SESSION 5: NEW INITIATIVES IN R & D

Chair: Matthew Bol, Sypher:Mueller

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

DEVELOPMENT OF A PORT-INJECTED M100 ENGINE USING PLASMA JET IGNITION AND PROMPT EGR

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Royal Military College of Canada

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Royal Military College of Canada, Kingston, Ontario

V. Battista
Transport Canada, Ottawa, Ontario

COLD STARTING MECHANISMS FOR S.I. ENGINES

Port-Injected Engine: Spark ignition of vaporized fuel

Spark Ignited DISC Engine: Spark vaporization/ignition of liquid fuel droplets

PROVIDING FUEL VAPOUR AT -30°C

- < 10% of gasoline or M85 will vaporize at -30°C
- Injecting > 10 times the stoichiometric fuel quantity can enable starting
- > 90% of the fuel is wasted

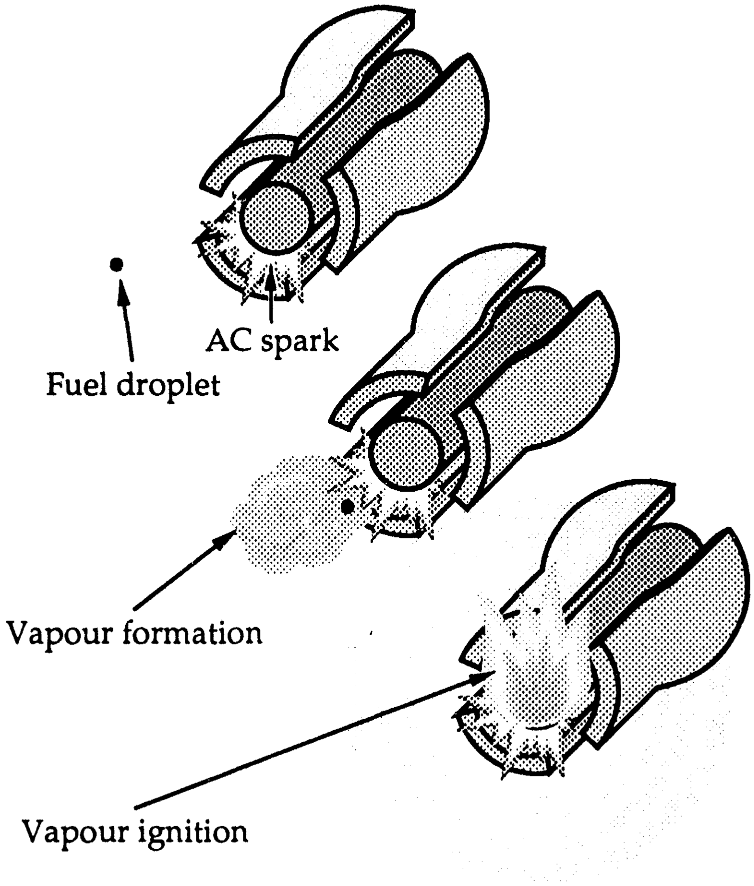
M85 EMISSIONS

"Formaldehyde emissions increase in proportion to the amount of mixture enrichment"

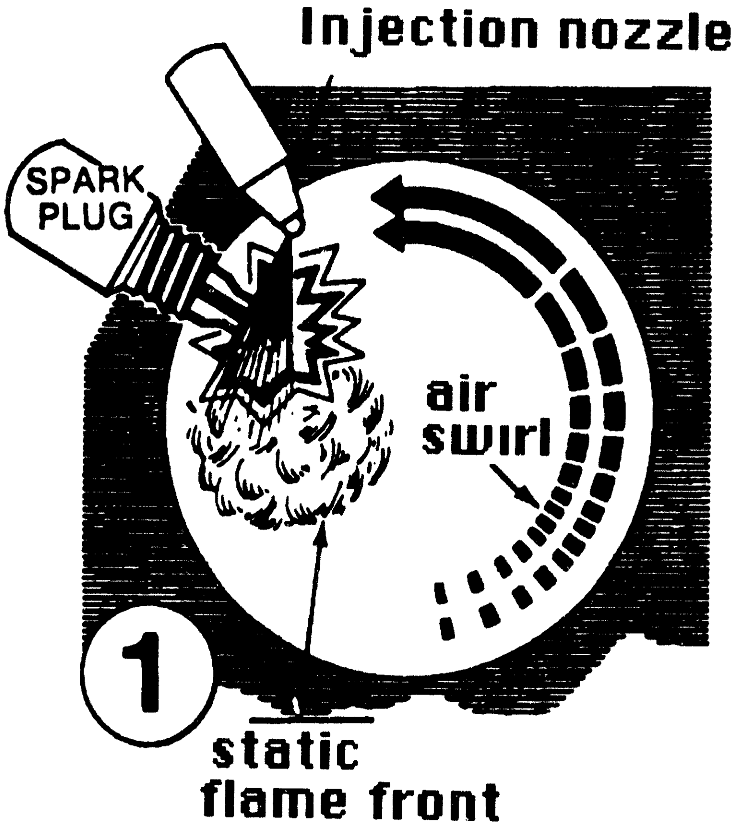
Iwachidou and Kawagoe, 1988

M100 COLD STARTING

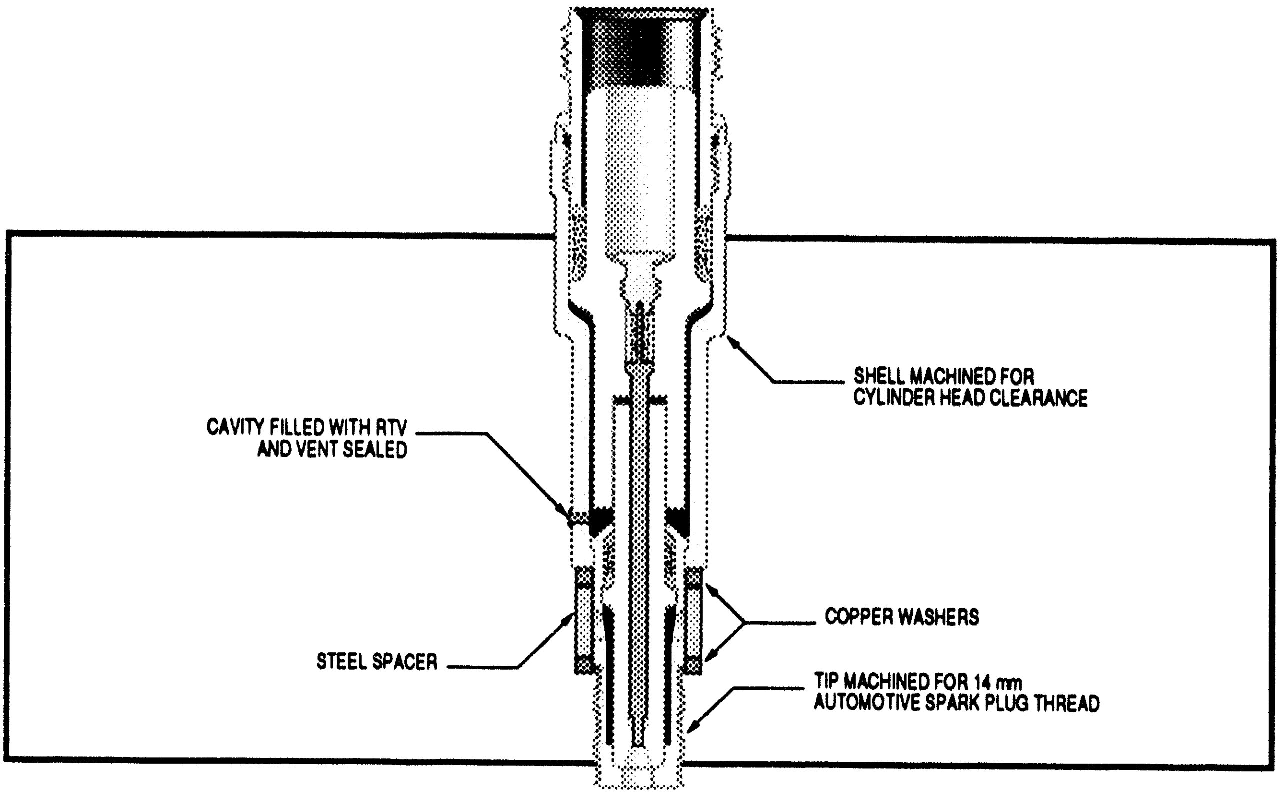
- M100 (neat methanol) contains no "light ends"
- Overfuelling is not effective for cold starting



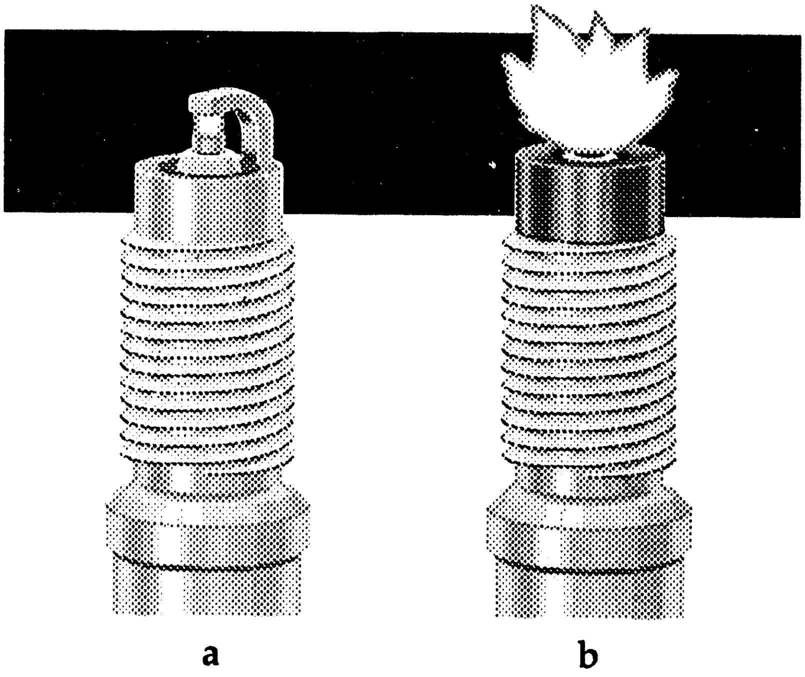
SPARK VAPORIZATION WITH THE DISC ENGINE (JORGENSEN, 1988)



SPRAY COMBUSTION IN THE DISC ENGINE (LEWIS, 1986)



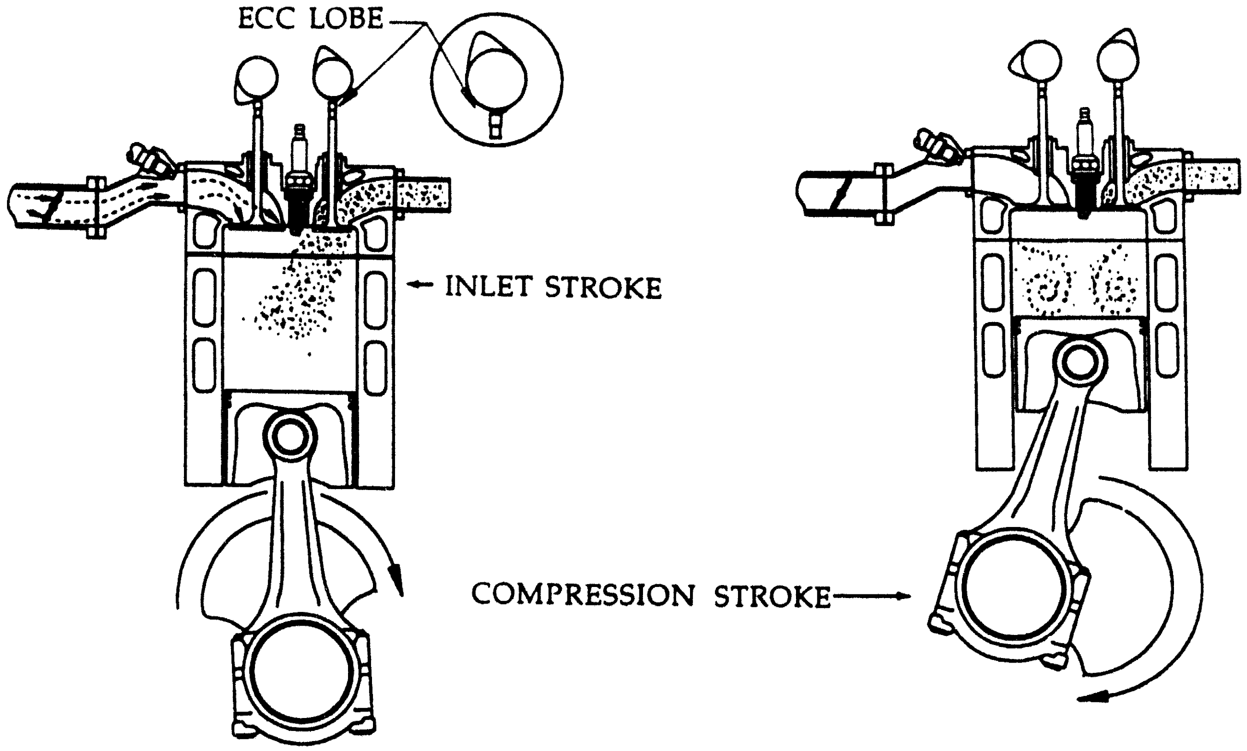
HIGH VOLTAGE RECESSED GAP IGNITOR



AIR-GAP SPARK PLUG (a) AND OPEN CAVITY PLASMA JET IGNITOR (b)

1. Plasma Jet Ignition (PJI)
2. Prompt EGR Using Exhaust Charged Cycle (ECC)

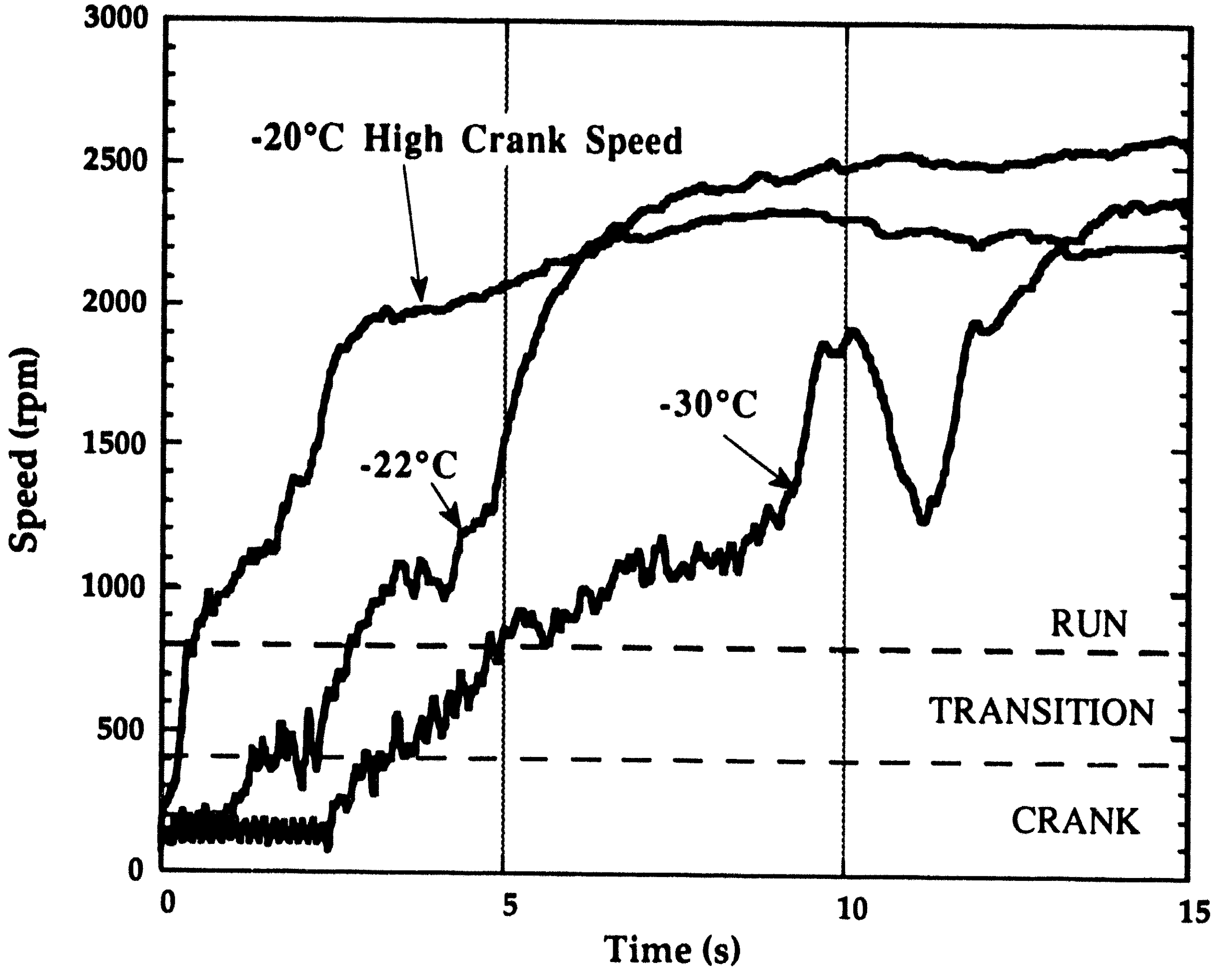
THE EXHAUST CHARGED CYCLE (ECC)



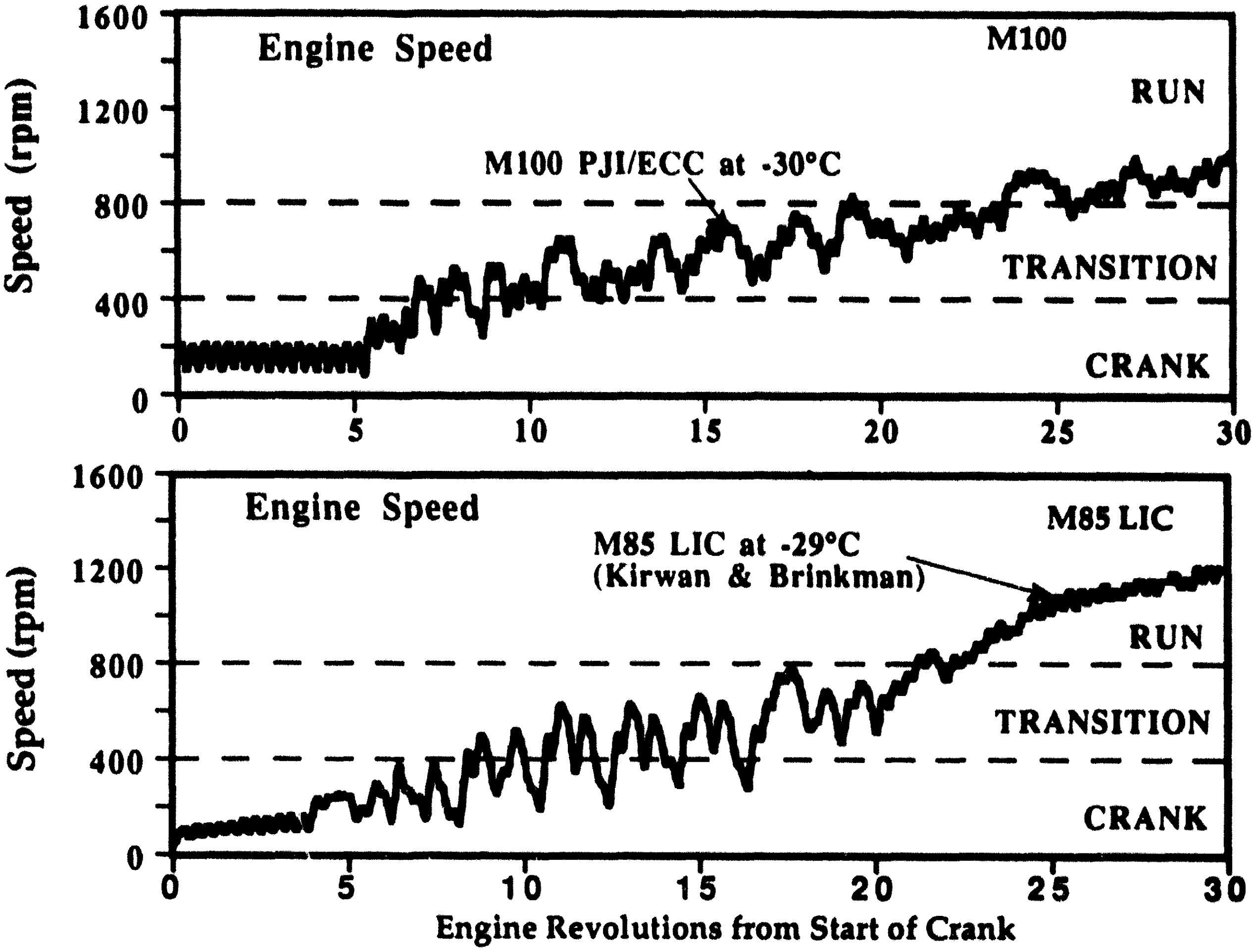
COLD STARTING HYPOTHESIS FOR PJI/ECC

1. First fire achieved by PJI through spark vaporization mechanism

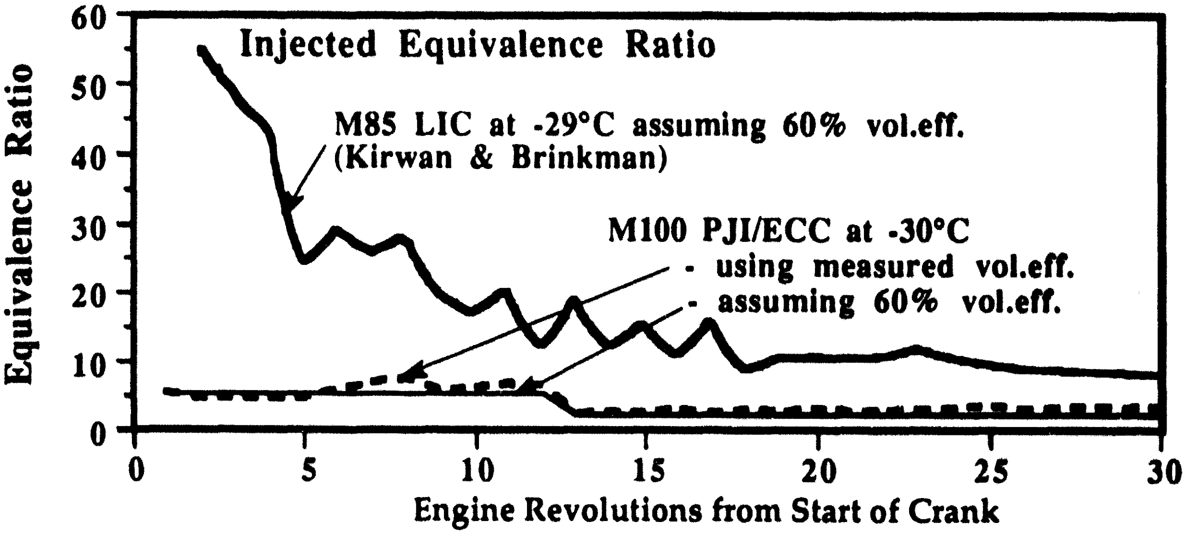
2. Transition to prevaporized combustion mode achieved by ECC through hot product recycle



