with which it is very familiar. Factors that will influence the costs in use are for example the fuel price level, maintenance costs and taxes. Furthermore, investments that are necessary to run on alternative fuels (safety adaptations to garages, installation of filling stations) will influence the decision. Besides, there are less business economics related considerations. In North-America the decision is mostly made looking at the so-called *total package* and, therefore, most, if not all the engine manufacturers are producing and selling lean-burn engines.

In view of this equivocality it is worth looking at the technical aspects which determine the feasibility of both engine concepts.

Technical Aspects

Traditionally, a typical engine for a European city bus applications has a displacement of 10 to 12 litres and a power output of 160 to 200 kW, depending on the area of use. The current development trend is clearly towards smaller engines with a somewhat higher power output. The increase in specific power output will improve the part load efficiency, but has its consequences for engine development, as it will certainly increase the working temperature of the engine.

Emissions

As already stated the stoichiometric engine has a clear advantage with respect to the emission output. Figure 4 shows the comparison between the NO_x emission of a stoichiometric and a lean burn engine. With a suitable control strategy, which among others takes care of enough CO in the exhaust gas, the three-way catalyst is capable of reducing the NO_x-emission to less than 1 g/kWh. With increasing load the lean burn gas engine will produce more and more NO_x. In order to reduce the emission of nitrogen oxide the ignition timing has to be retarded. The effect of this retardation on efficiency is limited for, in this case, the 2.5 g/kWh NO_x-calibration. However, aiming for 1 g/kWh will have its effect on fuel consumption and, moreover, on the running stability of the engine, as the ignition timing has to be additionally retarded. It is important to emphasize that the 1 g/kWh NO_x limit is presently difficult to reach with a production engine.

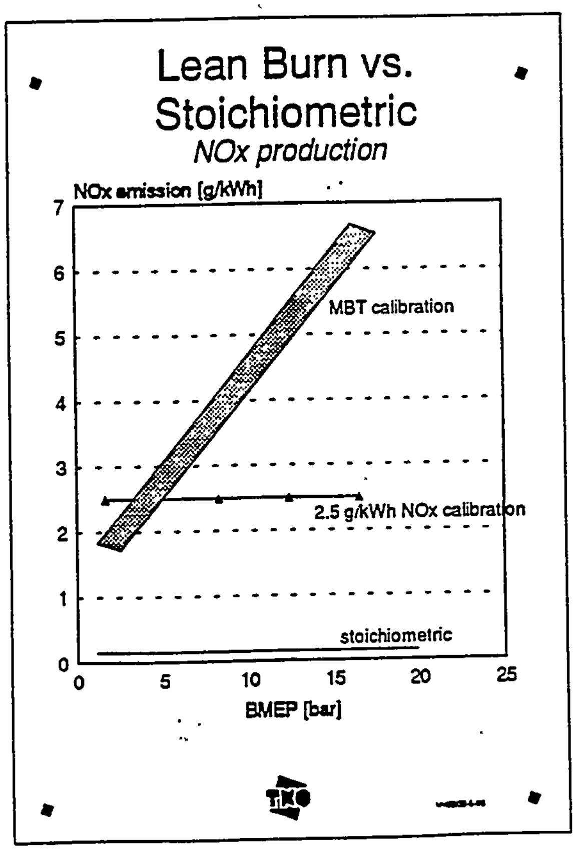

Figure 4

An other important emission component, perhaps more important than NO_x, is the hydrocarbon emission. The stoichiometric engine will reach the EEV emission values without too many problems. The lean burn version has considerably more difficulty to reach the 0.6 g/kWh HC (figure 5). Main issues are here the light-off temperature and the conversion efficiency of the inevitable oxidation catalyst. A great amount of research has been carried out to improve these two crucial characteristics of this type of catalyst. Current tests demonstrate conversion of 80..95% over the lifetime of the catalyst.

During the past years TNO have put a considerably amount of effort in combustion chamber research. A number of different combustion chamber configurations was tested. Figure 6 graphically demonstrates an example of test results with a compact and an open chamber. It turned out that very good results can be obtained with relatively combustion chamber configurations. A compact chamber, having a higher swirl ratio, has a more stable ignition behaviour. However, the open chamber has, at the same λ-value, a lower NO_x-emission. The choice of the swirl and squish ratio, the position of the spark plug etc. is crucial to obtain the best engine performance for lean burn engines. As can be seen in the same figure, the current ignition systems on the market limit the possibility to use compact combustion chambers.