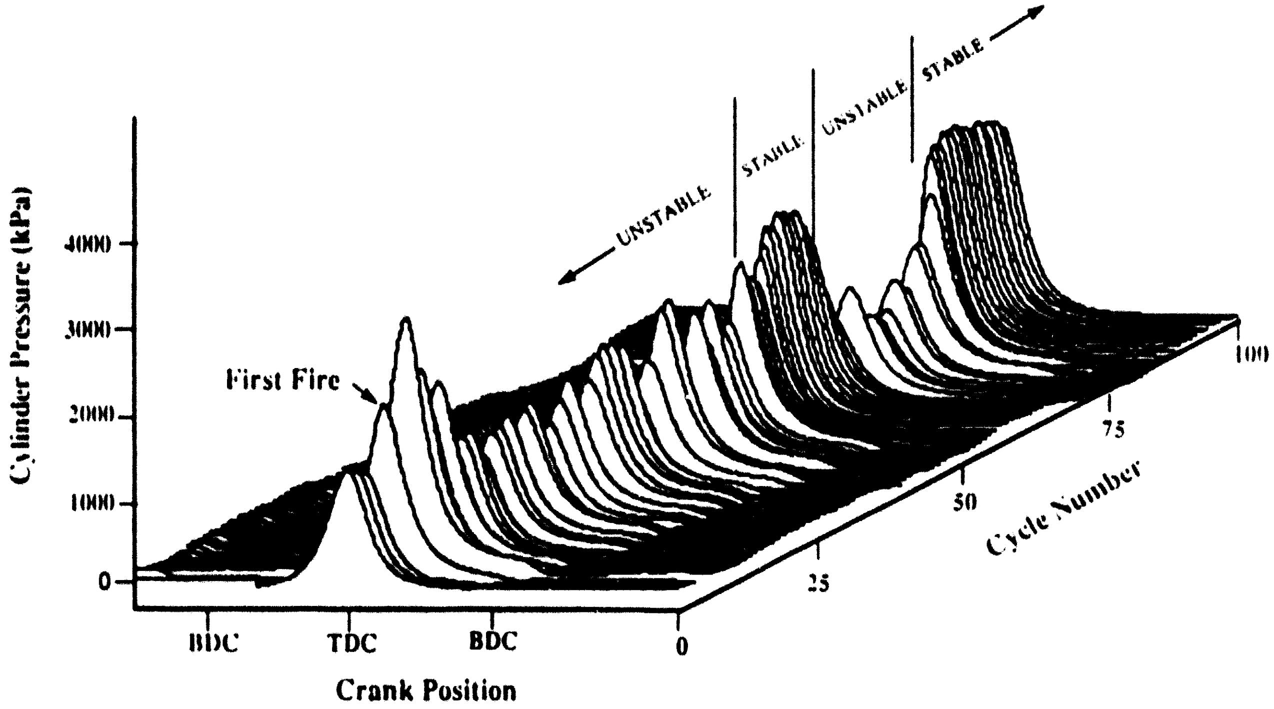
TIME TO RUN AND IDLE WITH M100 PJI/ECC



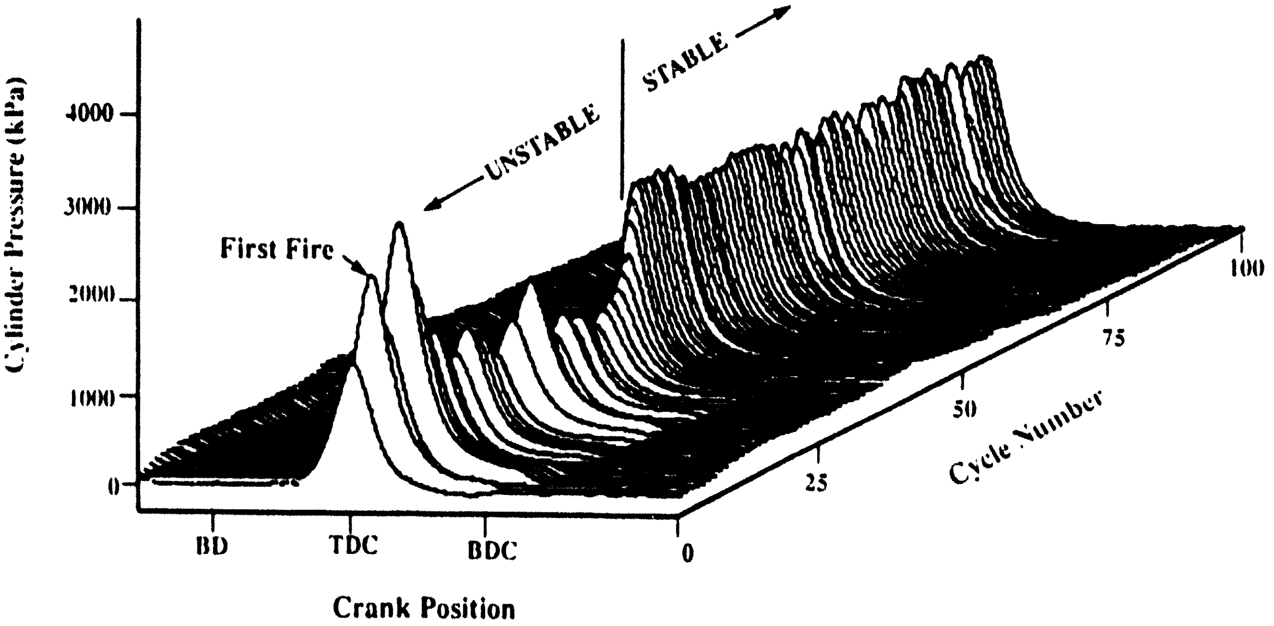
CRANK-TO-RUN BEHAVIOUR



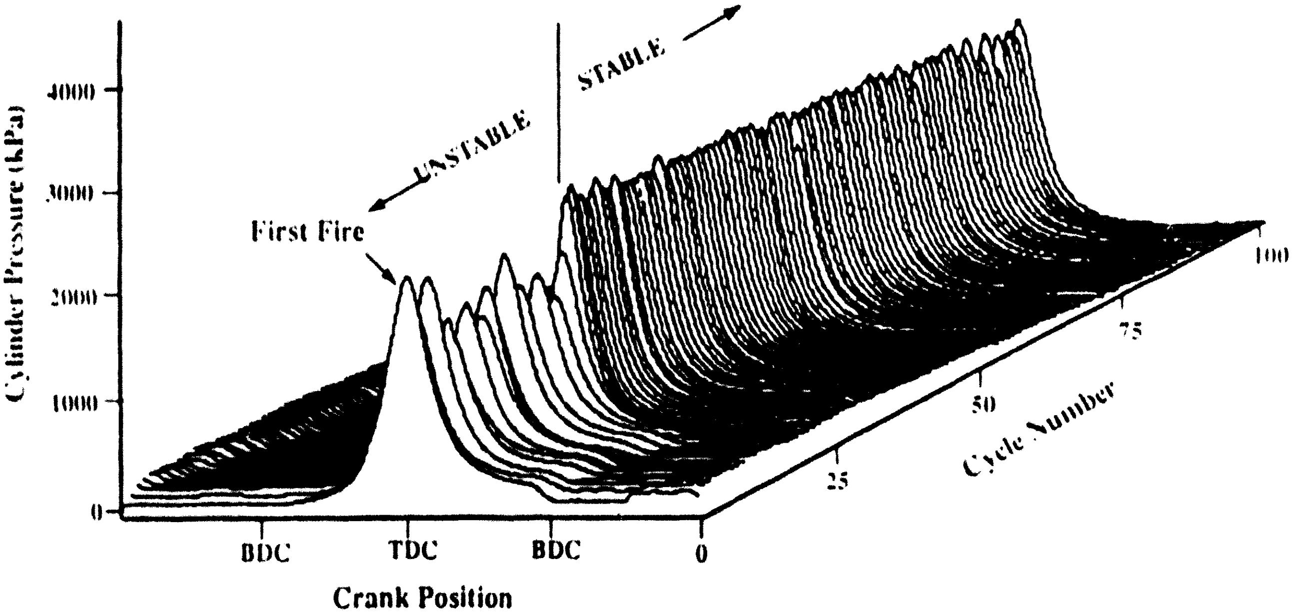
CRANKING EQUIVALENCE RATIO



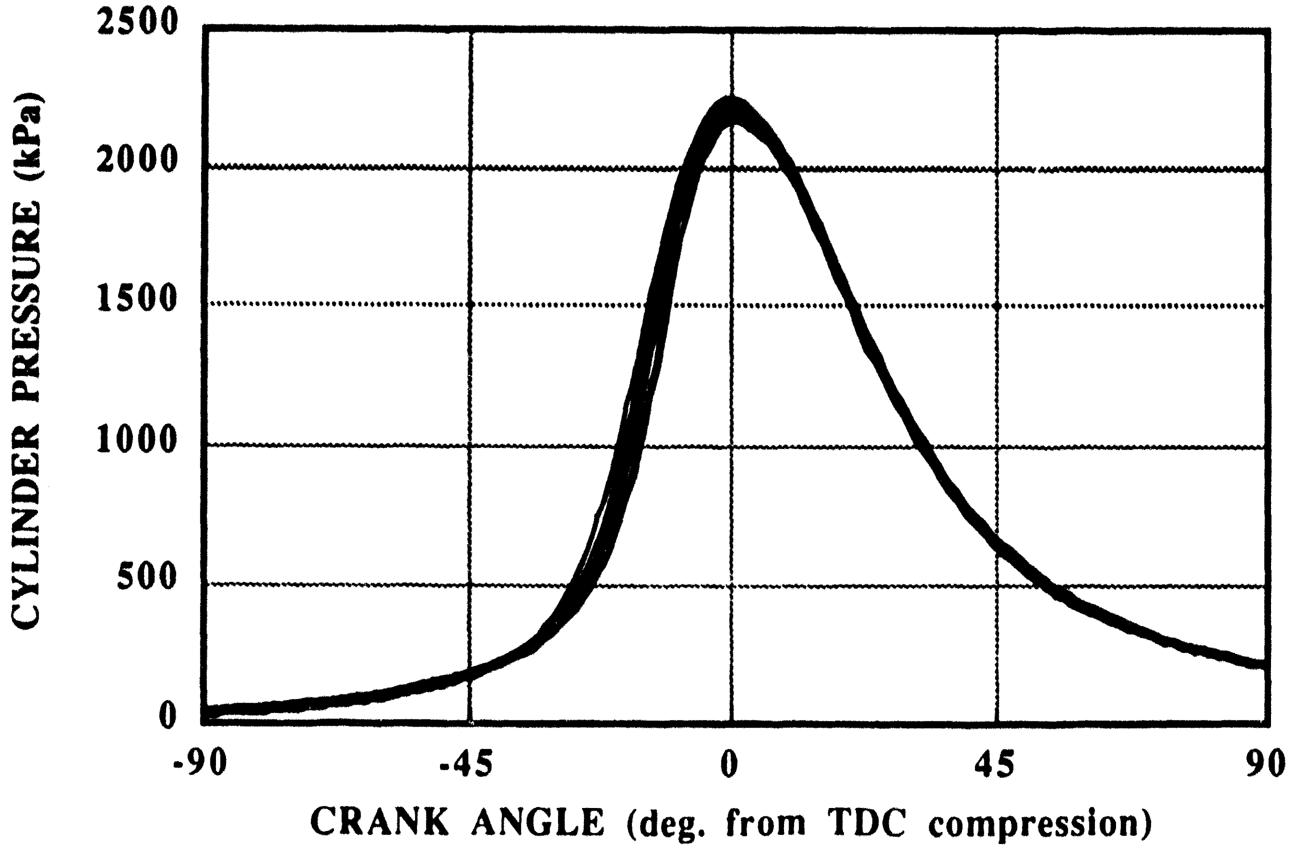
CYLINDER PRESSURE DATA FROM -30°C COLD START TEST



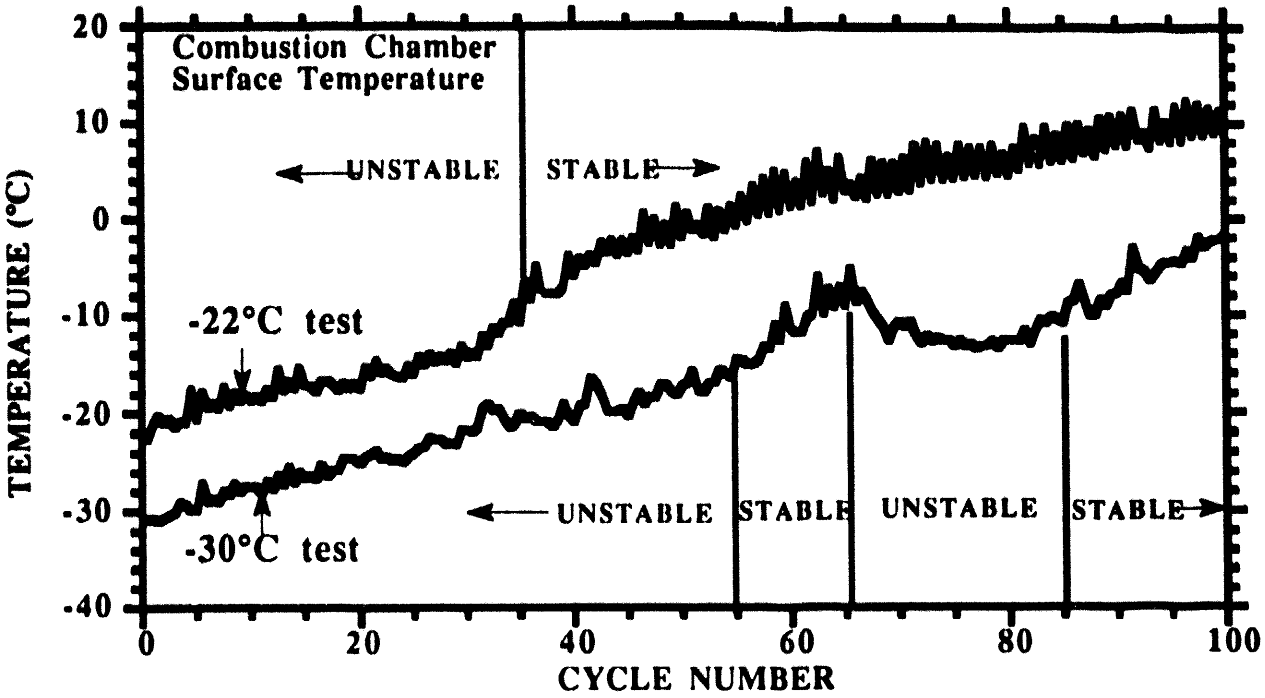
CYLINDER PRESSURE DATA FROM -22°C COLD START TEST



CYLINDER PRESSURE DATA FROM -20°C COLD START TEST WITH HIGH CRANKING SPEED



CONSECUTIVE CYCLES FROM STABLE RUNNING AFTER STARTING AT -20°C



ENGINE TEMPERATURE DATA FOR M100 PJI/ECC
COLD STARTING TESTS AT -30°C AND -22°C

CONCLUSIONS

1. Proof of concept performance: Cold starting at -30°C, 5s crank-to-run.
2. Cold starting performance compares favourably to M85 blends using full boiling range gasoline.
3. Fuel/air equivalence ratios required for cold starting are 10-30% of typical M85 values.
4. Exceptionally good combustion stability achieved following sub-zero cold starts.

WORK IN PROGRESS

1. Use of external EGR to reduce fuel consumption.

2. Use of Plasma Jet Ignition and Prompt EGR to increase tolerance to external EGR.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

DEVELOPMENT OF A PORT-INJECTED M100 ENGINE USING PLASMA JET IGNITION AND PROMPT EGR

D.P. Gardiner, V.K. Rao, and M.F. Bardon, Royal Military College, Kingston, Ontario, V. Battista, Transport Canada, Ottawa, Ontario

Q. Robert Siewert, General Motors: Have you tried to start using the plasma jet only without the prompt EGR?

A. Experiments at the University of Alberta tested with the plasma jet only and managed to start the engine at minus 15oC. They had to crank longer than we like to do, and it did not run smoothly. We began our work with prompt EGR on gasoline and on methanol; the plasma jet was added later.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

VISIBILITY OF METHANOL POOL FLAMES

Ö.L. Gülder, B. Glavinčevski
National Research Council Canada

V. Battista
Transport Canada

VISIBILITY OF METHANOL POOL FLAMES

Ö. L. Gülder ,   B. Glavinčevski
Combustion & Fluids Engineering, M-9
IECE, National Research Council Canada
Ottawa, Ontario, Canada

and

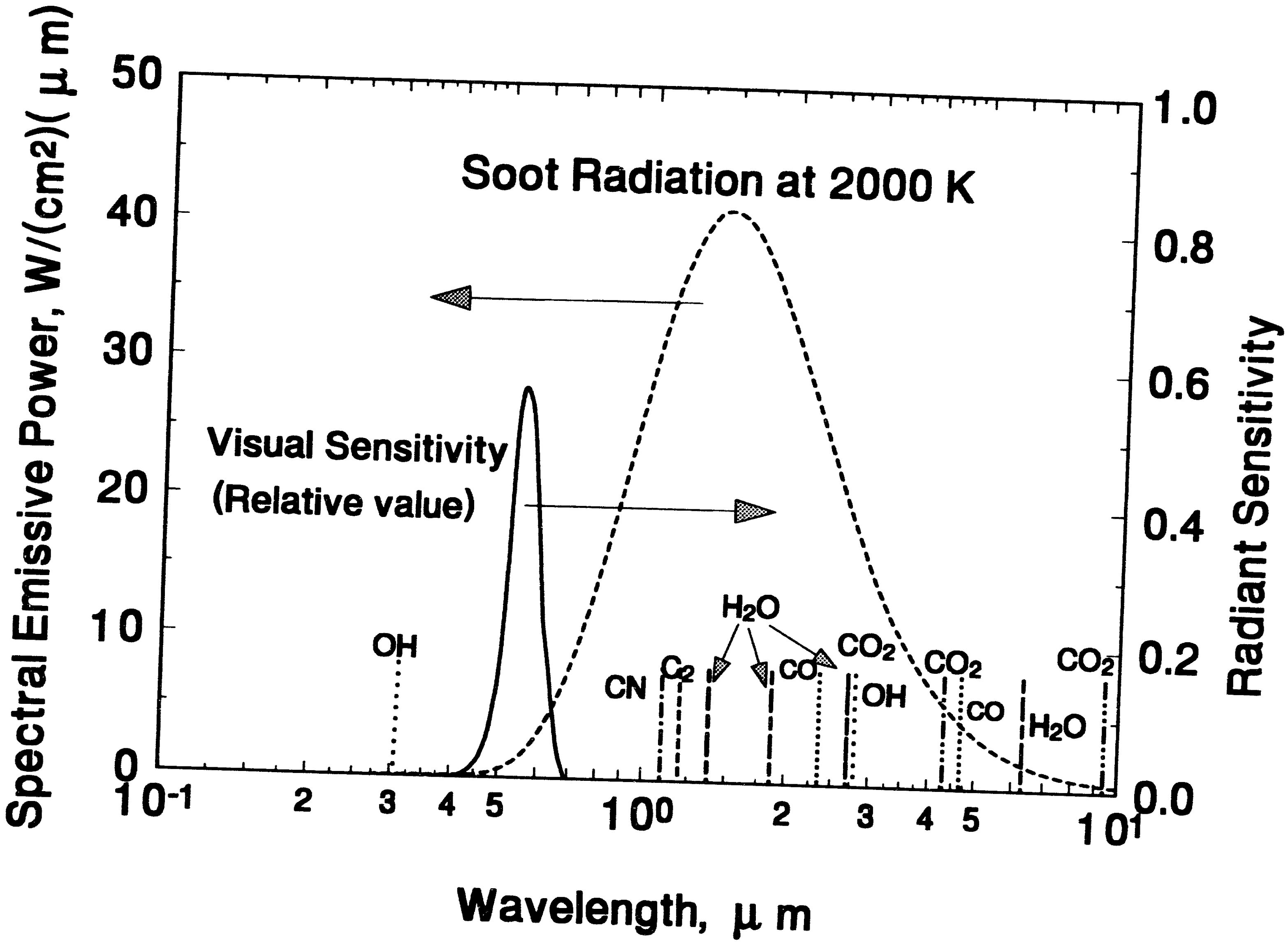
V. Battista
Road Safety and Motor Vehicle Regulation
Transport Canada
Ottawa, Ontario, Canada

1993 Windsor Workshop on Alternative Fuels

Funding: PERD Committee 5.5, Transport Canada, and NRC

PROBLEM

- Very low luminosity of a methanol diffusion flame represents a potential safety issue
- In hydrocarbon diffusion flames, soot particles are formed as a result of pyrolysis and observed as an intense yellow radiation
- Methanol pyrolysis does not produce any soot, and hence methanol poool flames burn with a faint blue colour of very low visibility
- This decreases the likelihood of a fire being noticed immediately


Soot Radiation at 2000 K
Visual Sensitivity
(Relative value)
Spectral Emissive Power, W/(cm²)(μ m)
Radiant Sensitivity
Wavelength, μ m
0
10
20
30
40
50
0.0
0.2
0.4
0.6
0.8
1.0
10-1
2
3
4
5
100
2
3
4
5
101
OH
CN
C2
H2O
CO
CO2
OH
CO2
CO
H2O
CO2

WHY METHANOL DOES NOT SOOT ?

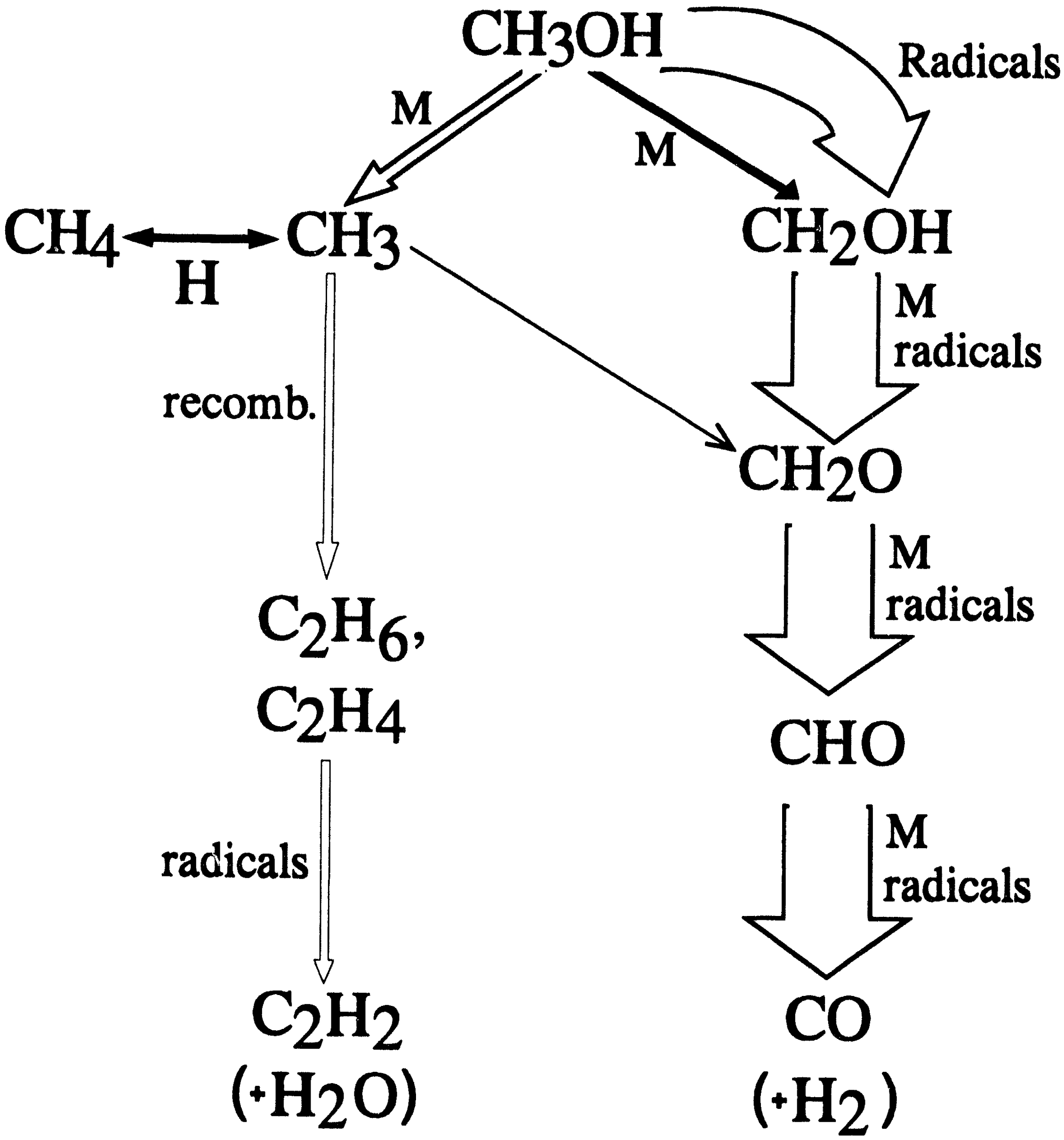
- No clear answer backed by experimental evidence

- The reason for this is a lack of a basic understanding of soot formation mechanism in hydrocarbon flames

- *Soot Formation Mechanisms in Flames:*

  - *neutral species condensation reactions*

  - *chemi-ions are dominant in forming soot precursors*


CH3OH
Radicals
M
M
CH4
H
CH3
CH2OH
M
radicals
recomb.
CH2O
M
radicals
C2H6,
C2H4
CHO
radicals
M
radicals
C2H2
(+H2O)
CO
(+H2)

POTENTIAL ANSWERS

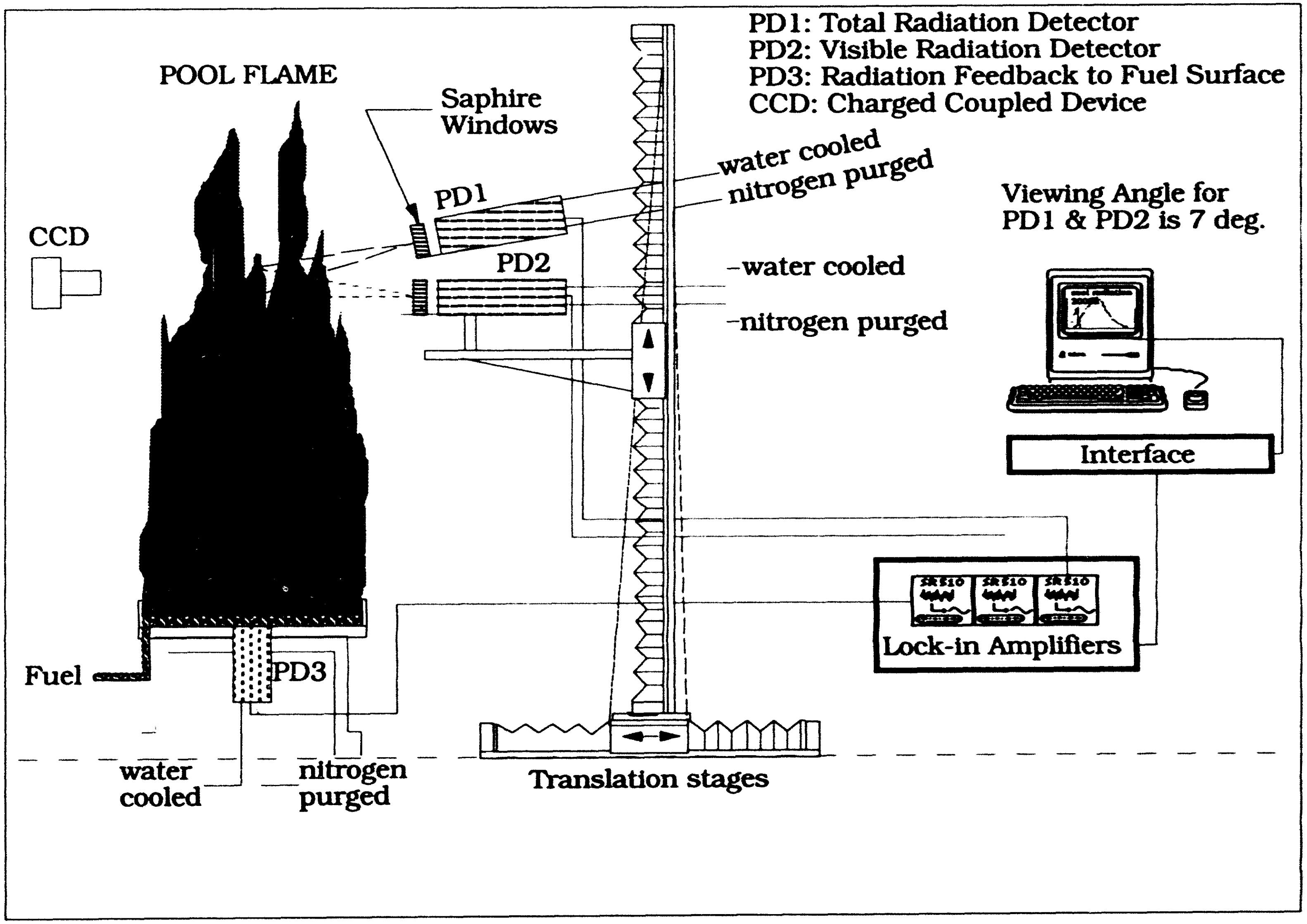
- During pyrolysis, almost all methanol dissociates into carbon monoxide and hydrogen. Very small amount of acetylene(s) formed

  In hydrocarbon pyrolysis, a lot of lower hydrocarbons especially acetylenes and olefins are formed

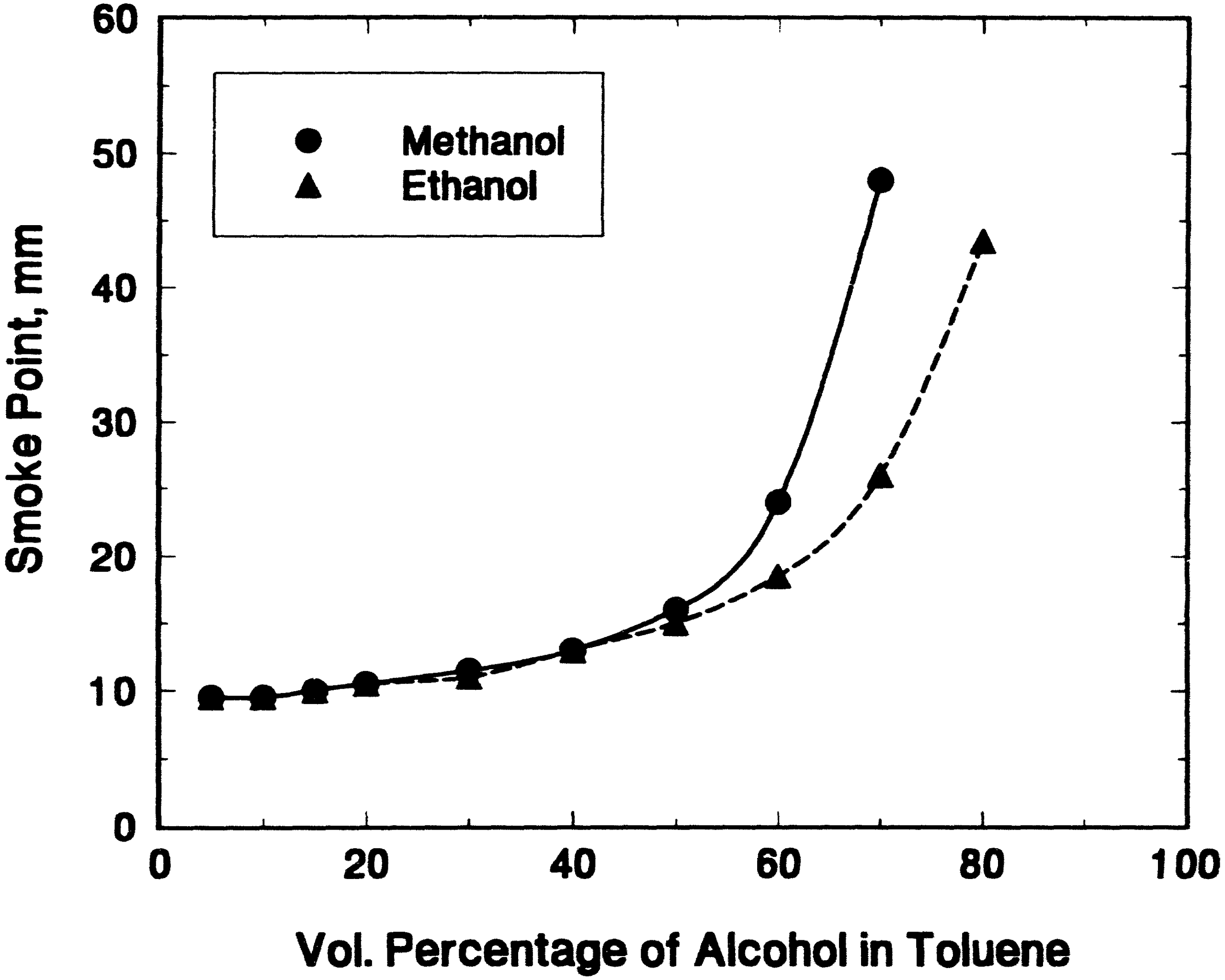
- Due to existence of oxygen atom in fuel structure OH radical is readily formed, and can oxidize any potential soot precursor

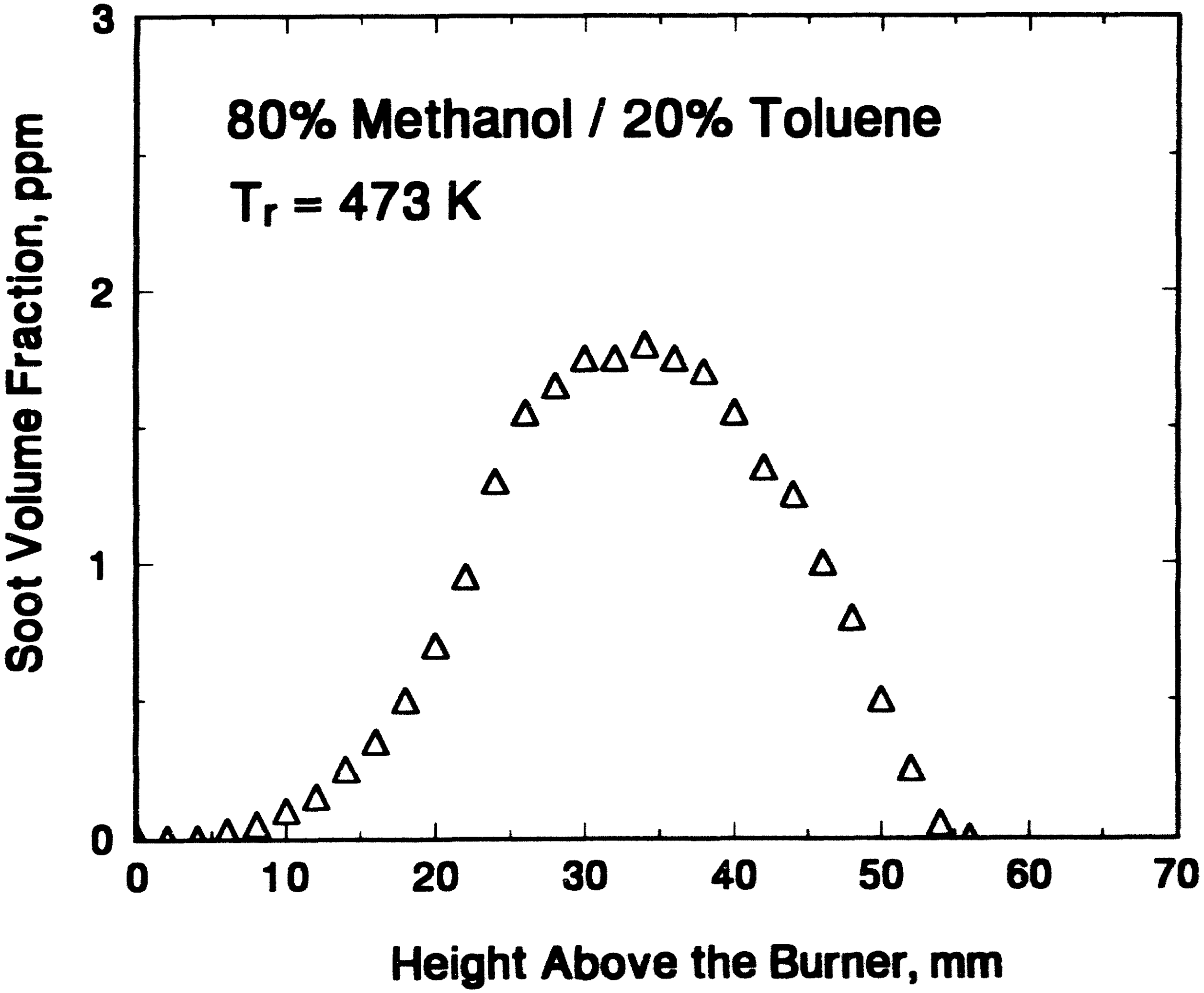
EXPERIMENTAL WORK

- Laminar diffusion flame experiments: *SOOT*
  - Methanol and air are heated to 673 K to elevate the flame temperature
  - Methanol hydrocarbon blends
  - Methanol with additives
- Pool flame experiments: *RADIATION*
  - Two different pool flames: 0.1 m & 0.3 m diameters
  - Methanol with additives



Schematic of the pool flame burning rig


Methanol
Ethanol
Smoke Point, mm
0
10
20
30
40
50
60
0
20
40
60
80
100
Vol. Percentage of Alcohol in Toluene


80% Methanol / 20% Toluene
T_r = 473 K
Soot Volume Fraction, ppm
0
1
2
3
0
10
20
30
40
50
60
70
Height Above the Burner, mm

NON-HYDROCARBON ADDITIVES - I

- Ten compounds of Group 5 and 6 elements:
  - expected to have some influence on carbon chemistry during pyrolysis and oxidation of hydrocarbons
  - some of these additives (1000 ppm to 1.2% in methanol) provided significant improvement in luminosity in diffusion flames
  - Laser extinction measurements in these flames showed no sign of soot. Observed luminosity is due to gaseous emissions

NON-HYDROCARBON ADDITIVES - II

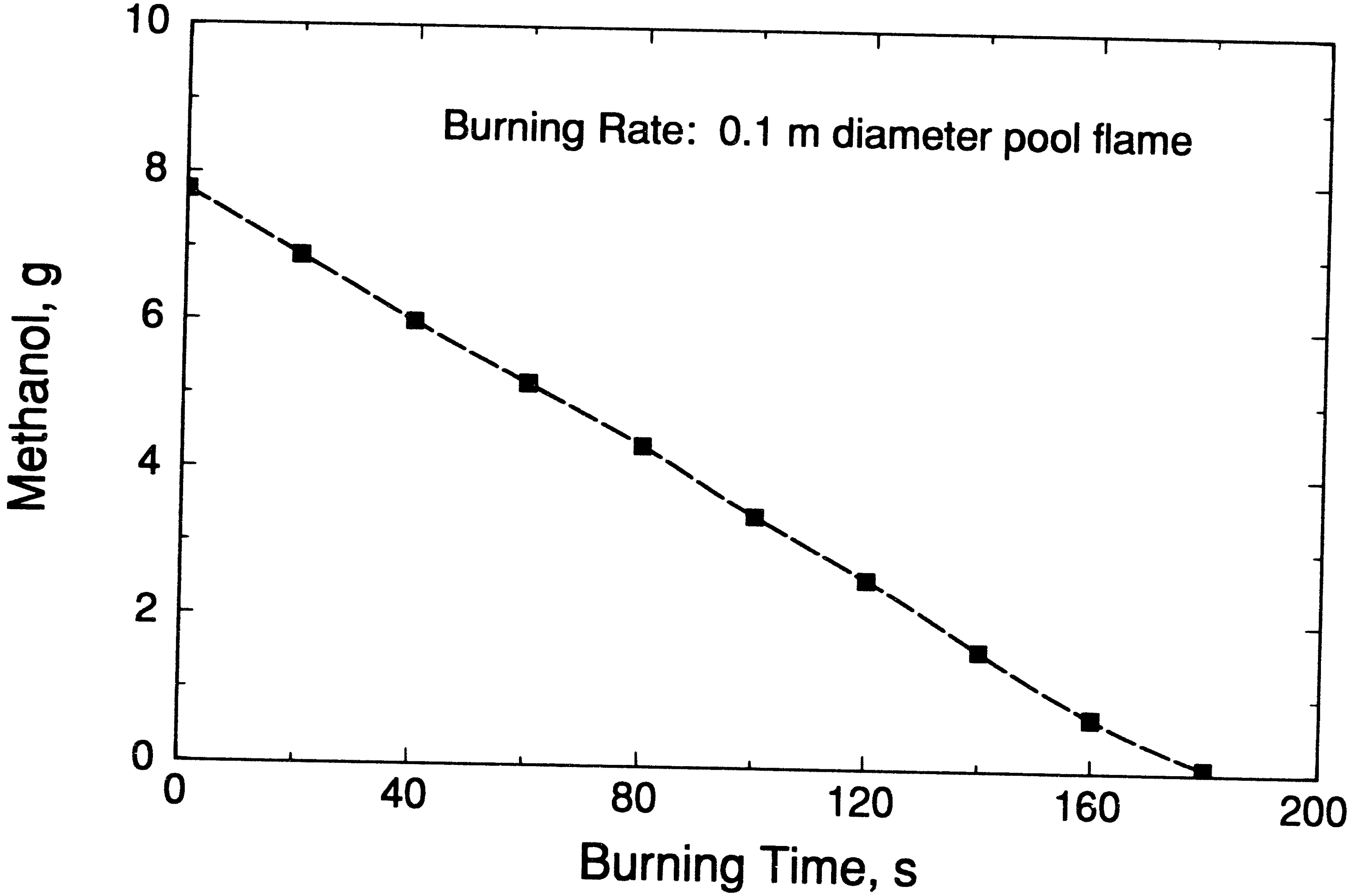
- **Three of these ten compounds yielded promising results**
- **At 0.5 to 1.2% level, measured visible flame luminosity of the pool flames is comparable to the luminosity of M85**
- **These additives leave some residual material**
- **These additives may not be suitable for catalytic converters**

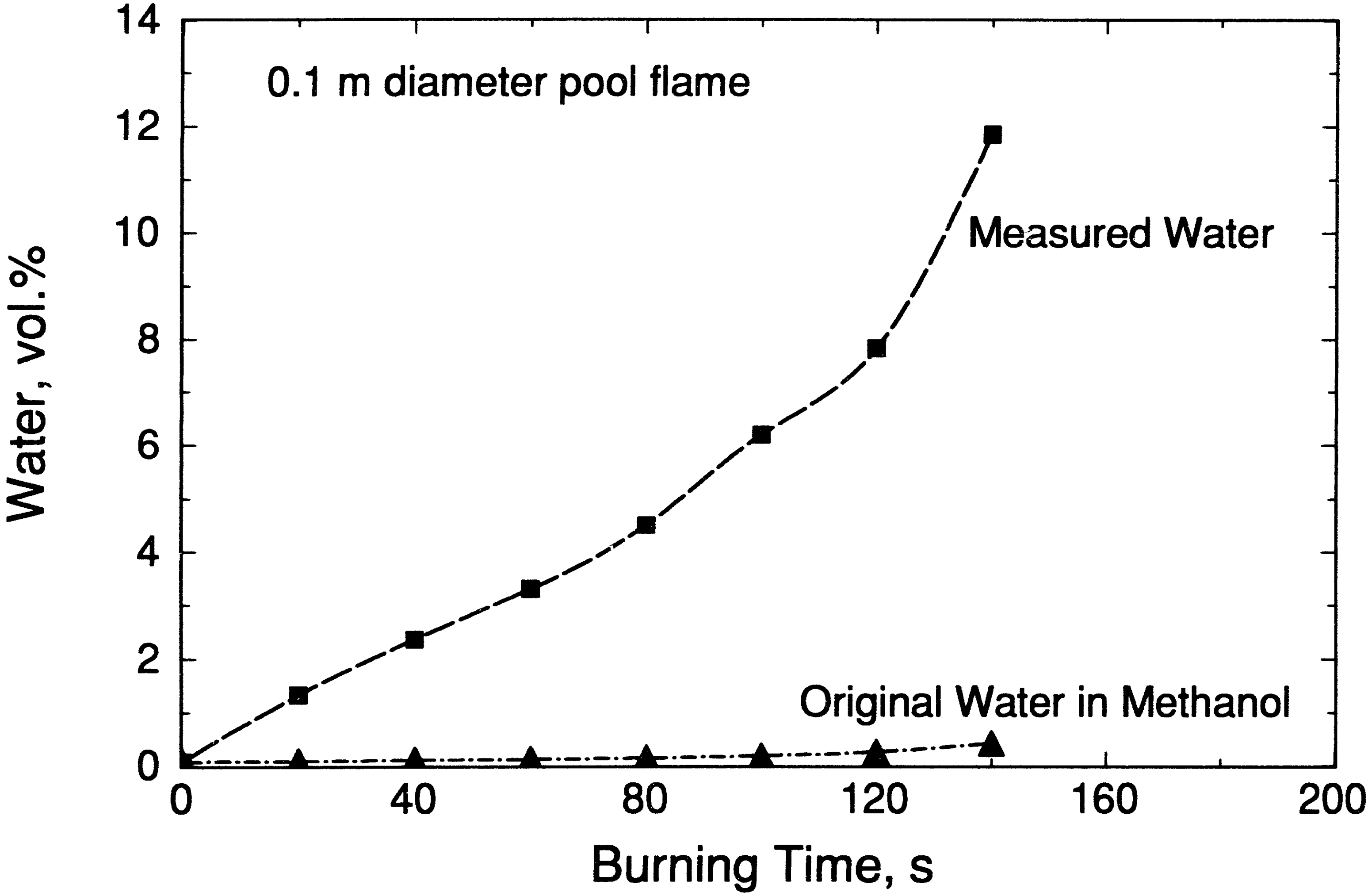
NON-HYDROCARBON ADDITIVES - III

- Ferrocene:
    - 0.5 to 1% addition colors the methanol flame
    - No evidence of soot formation in diffusion flame
    - Pool flame visibility significantly improved
    - Leaves residual material

HYDROCARBON ADDITIVES

- Narrowed to one from more than one hundred
- MVE3 consists of several hydrocarbons:
  - none of the components aromatic
  - 4% MVE3 provides luminosity comparable to M85
  - MVE3 initiates soot formation in pool flames
  - Luminosity enhancement of MVE1 lasts for the full burning period in both sizes of pool flames


Burning Rate: 0.1 m diameter pool flame
Methanol, g
Burning Time, s
0
2
4
6
8
10
0
40
80
120
160
200


0.1 m diameter pool flame
Measured Water
Original Water in Methanol
Water, vol.%
Burning Time, s
0
2
4
6
8
10
12
14
0
40
80
120
160
200

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

VISIBILITY OF METHANOL POOL FLAMES

Ö.L. Gülder, B. Glavinčevski, National Research Council Canada

Q. Norman Brinkman, General Motors: Can you tell us the composition of MVE-3? Does it contain any triple bonds?

A. I cannot say because the product may be licensed and marketed. It does not contain acetylenes, and its specific gravity is similar to gasoline.