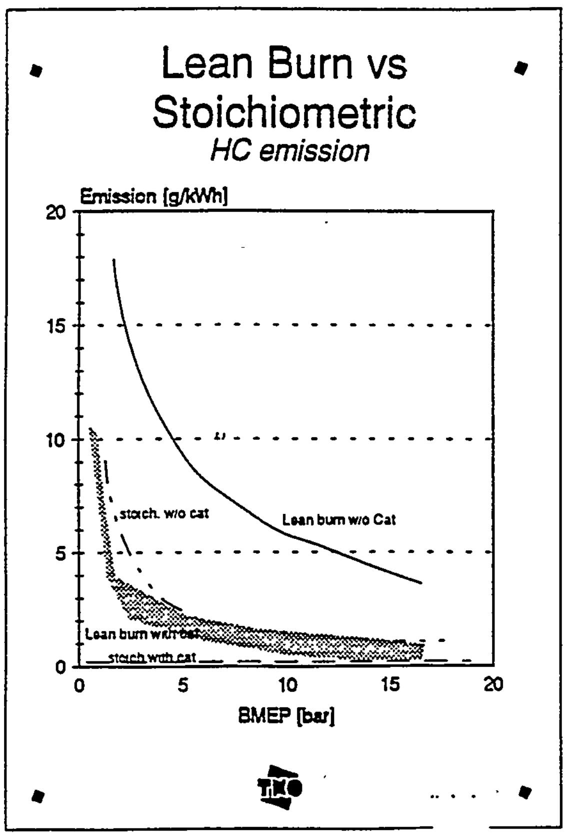

Figure 5

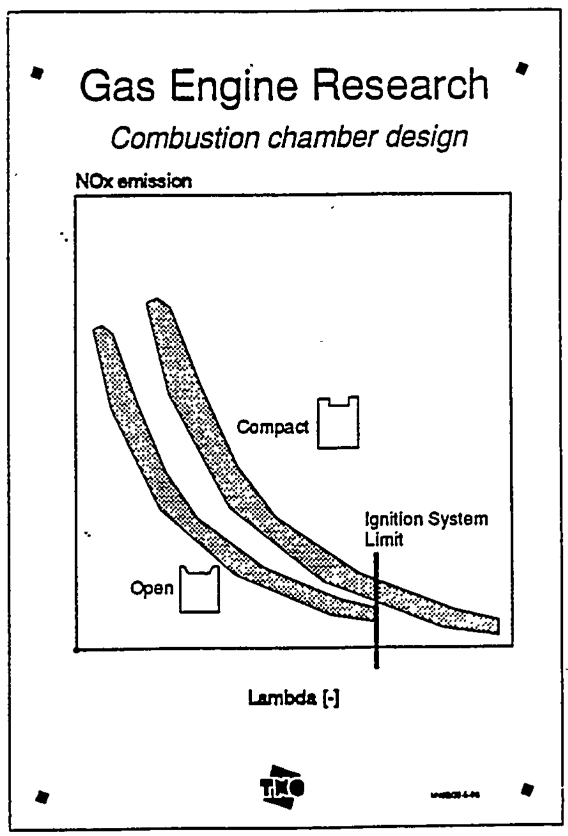

Figure 6

Ignition systems

The point raised in the previous paragraph, a suitable ignition system (including the spark plug), is currently a major concern for the effective development of lean burn gas engines. As the charge density in a lean burn engine is higher than in a stoichiometric engine, the voltage required is also considerably higher. Striving towards lower NO_x-emissions the λ-value will increase, too. Basically, the perfect ignition system would be one with the combined advantages of the different available ignition systems, i.e.: the quick rise-time of the capacitive system, the long spark duration of the inductive system and the very high energy of the plasma ignition system. Knowing, that during transients and due to wear of the spark plug the ignition voltage required becomes higher it will be clear that the development of a well performing lean burn gas engine for more and more stringent emission limits is an ordeal. Figure 7 shows the ignition voltage required at different engine loads for a stoichiometric engine, a lean burn engine with different λ-values, spark plugs and spark plug gaps, as well as the effect of transients, wear and fouling. Figure 8 schematically demonstrates the difficulty with spark plug gaps. At full engine load (high charge density and temperature) a small spark plug gap is required, whereas at idle speed (low charge density and temperature) a bigger spark plug gap is required. The figure shows the ignition capability of a spark plug with a certain spark plug gap.