Q. Anonymous: Does the additive form soot?

A. Yes, it does.

Q. Alex Lawson, Alex Lawson Associates: I would suggest engine tests to measure emissions.

A. That is part of the plan.

Q. Vinod Duggal, Cummins Engine Co.: Does it help in cold starting?

A. I am not sure, but it probably does not.

Q. Matthew Bol, Sypher:Mueller International: Do you have an estimate of cost?

A. About two cents per liter.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

FAST BURN COMBUSTION DEVELOPMENT FOR NATURAL GAS ENGINES

W.A. Goetz
ORTECH

R.L. Evans
University of Victoria

V.K. Duggal
Cummins Engine Co. Inc.

Acknowledgments

CANADIAN GAS ASSOCIATION

SOUTHERN CALIFORNIA GAS COMPANY

CUMMINS ENGINE COMPANY Inc.

Targets

- Reduce ignition delay and combustion duration
- Increase heat release
- Extend lean flammability limit
- Increase thermal efficiency
- Reduce emissions, emphasizing NOx

Objectives

- Evaluate the effect of turbulence generating jets on ignition delay and heat release in a single cylinder NG fueled engine.
- Implement most effective approaches for fast burn on a single cylinder L10 NG engine.
- Implement the best technology on a multi-cylinder L10 and develop a control strategy for transient evaluation.
- Explore the potential of high BMEP (~ 250 psig) / low NO_X combination.

Technical Approach

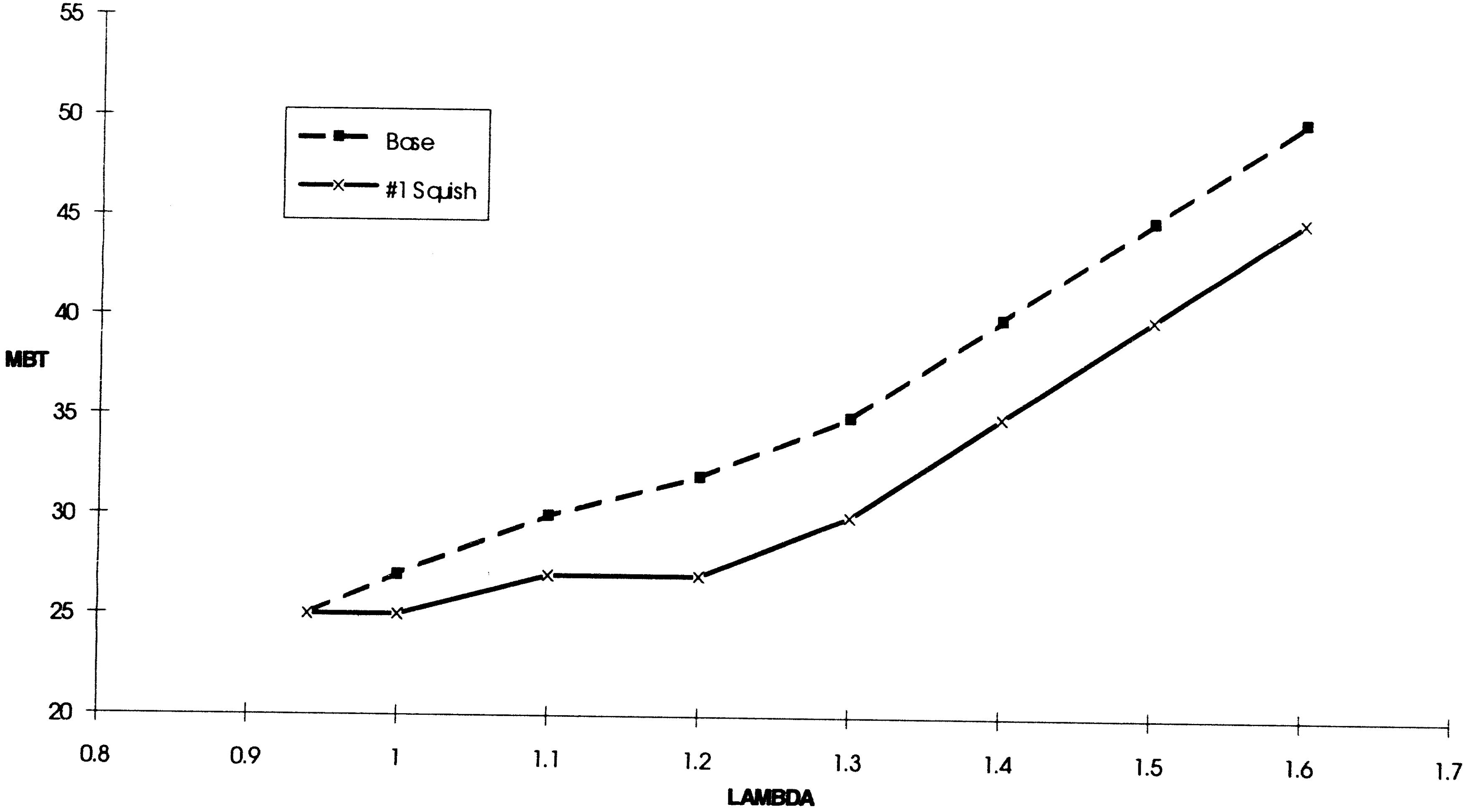
PHASE I: Evaluate effects of fast burn technology on a single cylinder Ricardo Hydra Engine.

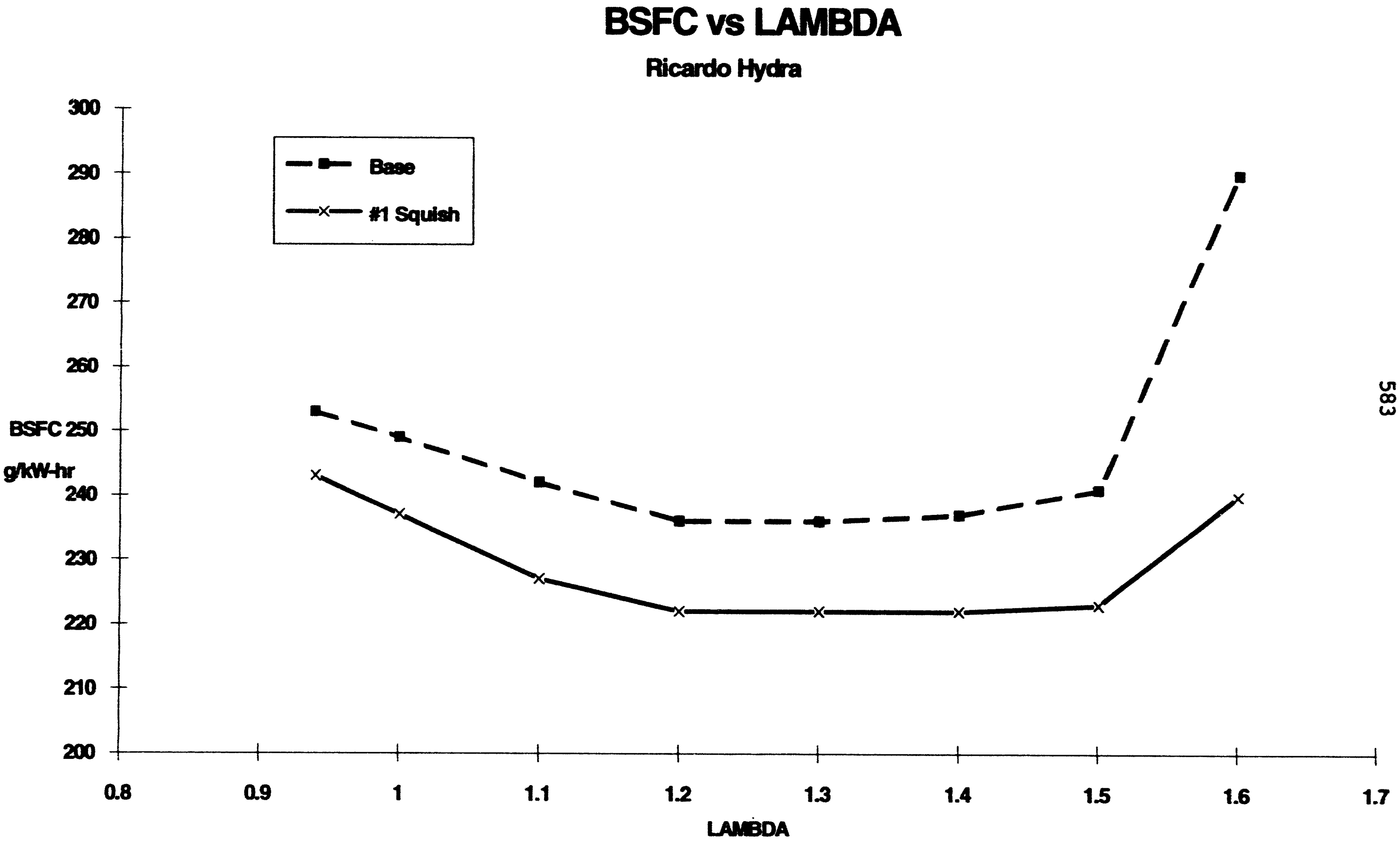
PHASE II: Select the most promising configurations and test them on a single cylinder L10 engine

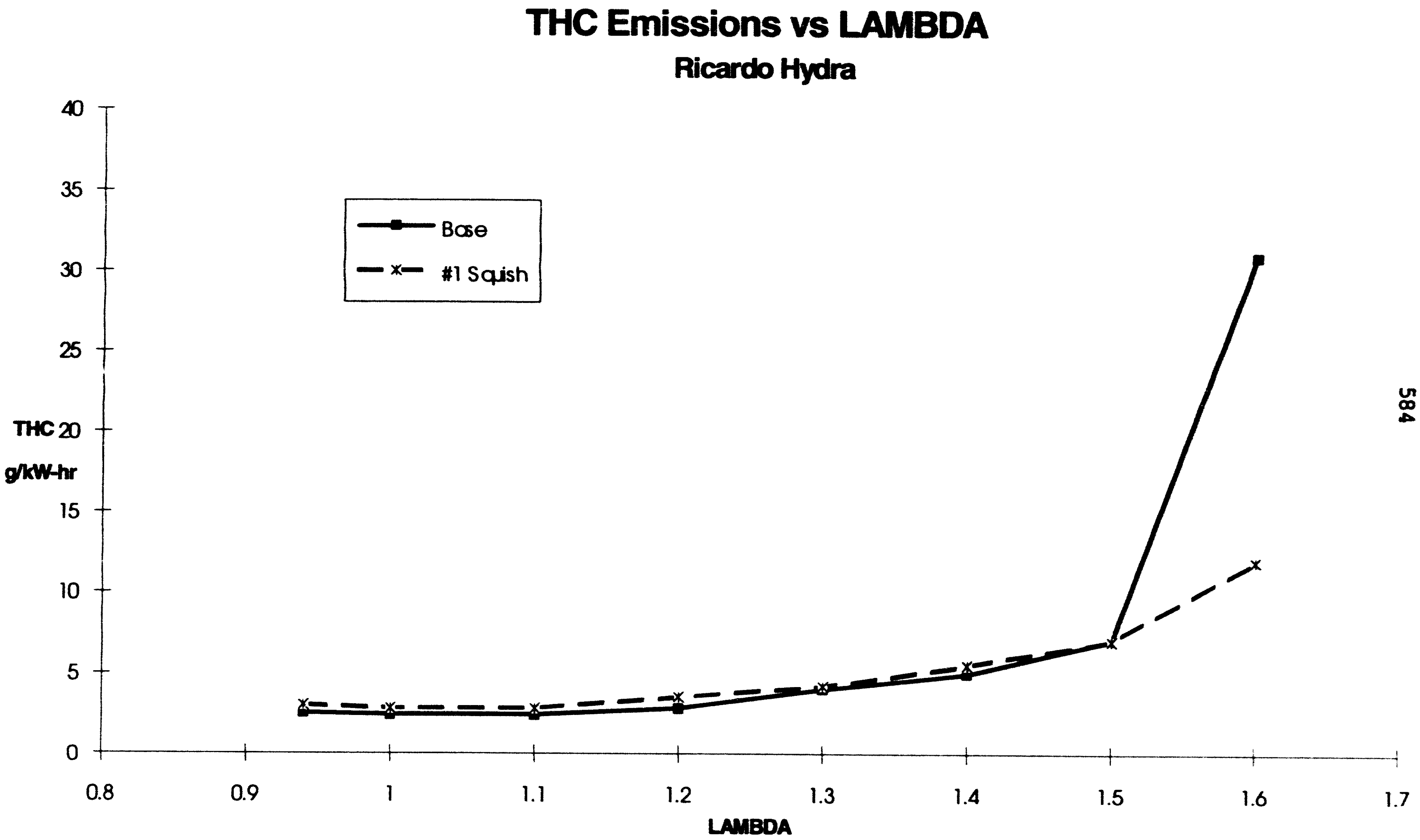
PHASE III: Document the benefits of fast burn combustion technology on a multi-cylinder L10 engine

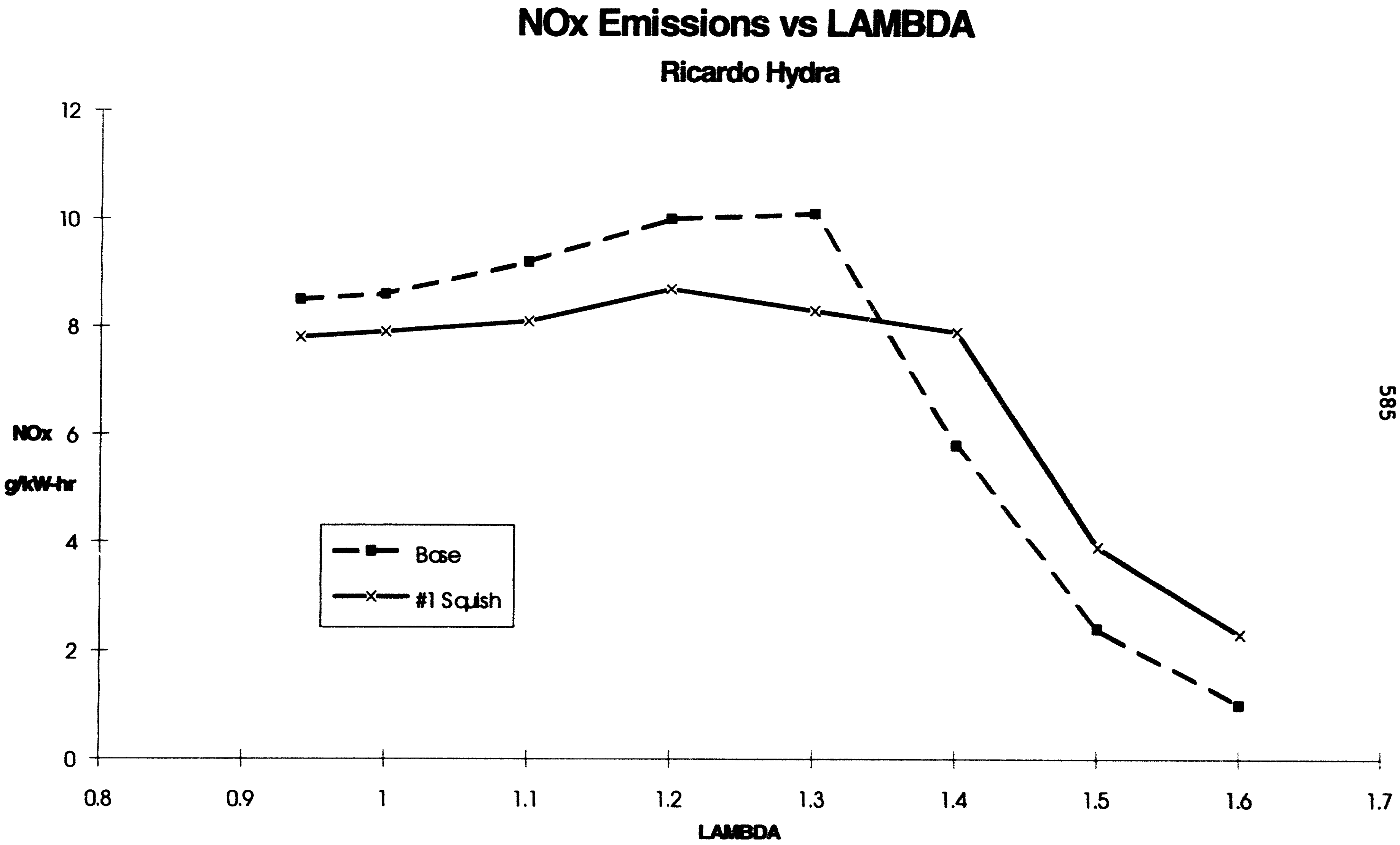
MBT vs LAMBDA

Ricardo Hydra




BSFC vs LAMBDA
Ricardo Hydra
■ Base
× #1 Squish
BSFC g/kW-hr
300
290
280
270
260
250
240
230
220
210
200
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
LAMBDA


THC Emissions vs LAMBDA
Ricardo Hydra
Base
#1 Squish
THC
g/kW-hr
0
5
10
15
20
25
30
35
40
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
LAMBDA

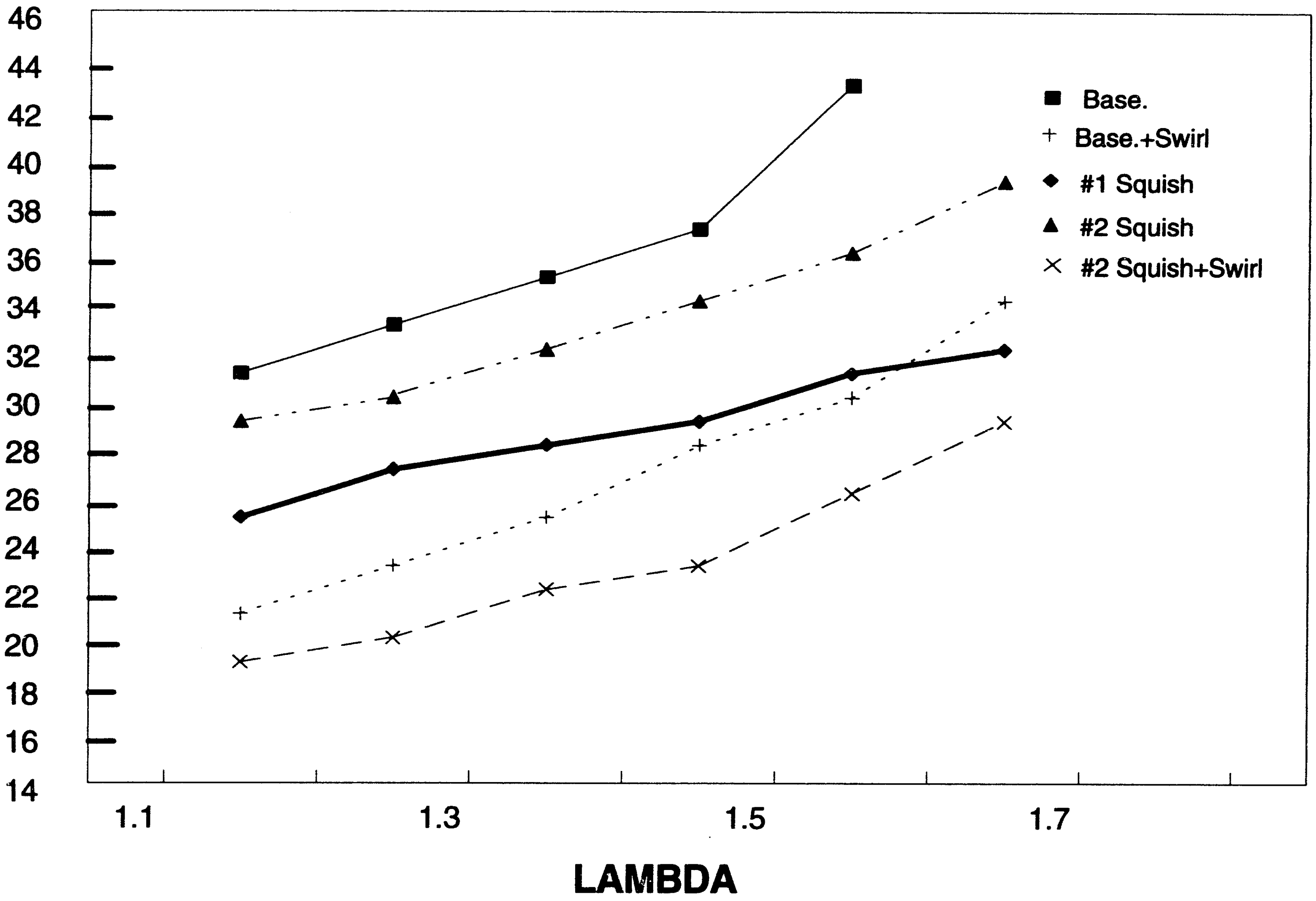

NOx Emissions vs LAMBDA
Ricardo Hydra
NOx
g/kW-hr
12
10
8
6
4
2
0
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
LAMBDA
Base
#1 Squish

Fast Burn Combustion Chamber Parameters

Engine Configurations	Swirl Ratio	Squish Ratio
Stock L10 240G	quiescent chamber	0.51
Stock L10 240G + swirl plates	2.5:1	0.51
#1 Squish	quiescent chamber	0.75
#2 Squish	not available	0.75
#2 Squish + swirl plates	not available	0.75

MBT vs. LAMBDA

Single Cylinder L10



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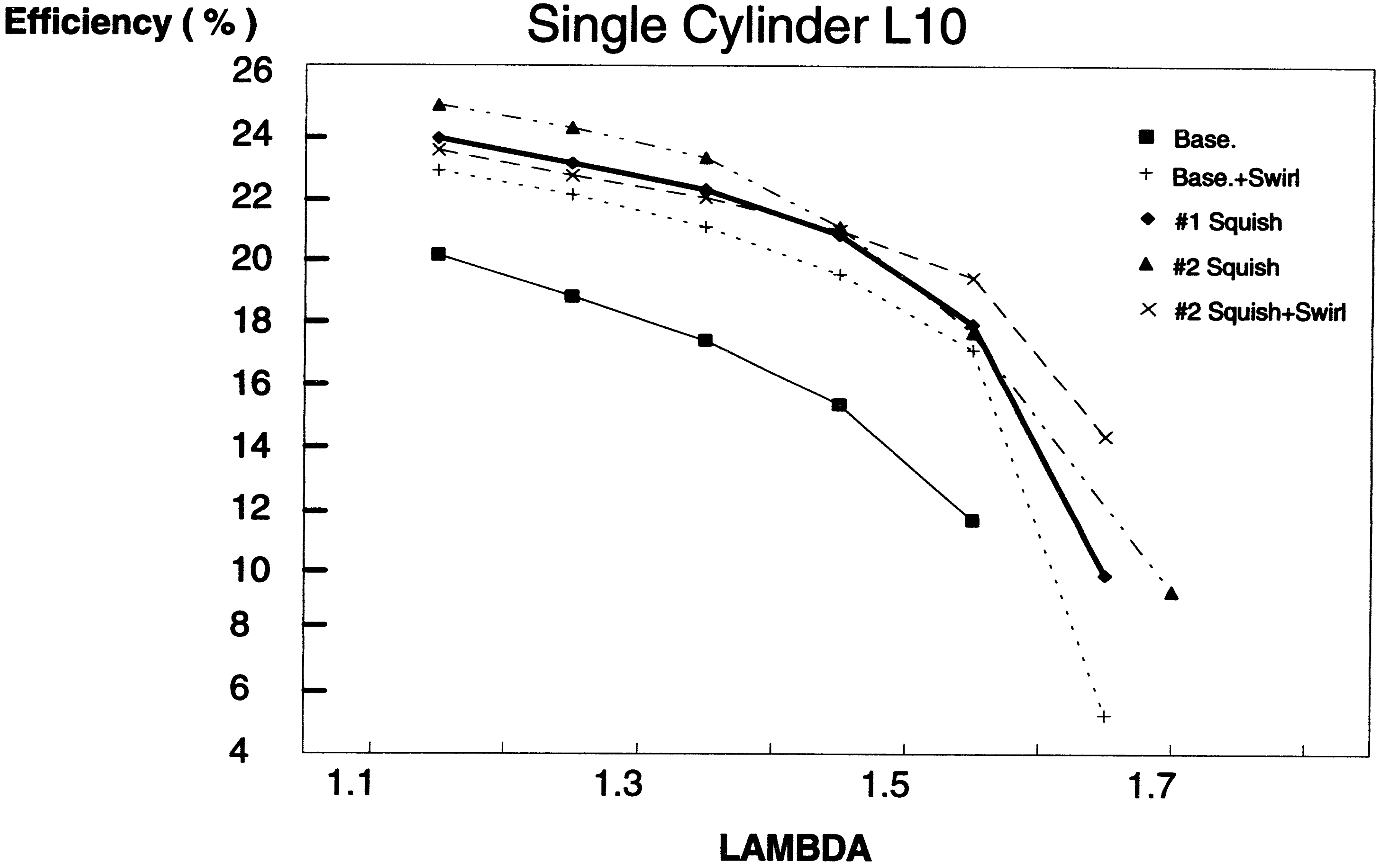
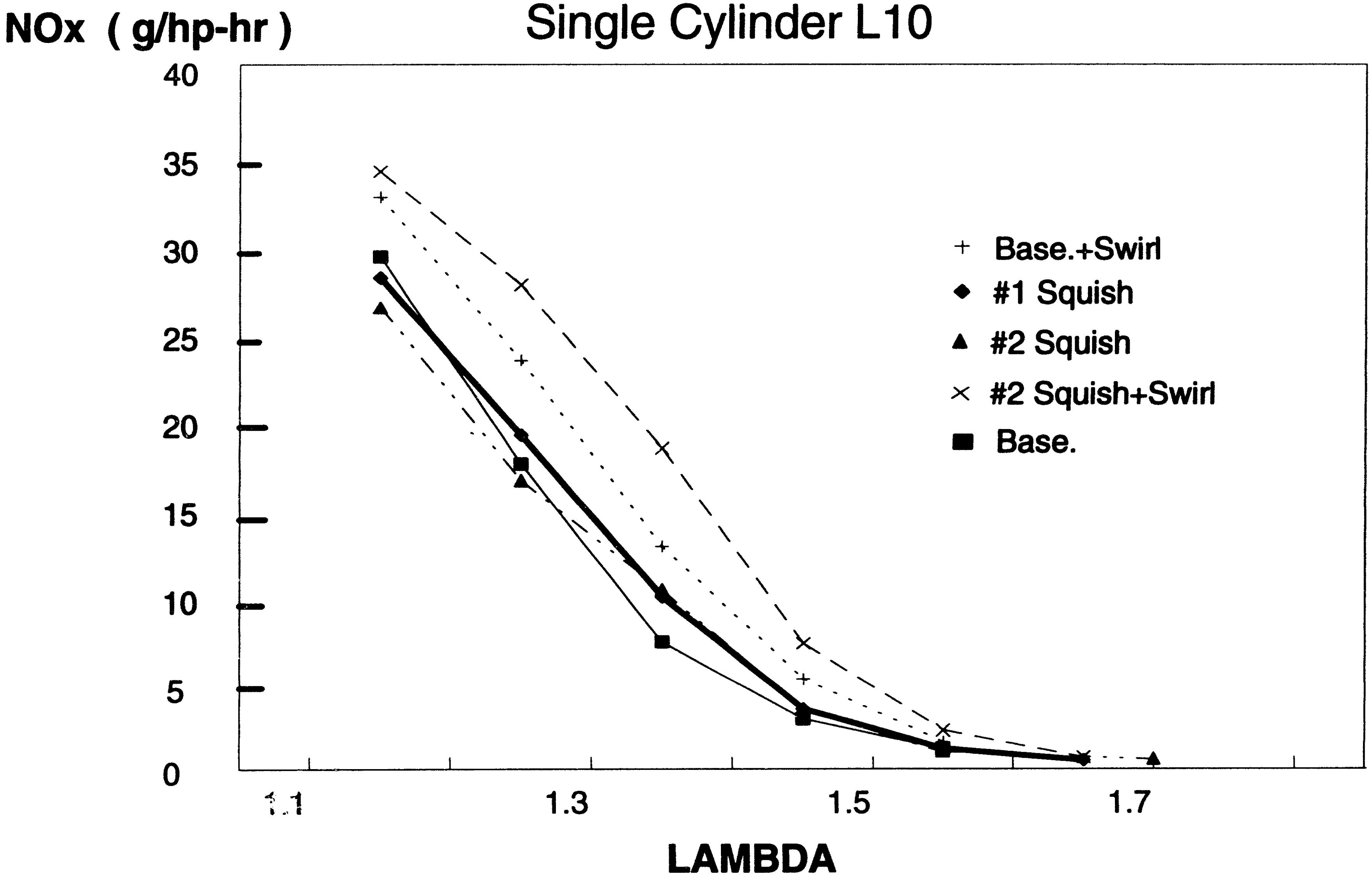
Efficiency vs. LAMBDA

Single Cylinder L10



NOx Emissions vs. LAMBDA

Single Cylinder L10



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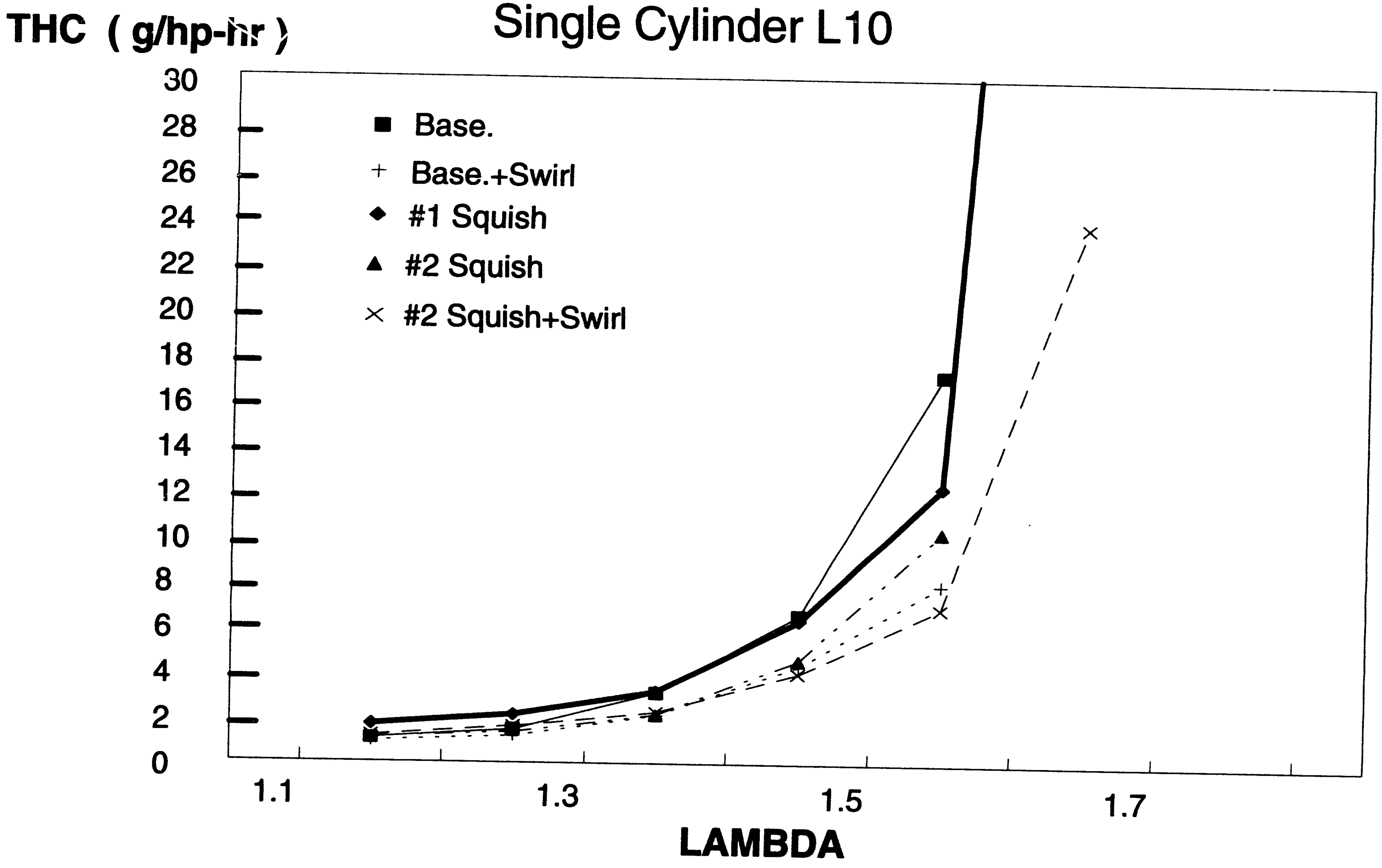
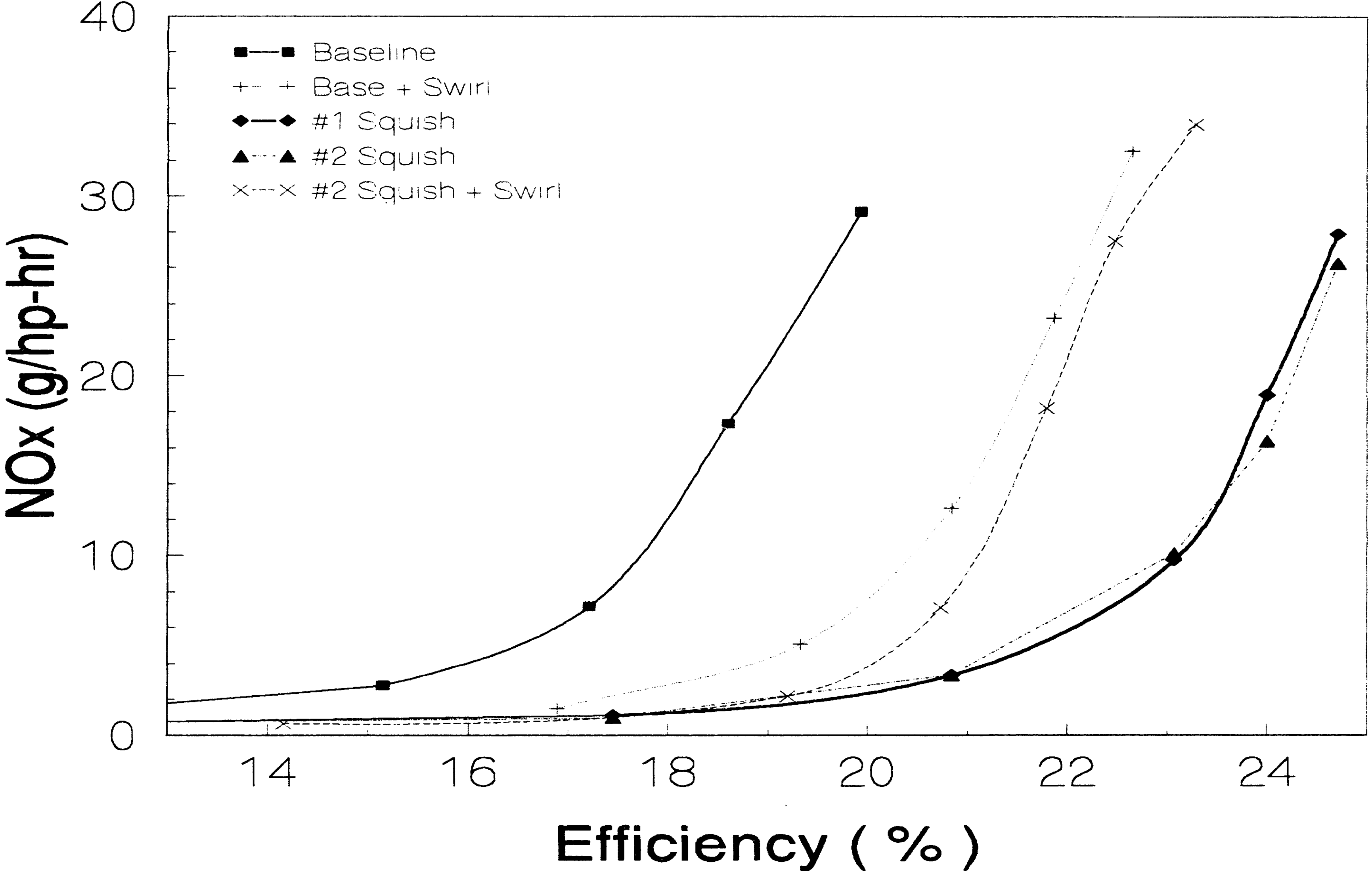
THC Emissions vs. LAMBDA

Single Cylinder L10



NOx vs. Effi. @ Various LAMBDA

2100 rpm, 120 kPa, MBT Timing



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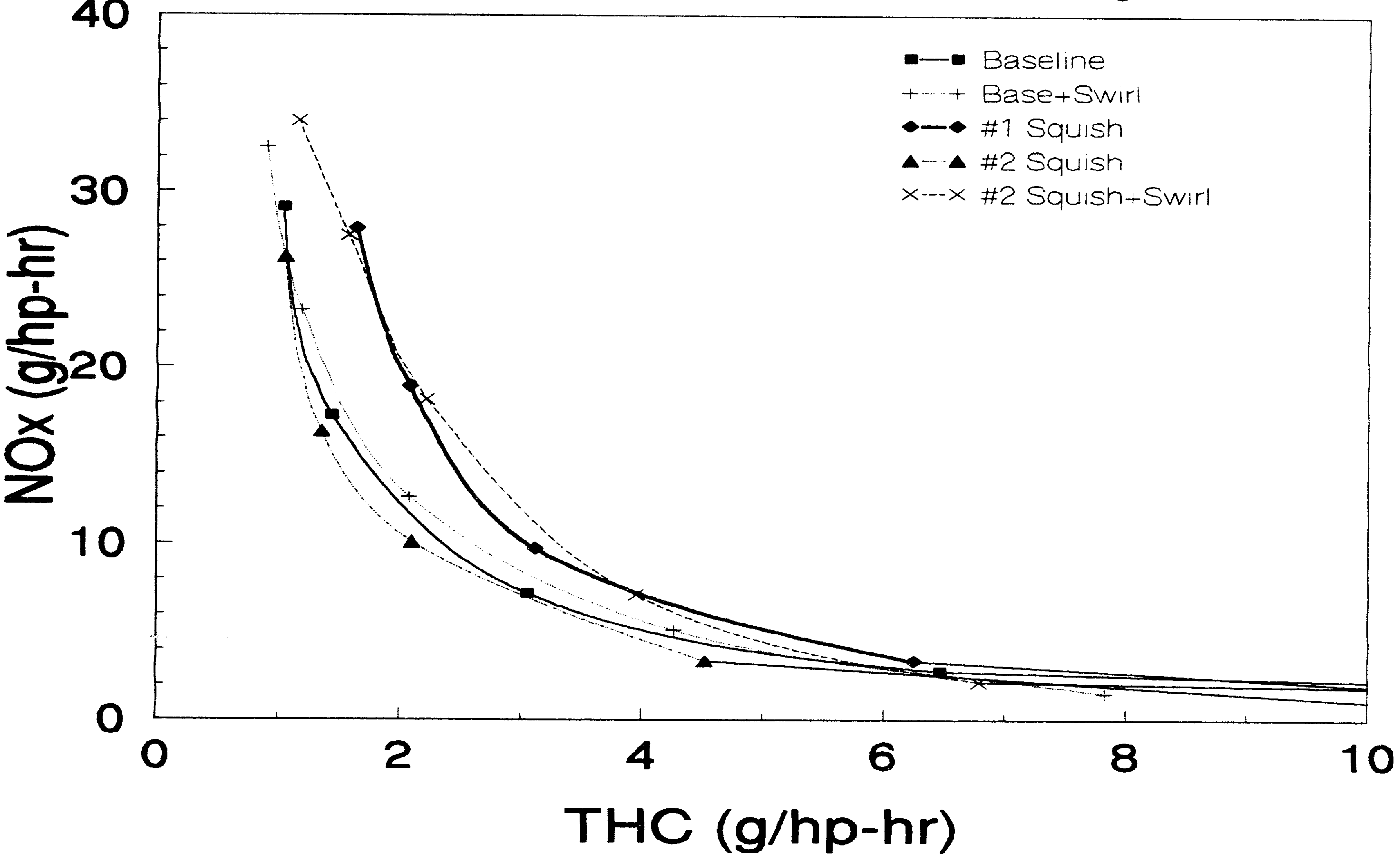
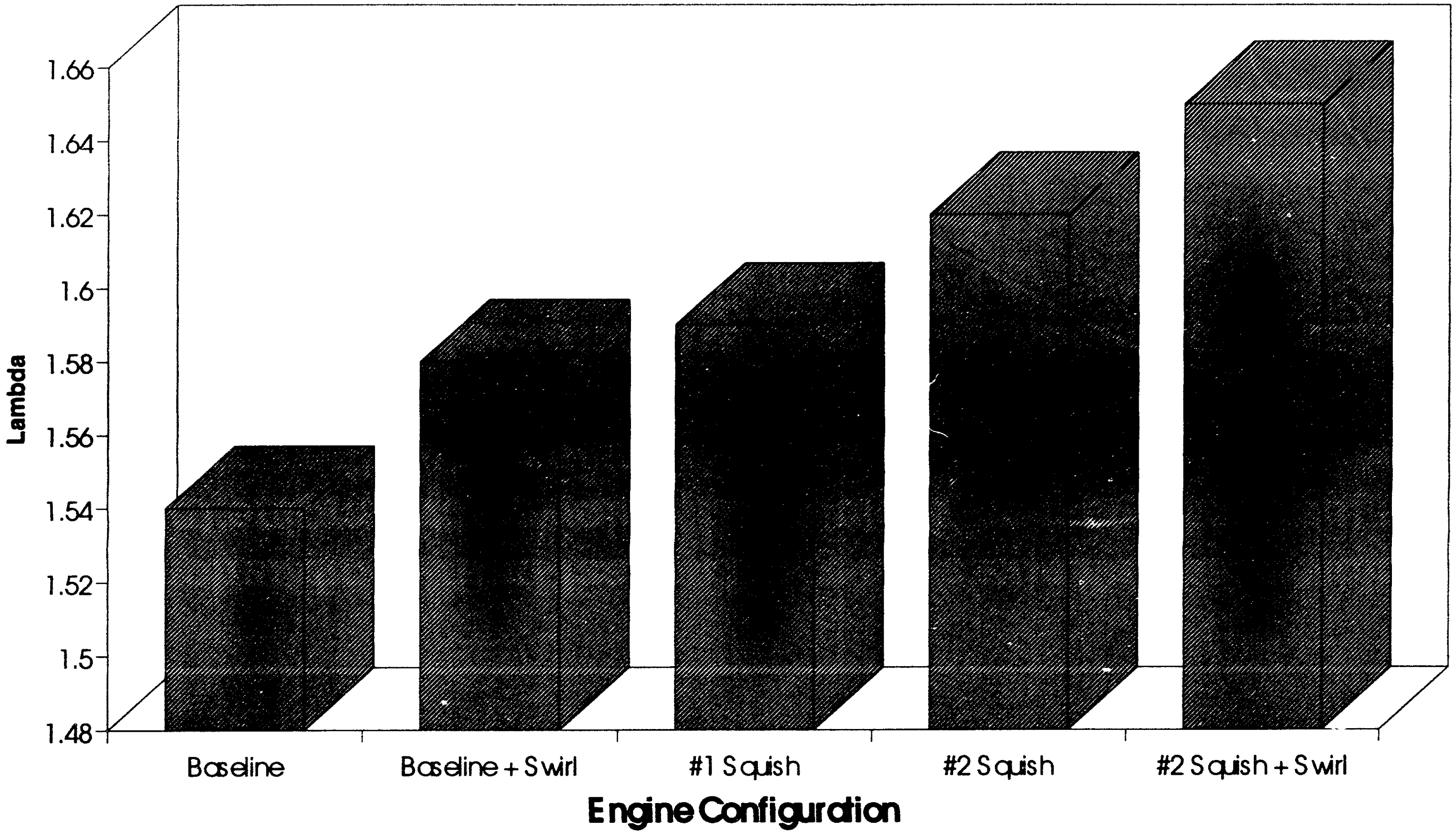
NOx vs. THC @ Various LAMBDA