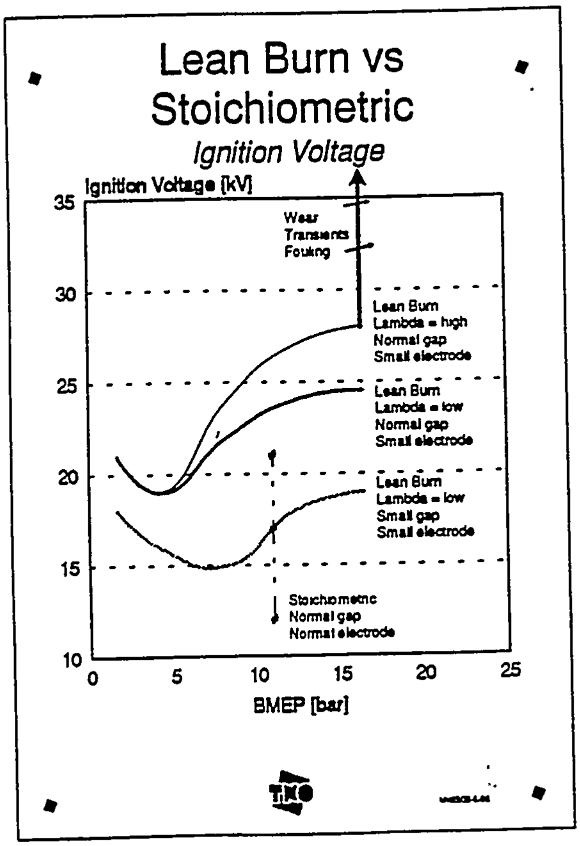

Figure 7

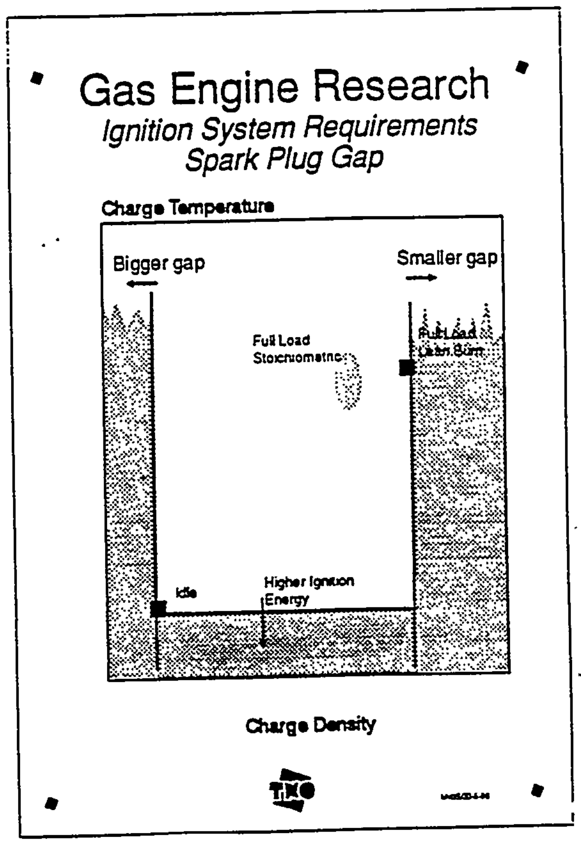

Figure 8

Mechanical and thermodynamical constraints and driveability
Due to the higher air-fuel ratio of the lean burn engine, the charge density of this engine is higher. This results in a higher in-cylinder maximum pressure. As current gas engines are more or less derived from a diesel engine this will normally not cause too many problems. Another effect of the higher air-fuel ratio is the higher boost pressures required. Firstly, this imposes certain properties to the turbocharger. Although these kind of boost pressures are almost the same as for the diesel engine, due to the fact that the gas engine is an otto engine the compressor map should be wider at those high pressures. Figure 9 shows an example of an application where the working line of the engine at full load is very close to the surge line and the choke line of the compressor. Secondly, a good driveability of the engine is more difficult to obtain. For the same transient response the time t_1 and t_2 (in figure 10) should be the same. Besides an appropriate control strategy in combination with drive-by-wire control, one could choose to use a turbocharger with a variable geometry for driveability reasons only.