2100 rpm, 120 kPa MAP, MBT Timing



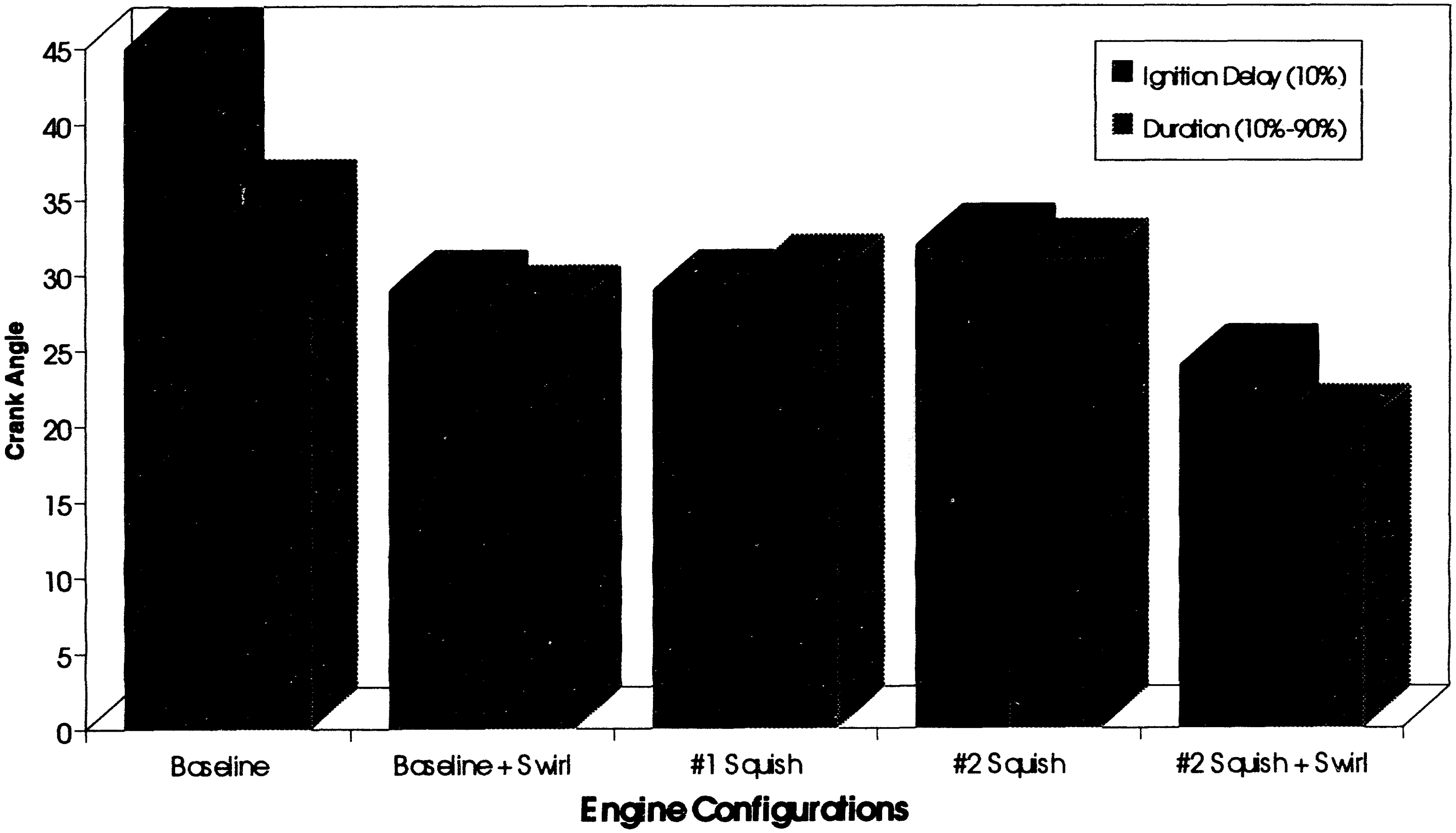
Lean Limit

2100 rpm, 180 kPa MAP, 21% efficiency



Ignition Delay & Combustion Duration

2100 rpm, 120 kPa MAP, 1.55 Lambda @ MBT



Single Cylinder Results

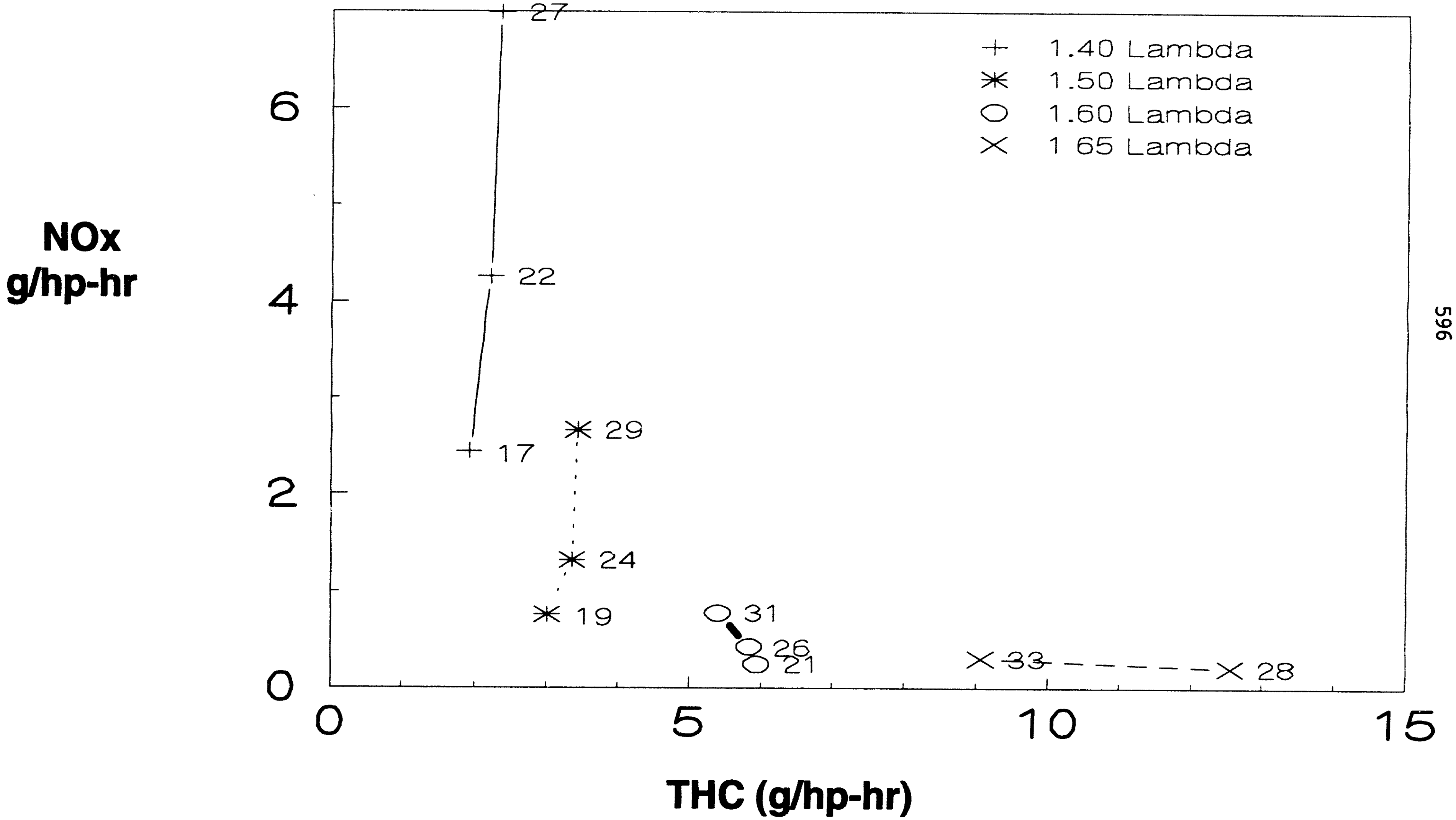
- Less advanced MBT spark timing

Reduced ignition delay

- Reduced combustion duration
- Extended Lean Limit
- Increased efficiency
- NO_x reduction through leaner operation and less spark advance
- Good correlation between the Ricardo Hydra and L10 single cylinder engine data

NOx vs. THC

Multi-cylinder L10



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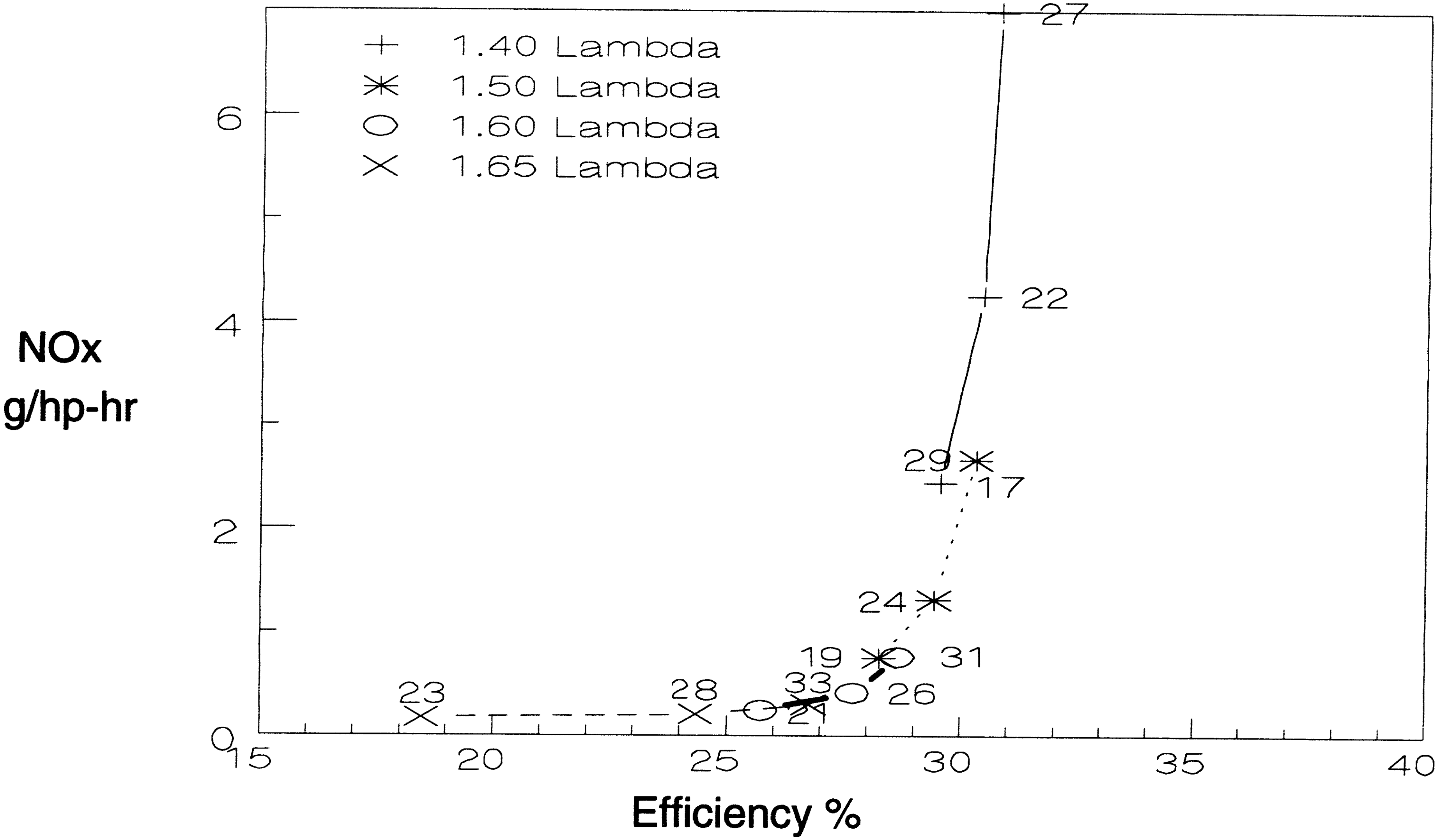
NOx vs. Efficiency

Multi-cylinder L10



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Multi-cylinder L10 Results

- THC is primarily a function of air/fuel ratio except near the lean flammability limit.
- The leaner the mixture, the greater the effect spark timing has on engine efficiency.
- NO_X is sensitive to spark timing at richer air/fuel ratios; at leaner air/fuel ratios, retarding spark timing is ineffective in NO_X reduction.
- The L10 was able to achieve 300 HP @ 2100 rpm and 250 psig BMEP.
- Two calibrations were developed (240 HP and 300 HP) and evaluated using a non-motoring transient test schedule.

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Emissions Summary

(g/hp-hr)	CO	NOx	NMHC	Part.
1994 CARB Standard (diesel derived engine)	15.5	5.0	1.2	0.10
Proposed 1994 EPA Standard	15.5	5.0	1.1	0.10
Fast Burn 300 hp without a catalyst (avg. non-motoring)	1.78	1.28	0.55	0.025
Fast Burn 240 hp without a catalyst (avg. non-motoring)	1.87	0.95	0.54	0.019

ORTECH

Conclusions

1. Fast burn combustion technology (squish and swirl) allowed the engine to operate up to 11% leaner, while maintaining the same efficiency.
2. Increased squish and swirl in the combustion chamber retarded the MBT timing.
3. NO_X can be reduced while maintaining efficiency and THC emission levels, through leaner mixtures and the retarded spark timing achieved by a combination of squish and swirl.

Conclusions

4. Leaner mixtures and reduced spark advance increased the knock margin of the engine, allowing the L10 to be operated at a higher BMEP

5. In-cylinder turbulence created by squish and swirl can improve efficiency by as much as 24%.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

EFFICIENCY VS EMISSIONS TRADEOFF WITH INCREASING COMPRESSION RATIO IN A LIGHT DUTY NATURAL GAS FUELED ENGINE

H.E. Jääskeläinen, J.S. Wallace
University of Toronto

Objective:

Comparative study between natural gas and gasoline fueling of an engine representative of current light duty vehicle, high specific output, design practice.

Nissan SR20DE Engine.

4 cylinder

1998 cc displacement

& 10:1 compression ratios
11.5:1

Pent roof combustion chamber with central spark plug,

DOHC, 4 valves/cylinder

Fueling Systems

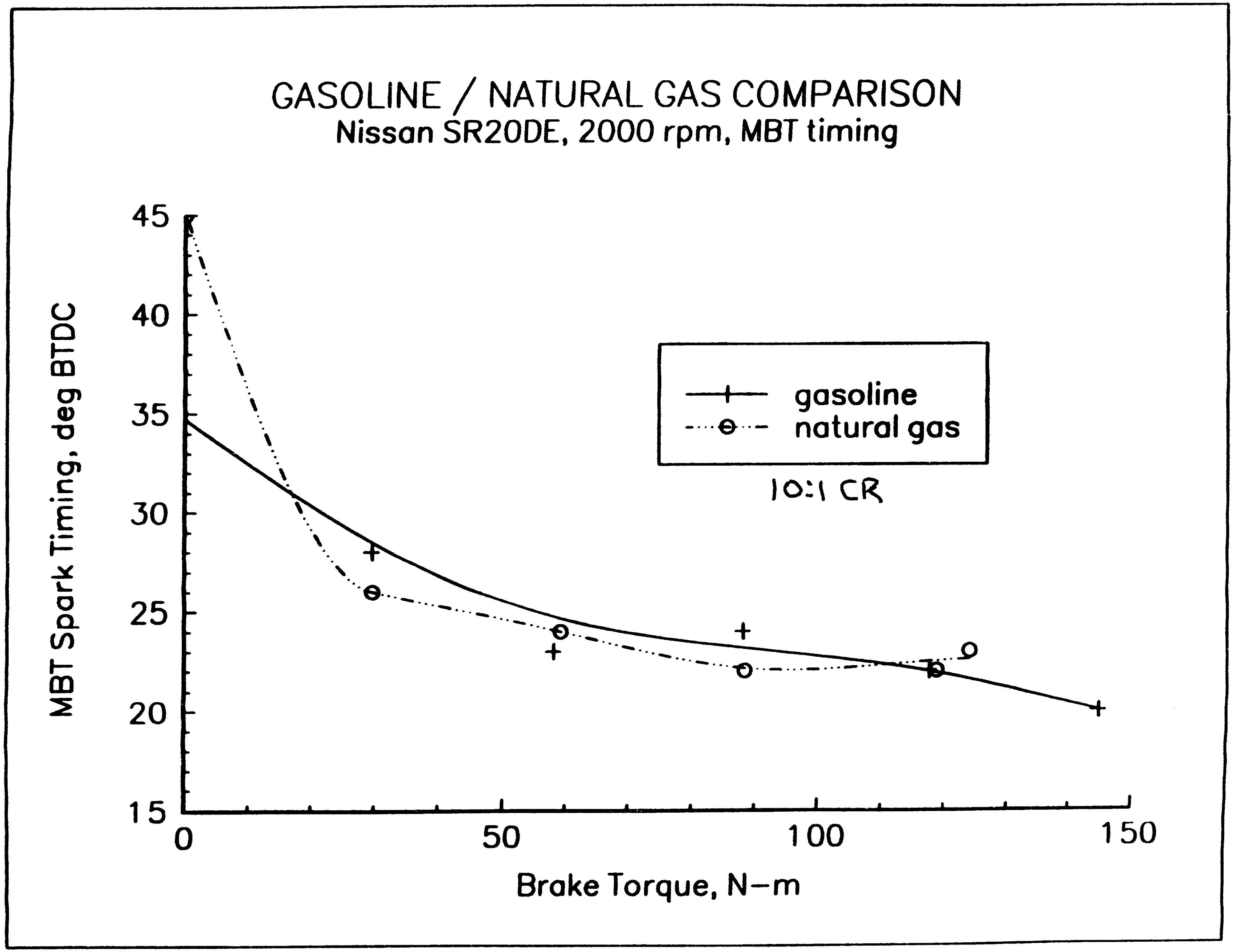
Gasoline:

closed-loop, sequential, port fuel injection.

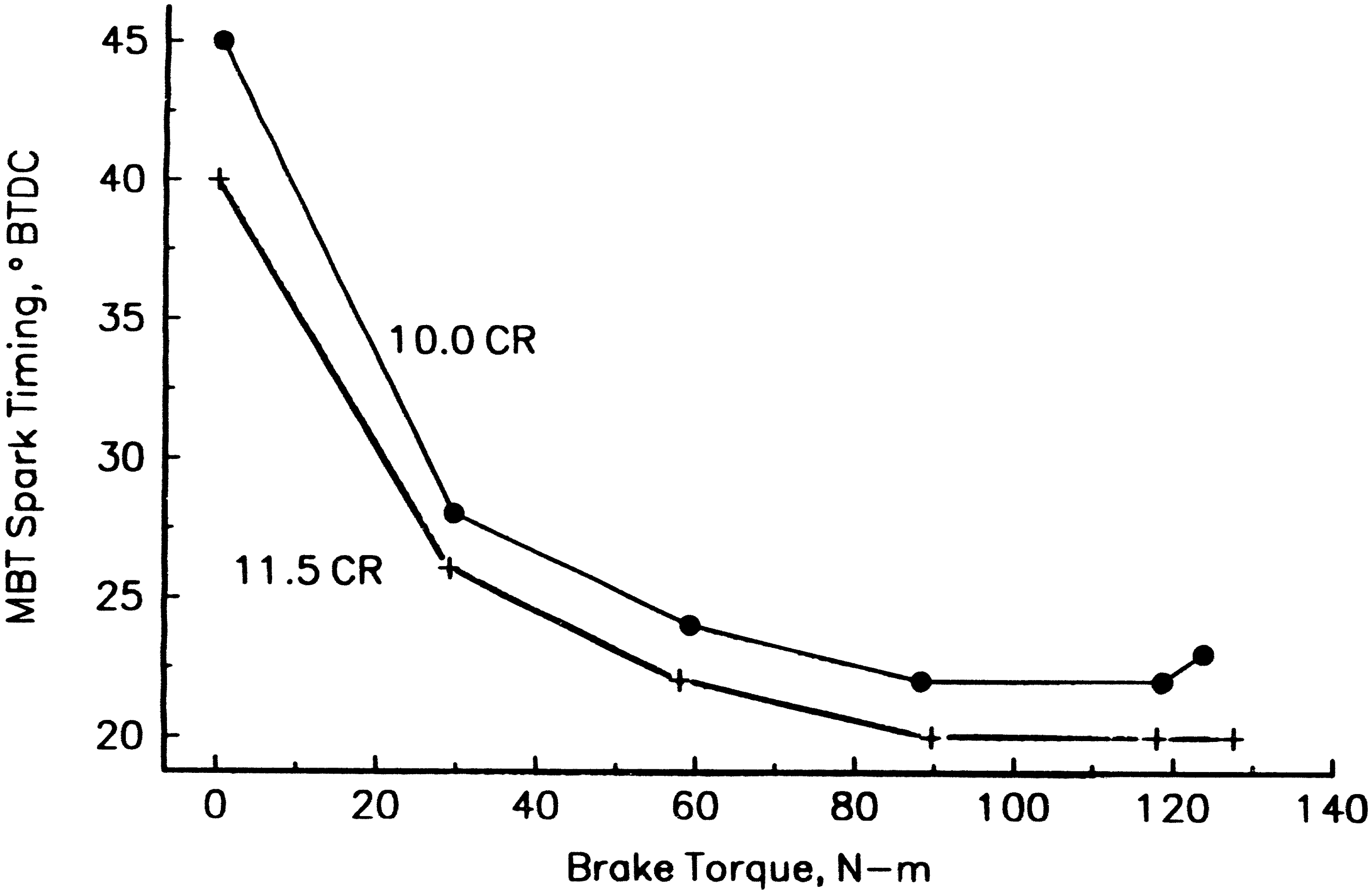
Natural Gas: Aftermarket

closed-loop carburetion, air valve type mixer.

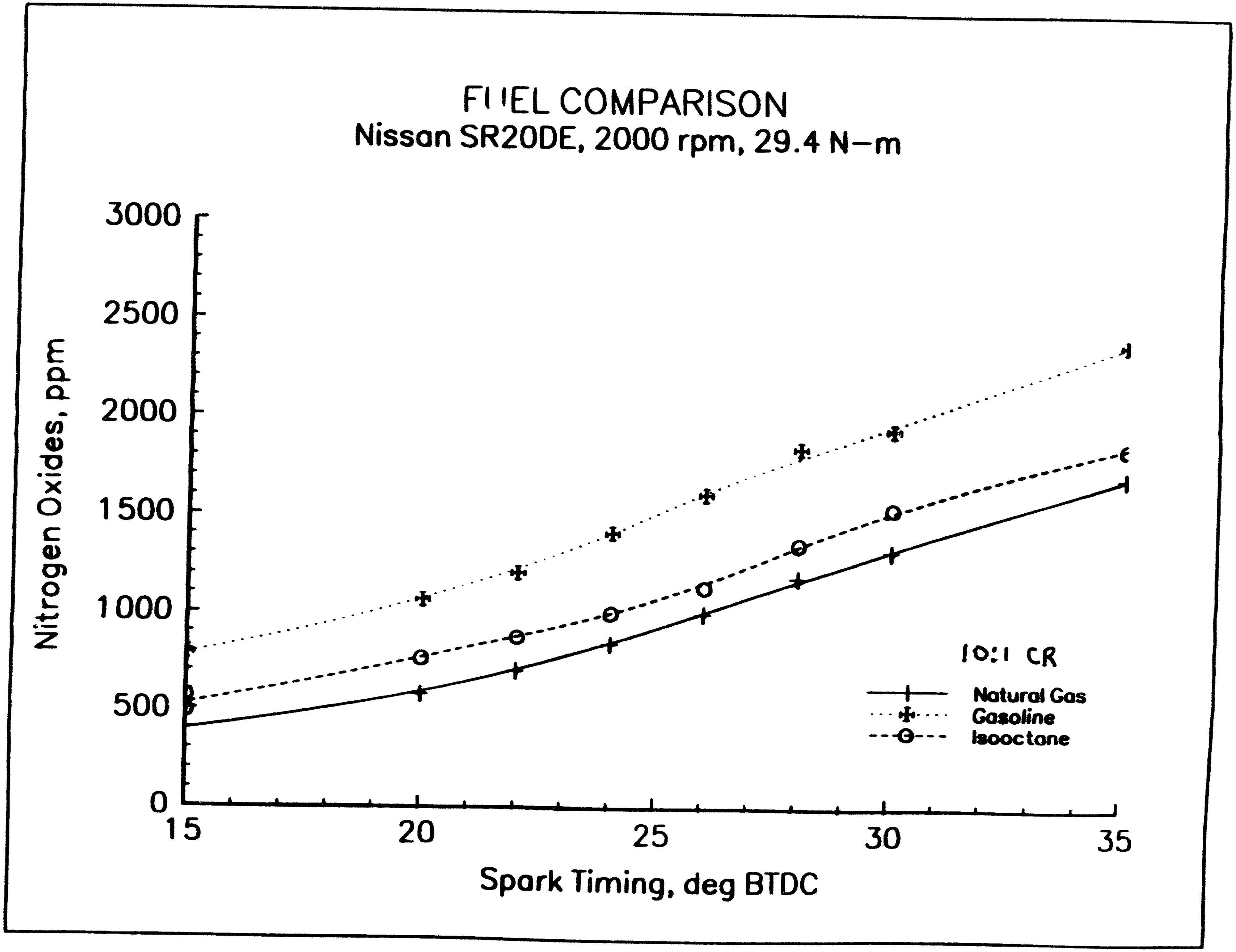
venturi type mixer was used for WOT.


GASOLINE / NATURAL GAS COMPARISON
Nissan SR20DE, 2000 rpm, MBT timing
MBT Spark Timing, deg BTDC
45
40
35
30
25
20
15
0
50
100
150
Brake Torque, N–m
gasoline
natural gas
10:1 CR

Little difference in spark advance due to the dominating effect of fluid dynamics on the combustion process.



EFFECT OF COMPRESSION RATIO
Nissan SR20DE, natural gas, 2000 rpm


FUEL COMPARISON
Nissan SR20DE, 2000 rpm, 29.4 N-m
Nitrogen Oxides, ppm
3000
2500
2000
1500
1000
500
0
15
20
25
30
35
Spark Timing, deg BTDC
10:1 CR
Natural Gas
Gasoline
Isooctane

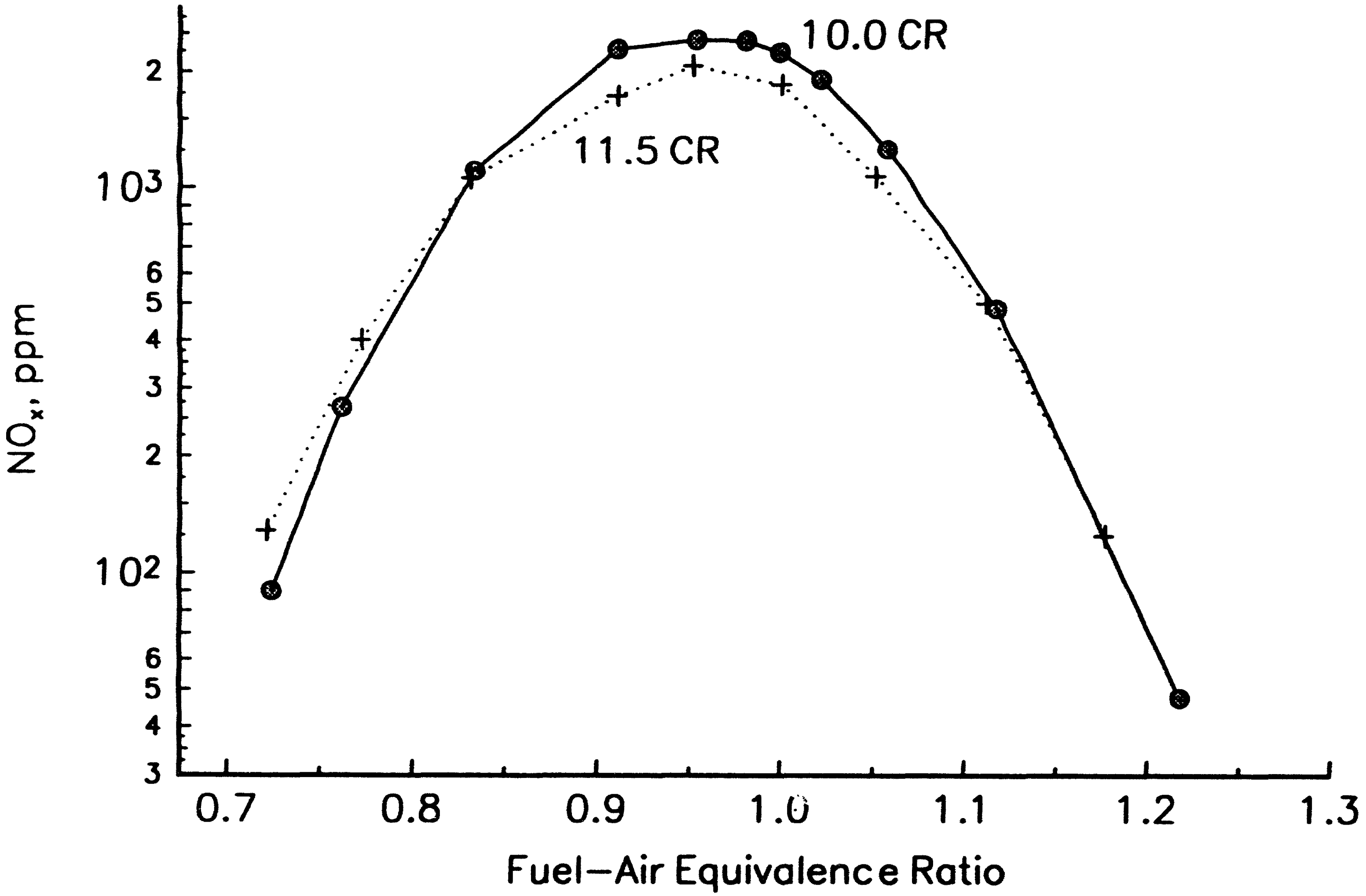
For similar spark timing, the lower flame temperature of natural gas produces less NO_x.

Adiabatic Flame Temperatures in Air:

Methane	2236 K
Isoocatne	2302 K
Benzene	2365 K

Effect of Compression Ratio

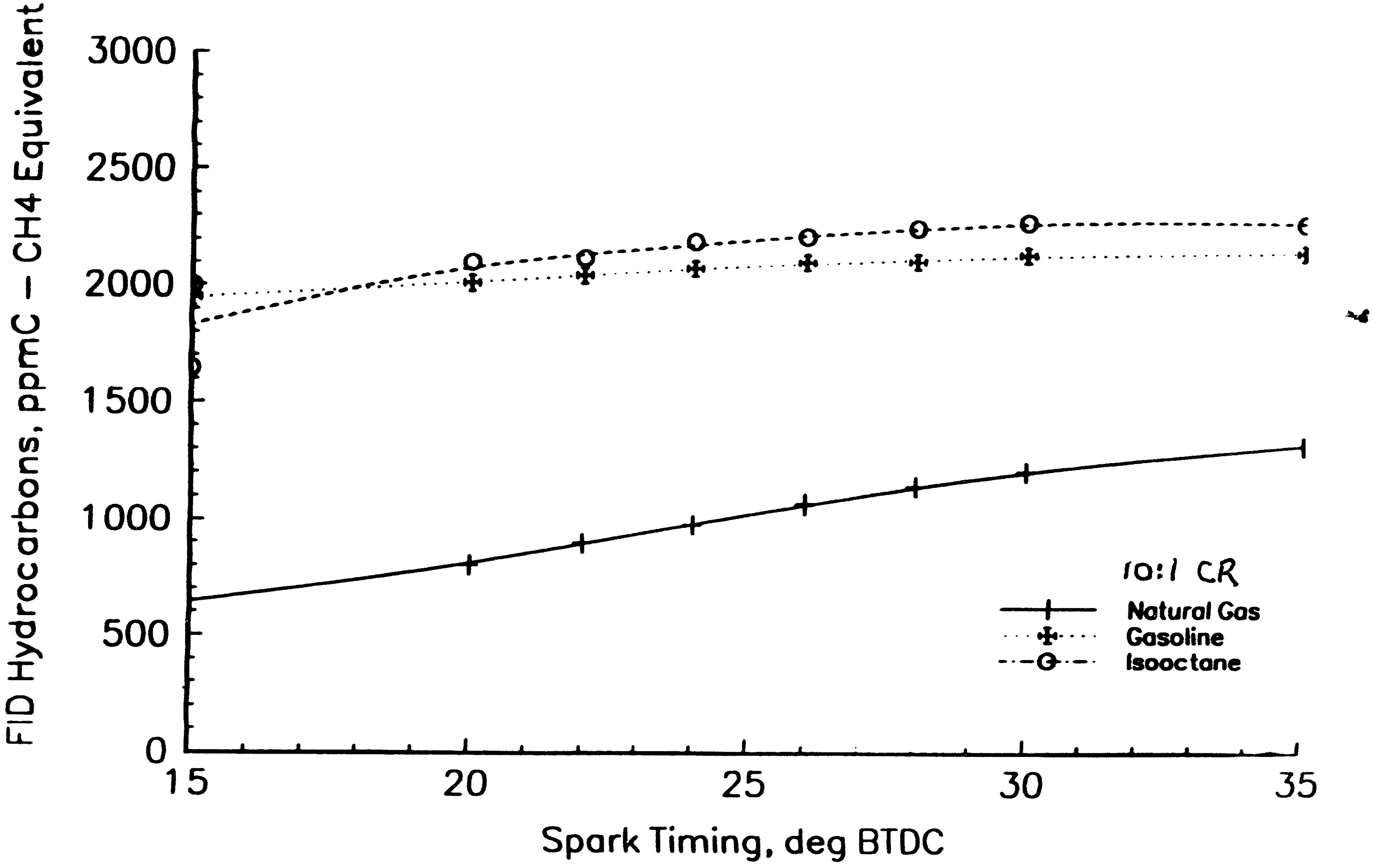
Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N–m



Spark advance held constant at stoichiometric MBT

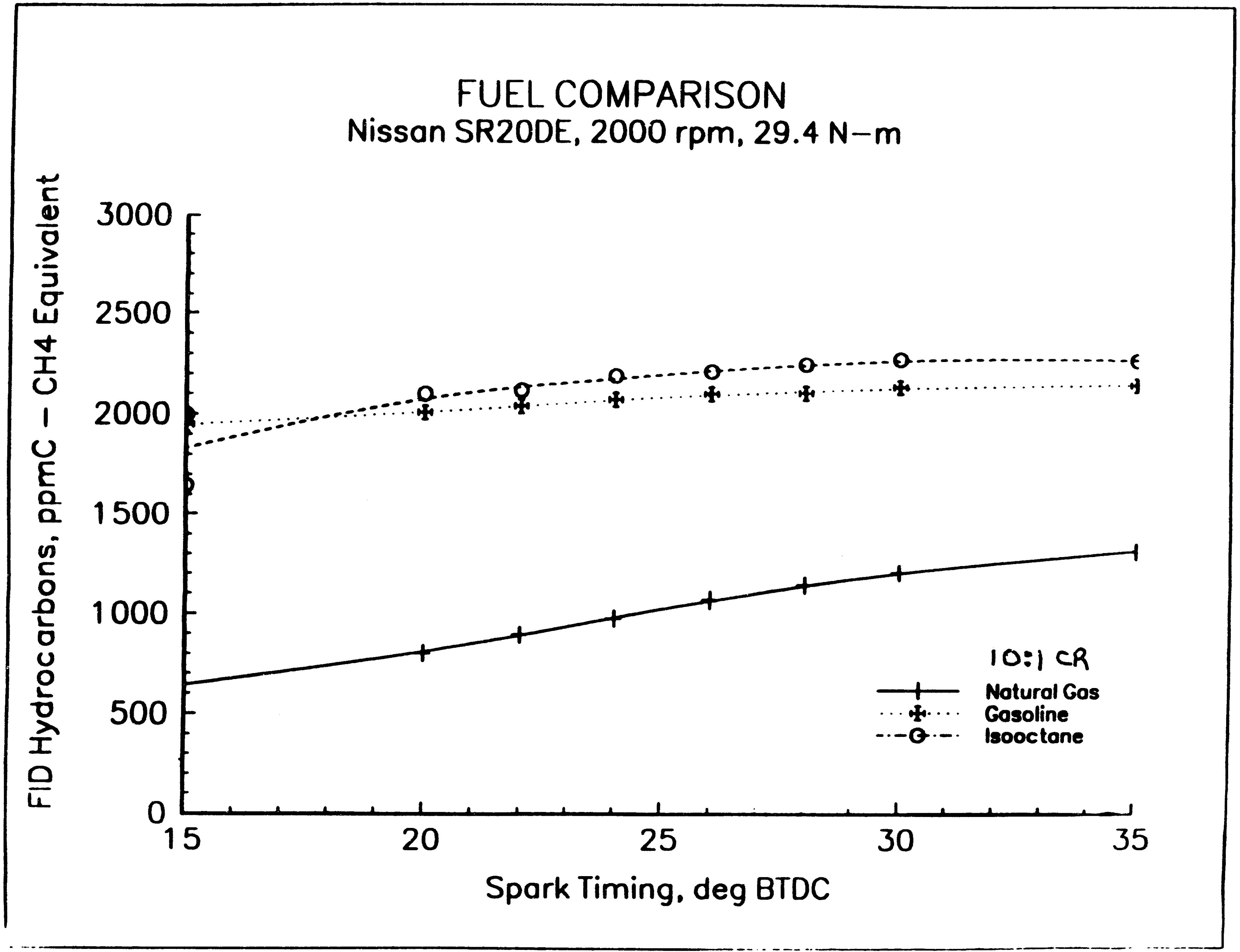
FUEL COMPARISON

Nissan SR20DE, 2000 rpm, 29.4 N–m



Sources of Hydrocarbon Emissions:

1. Crevices.
   - dependent on spark timing
   - dependent on fuel type
2. Oil layer
   - independent of spark timing
   - dependent on fuel type
   - enhanced by liquid fuel



FUEL COMPARISON

Nissan SR20DE, 2000 rpm, 29.4 N–m

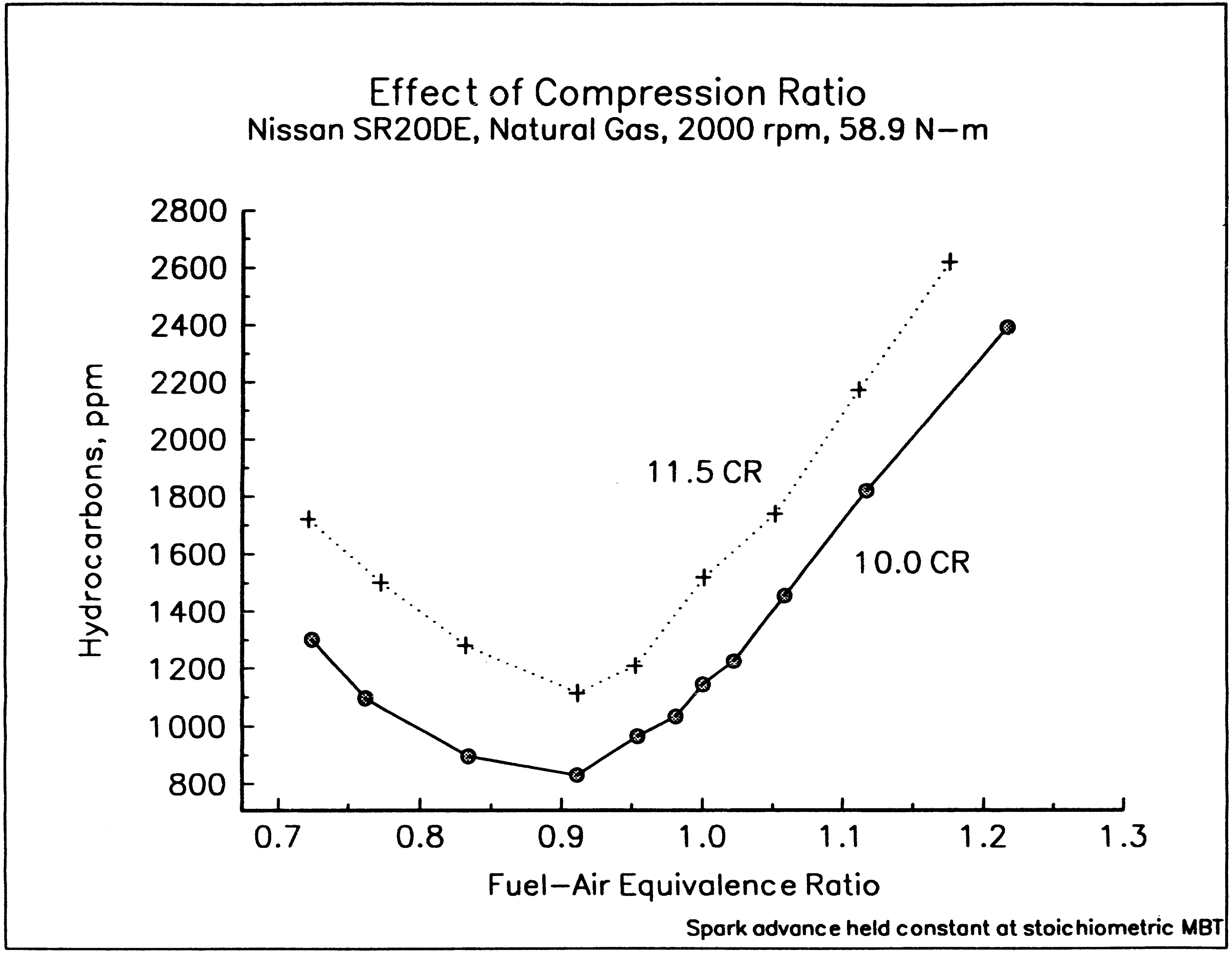
Gasoline Hydrocarbon Sources:

1. Crevices.
2. Oil layer.

Natural Gas Hydrocarbon Sources:

Oil layer mechanism virtually eliminated because of low solubility of methane in oil.

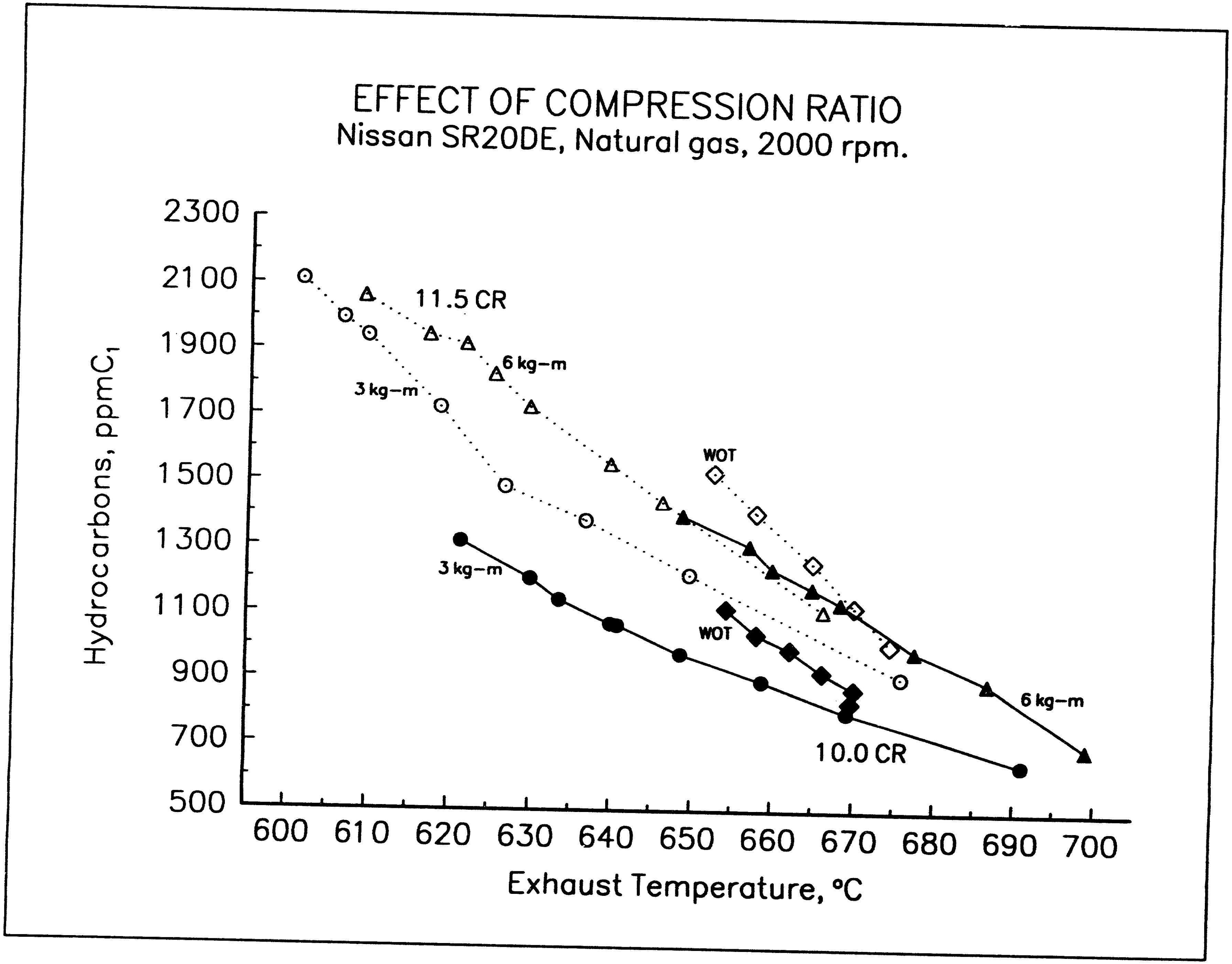
1. Crevices.