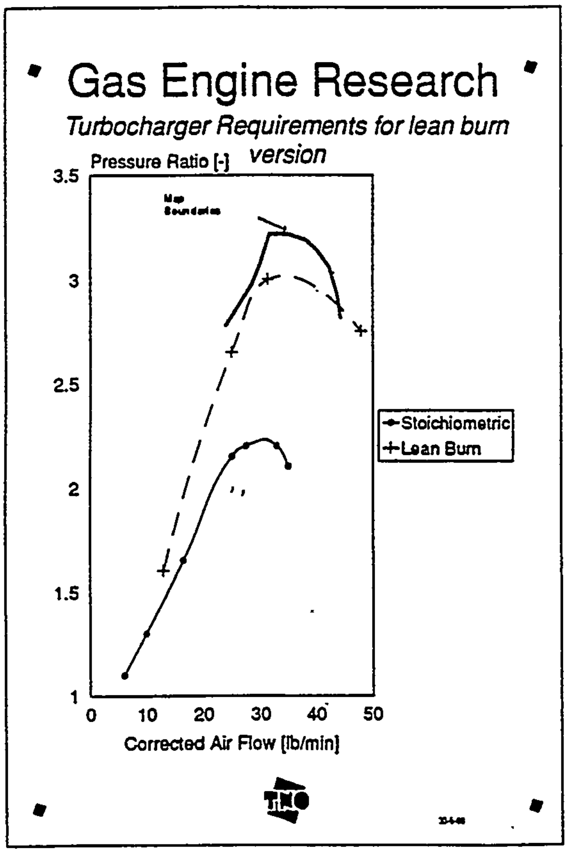

Figure 9

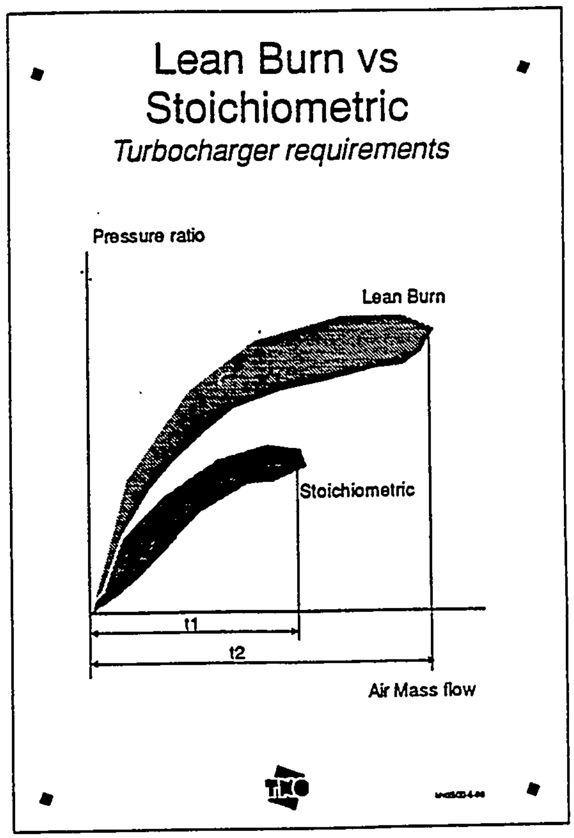

Figure 10

It is well known that the thermal loading of the stoichiometric engine is considerably higher than of the lean burn version. Figure 11 shows an example of pre-turbine exhaust temperatures measured on a number of engines running at maximum torque. It shows that the temperatures before the turbine are approximately 150 to 200 °C higher in the $\lambda=1$ engine. Temperatures at rated speed are even higher (50..100 °C). In the laboratory extreme values in the neighbourhood of 1100 °C were recorded. One of the options to reduce the temperature in the stoichiometric engine is the use of EGR (Exhaust Gas Recirculation). Tests were carried out to demonstrate the possibility to reducing the thermal loading of the engine by using EGR. Figure 12 shows the effectiviness of EGR compared with the lean burn engine. It turns out that by using 25% EGR the temperature can be reduced by 80..120 °C. The lean burn engine, however, running with an air excess of about 60% is much more effective in reducing the exhaust gas termperature (approximately 250 °C). Besides, using the recirculated exhaust gas to reduce the overall engine temperature, it is also very effective to reduce the NO_x emission. Research has demonstrated that 25% EGR can reduce the NO_x emission by 80% (figure 13) without penalizing the HC emission too severely. Further research has to prove whether a stoichiometric engine with an EGR system and a suitable EGR strategy could be able to reach future emission limits with only an oxidation catalyst, instead of a more expensive three-way catalyst.

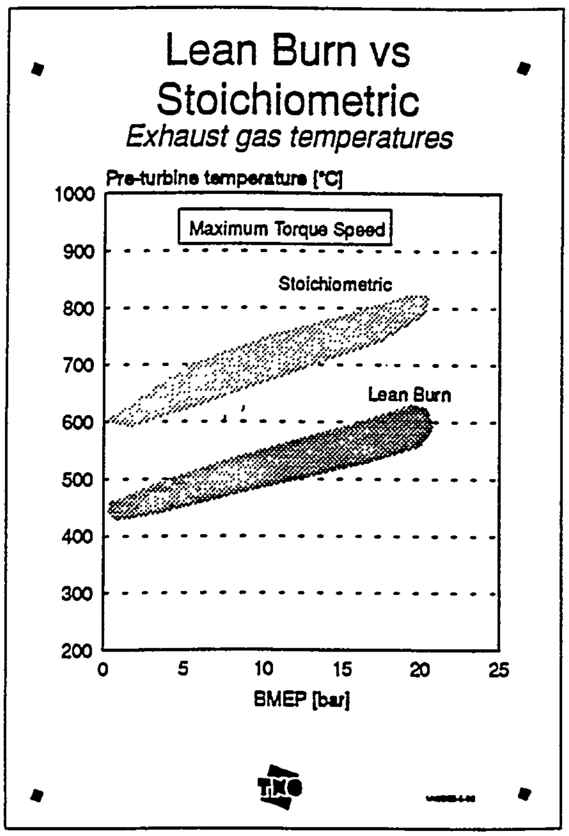

Figure 11

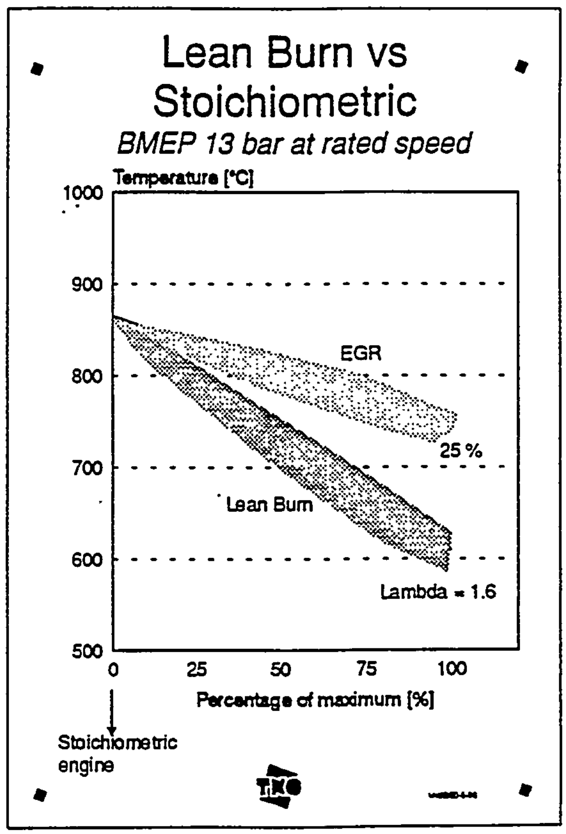

Figure 12

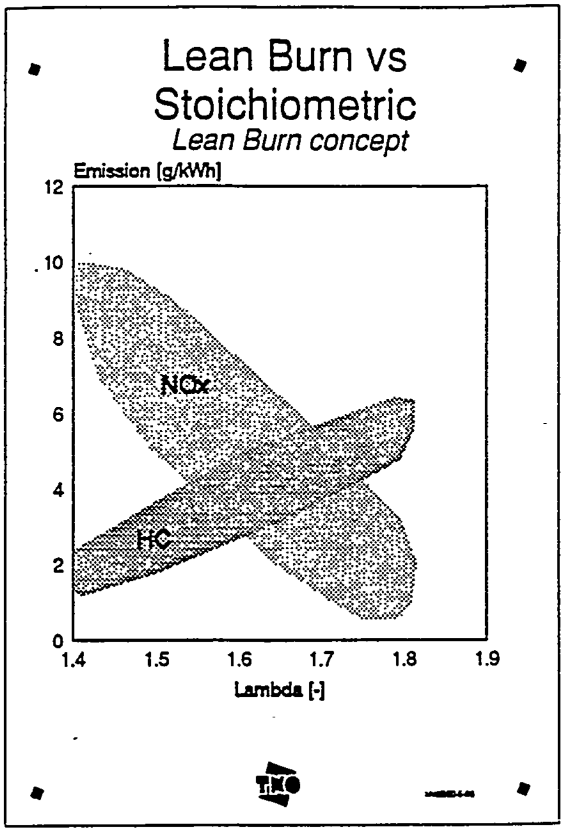

Figure 13 a

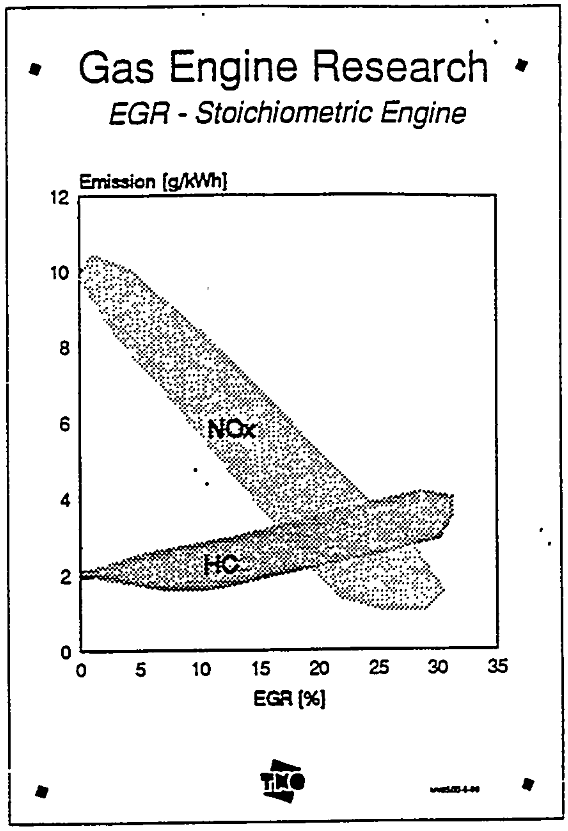

Figure 13 b

Considerations and Conclusion

It is clear that there are many issues to consider while making the decision for lean burn or $\lambda=1$ engine development. This paper demonstrates that technical feasibility is not the main item: both engine type can be made to comply with the current emission legislation and the emission legislation of the near future. The EEV standards currently under discussion allows lean burn engines to be developed. Only if exhaust emission values of less than 1 g/kWh NO_x are required the stoichiometric engine with a three-way closed loop controlled catalyst will be necessary. The lean burn engine has still a considerable advantage from the total efficiency point of view. Stoichiometric engines in practice still show an up to 30% higher energy consumption than their diesel twins. Although the lean burn engine has a clear efficiency advantage, from the driveability point of view the stoichiometric engine has it easier. The latter's higher temperature level of the combustion and of the exhaust gases is the reason that a more expensive catalyst or an EGR system has to be used, as well as other cost increasing equipment like a knock detection system and/or water-cooled turbine housings etc. On the other hand, the lean burn engine needs a more advanced ignition system and with its higher boost pressures a bigger (more expensive) turbocharger (if not a variable geometry turbocharger and a drive-by-wire control system).

No doubt, research to be carried out in the coming years will improve fuel consumption of the stoichiometric engine and emission performance of the lean burn engine. In the end, development and production costs and the costs of the engine in practice will determine the most viable engine concept. Costs in use depends of course, on the one hand, from durability and reliability of the engine (maintenance costs), but on the other hand from a favourable pricing of the fuel and concerned taxes. The industry, research companies and government have to work closely together in order to prove the technical feasibility of the use of alternative energy sources in the field and to take care of the economical application of the technology in the market.

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