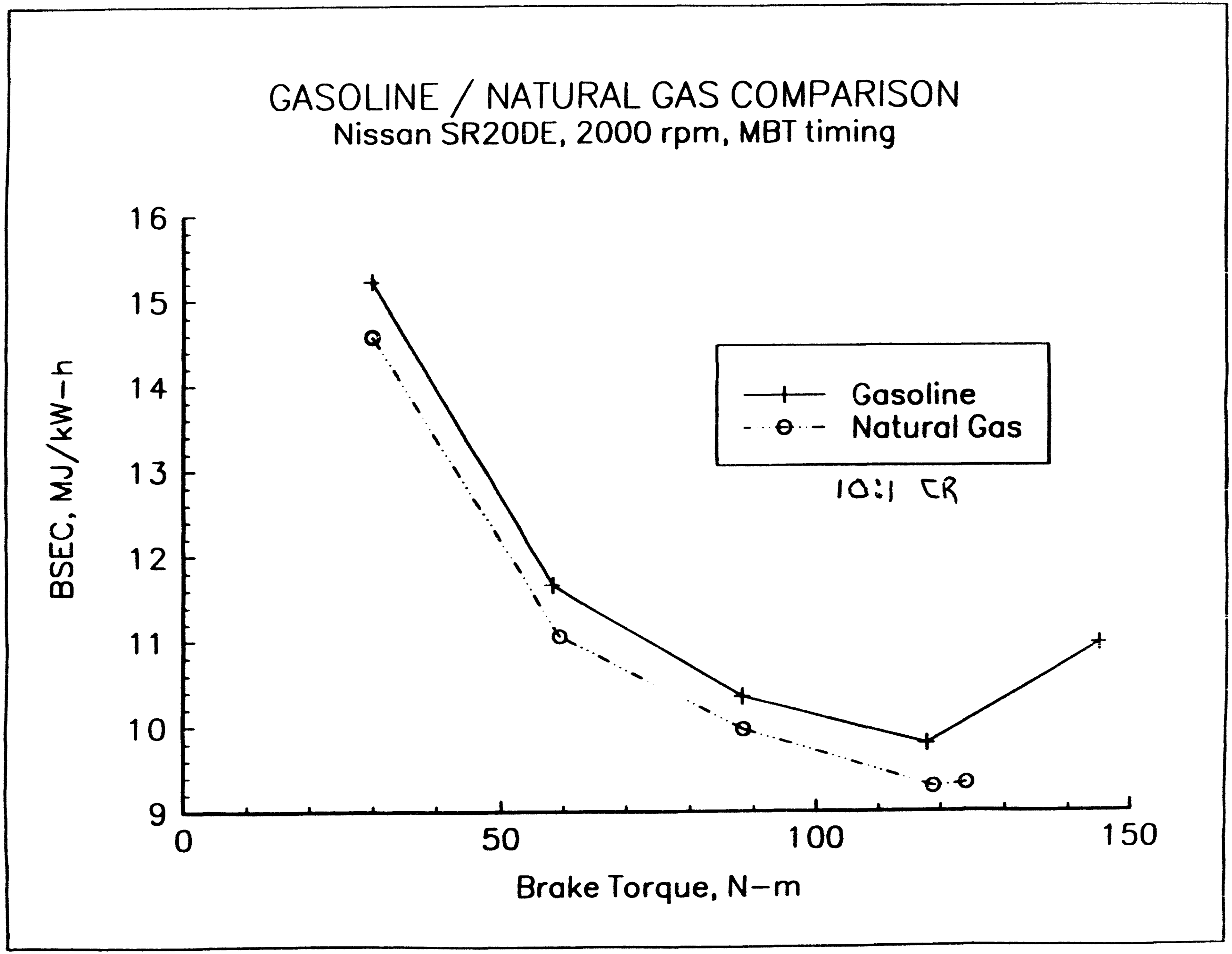
Effect of Compression Ratio

Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N–m

Spark advance held constant at stoichiometric MBT

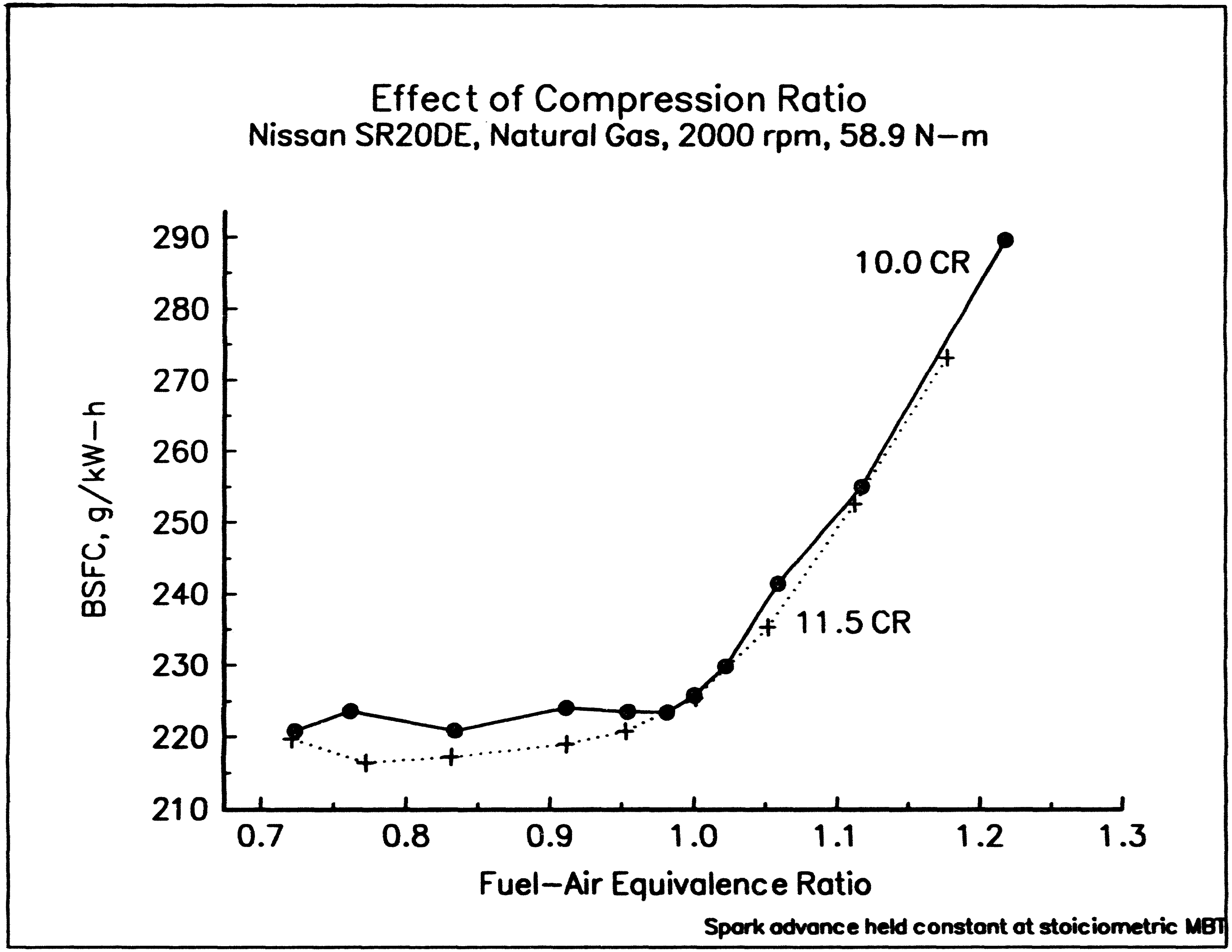


EFFECT OF COMPRESSION RATIO
Nissan SR20DE, Natural gas, 2000 rpm.


GASOLINE / NATURAL GAS COMPARISON
Nissan SR20DE, 2000 rpm, MBT timing
BSEC, MJ/kW-h
16
15
14
13
12
11
10
9
0
50
100
150
Brake Torque, N-m
Gasoline
Natural Gas
10:1 CR

Improved efficiency with natural gas:

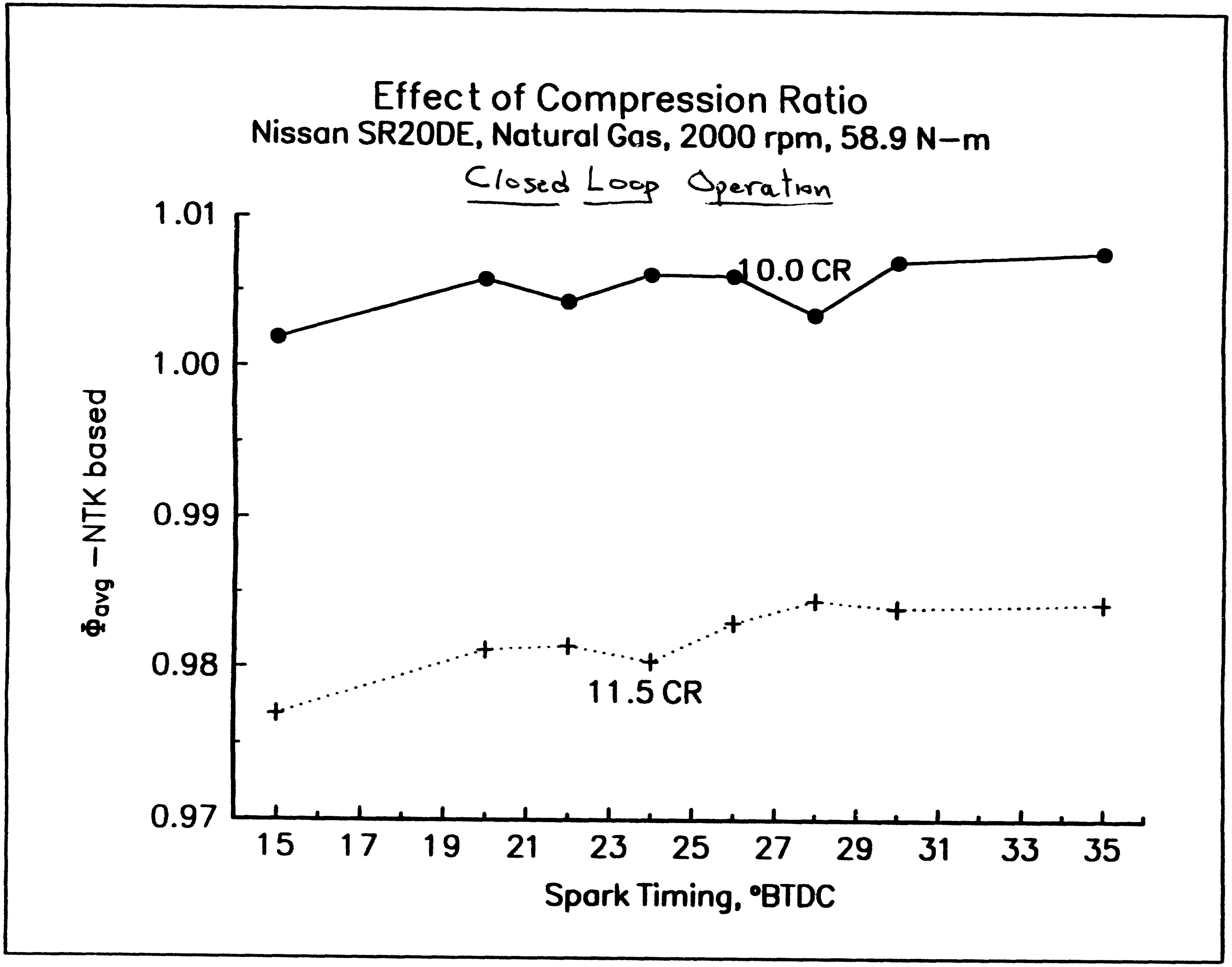
- combustion product composition increases ratio of specific heats.
- lower emissions of HC and CO carry away less energy.
- lower temperatures and heat losses.

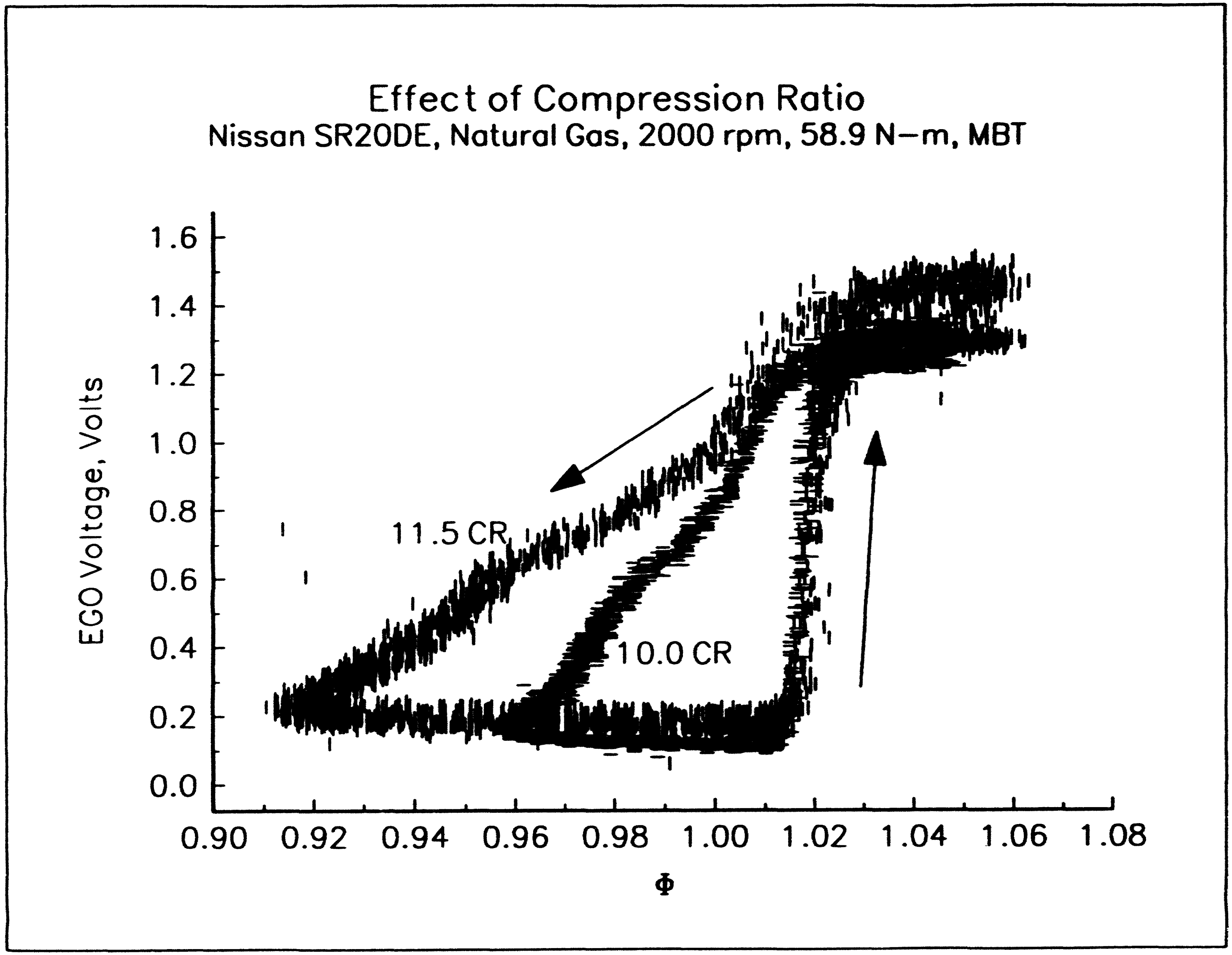


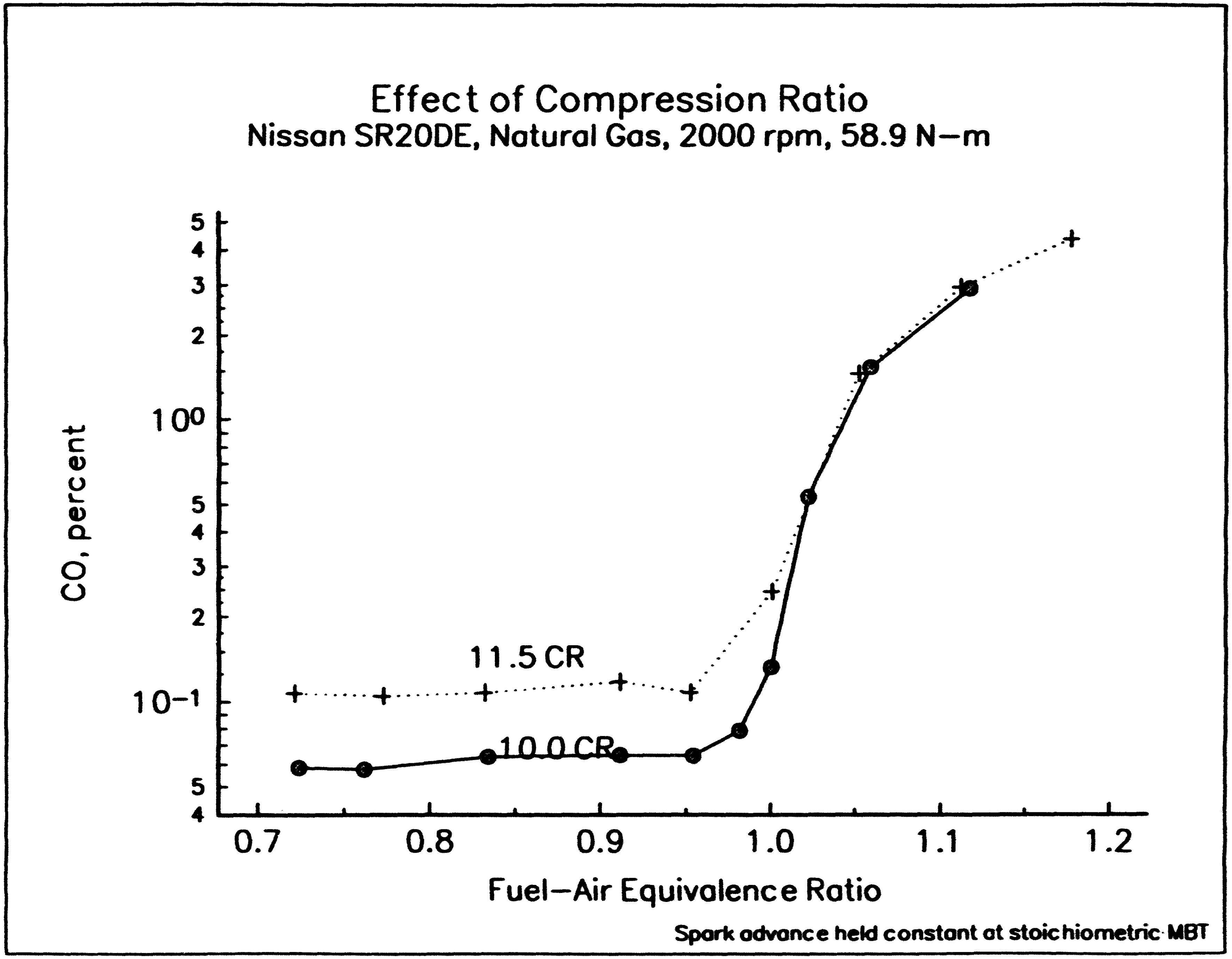
Effect of Compression Ratio

Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N−m

Spark advance held constant at stoiciometric MBT


Effect of Compression Ratio
Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N-m
Closed Loop Operation
1.01
1.00
0.99
0.98
0.97
Φ_{avg} -NTK based
10.0 CR
11.5 CR
15
17
19
21
23
25
27
29
31
33
35
Spark Timing, °BTDC


Effect of Compression Ratio
Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N−m, MBT


Effect of Compression Ratio

Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N−m

Spark advance held constant at stoichiometric MBT

WOT Torque Comparison.

fuel	CR	torque	ϕ	spark timing	percent of 10.0 CR gasoline torque
2000 rpm					
gasoline	10.0	149.5 N-m	1.16	20° BTDC	-
natural gas	10.0	130.0 N-m	1.05	23° BTDC	87.0
natural gas	11.5	134.2 N-m	1.05	20° BTDC	89.9
4800 rpm					
gasoline	10.0	167.7 N-m	1.18	23° BTDC	-
natural gas	10.0	142.4 N-m	1.06	23° BTDC	84.9
natural gas	11.5	147.0 N-m	1.05	18° BTDC	87.7

CONCLUSIONS

Increasing compression ratio yields:

- Higher hydrocarbon emissions because of reduced oxidation late in the expansion stroke.

- Less spark advance required for MBT timing

- At MBT spark timing, NOx emissions with 11.5:1 compression ratio are less than or equal to NOx emissions at 10.0:1 compression ratio.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support of:

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Ontario University Research Incentive Fund.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

EFFICIENCY VS. EMISSIONS TRADEOFF WITH INCREASING COMPRESSION RATIO IN A LIGHT DUTY NATURAL GAS-FUELED ENGINE

Hannu E. Jaaseklainen and James S. Wallace, University of Toronto

Q. William Liss, Gas Research Institute: Would it be feasible to advance the spark timing in order to regain some of the power lost by converting from gasoline to natural gas?

A. Yes, that would increase power, but it would also adversely affect the NOx emission.

Q. Question inaudible.

A. I think we had 3 to 6 percent better energy consumption by changing from gasoline to natural gas.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

EXHAUST EMISSIONS AND FUEL ECONOMY OF TRANSIT BUSES - CHASSIS DYNAMOMETER TEST RESULTS

T. Topaloglu
Ministry of Transportation of Ontario

Exhaust Emissions and Fuel Economy of Transit Buses – Chassis Dynamometer Test Results

Presented to the
1993 Windsor Workshop
on Alternative Fuels

Presenter: Dr. Toros Topaloglu

Contributors: O. Colavincenzo, D. Elliott, J. Turner,
D. Petherick, C. Kaskavaltzis
(Min. of Transportation)
C. Prakash And G. Rideout
(Environment Canada)

ONTARIO
Ministry
of
Transportation

Transportation
Technology and
Energy Branch

June, 1993

PURPOSE

To inform the 1993 Windsor Workshop attendees of recent measurements of the exhaust emissions and fuel economy characteristics of CNG, Methanol, and Diesel (with and without particulate traps) powered transit buses.

BACKGROUND

- Ontario transit systems are demonstrating:
  - CNG (75 buses in Hamilton, Toronto, and Mississauga)
  - Methanol (6 buses in Windsor)
  - Diesel (8 buses in Ottawa)
    particulate traps
- The Ministry of Transportation of Ontario is the overall coordinator of the program

Ontario TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

BACKGROUND (cont'd)

- The program enjoys the enthusiastic participation of:
    - Energy, Mines, and Resources Canada
    - Environment Canada
    - Ministry of Environment and Energy Ontario
    - Bus, engine, and component suppliers
    - Fuel and fuelling system suppliers
    - Industry associations
- The program includes a chassis dynamometer exhaust emissions and fuel economy test component which is being conducted at Environment Canada

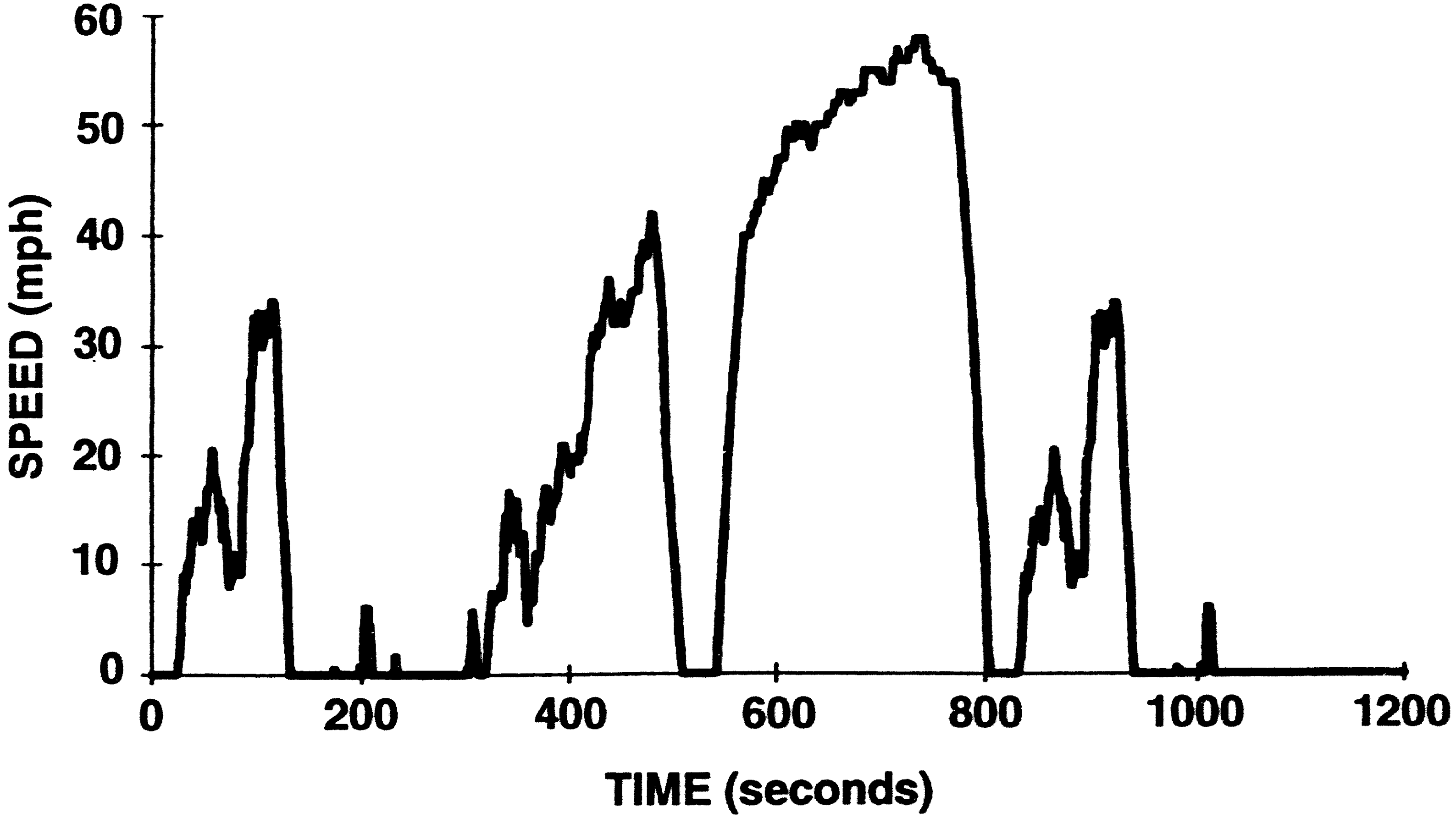
SCOPE OF TEST PROGRAM

- Test buses representative of each new technology and compare them with corresponding baseline diesels under "identical" conditions
- Repeat testing over a substantial portion of useful bus life to assess long-term performance
- Measure exhaust emissions of:

– Particulate matter	(PM)	– Carbon dioxide	(CO_2)
– Oxides of nitrogen	(NO_x)	– Formaldehyde	(HCOH)
– Carbon monoxide	(CO)	– Corbonyls	(RCOH)
– Hydrocarbons	(HC)		

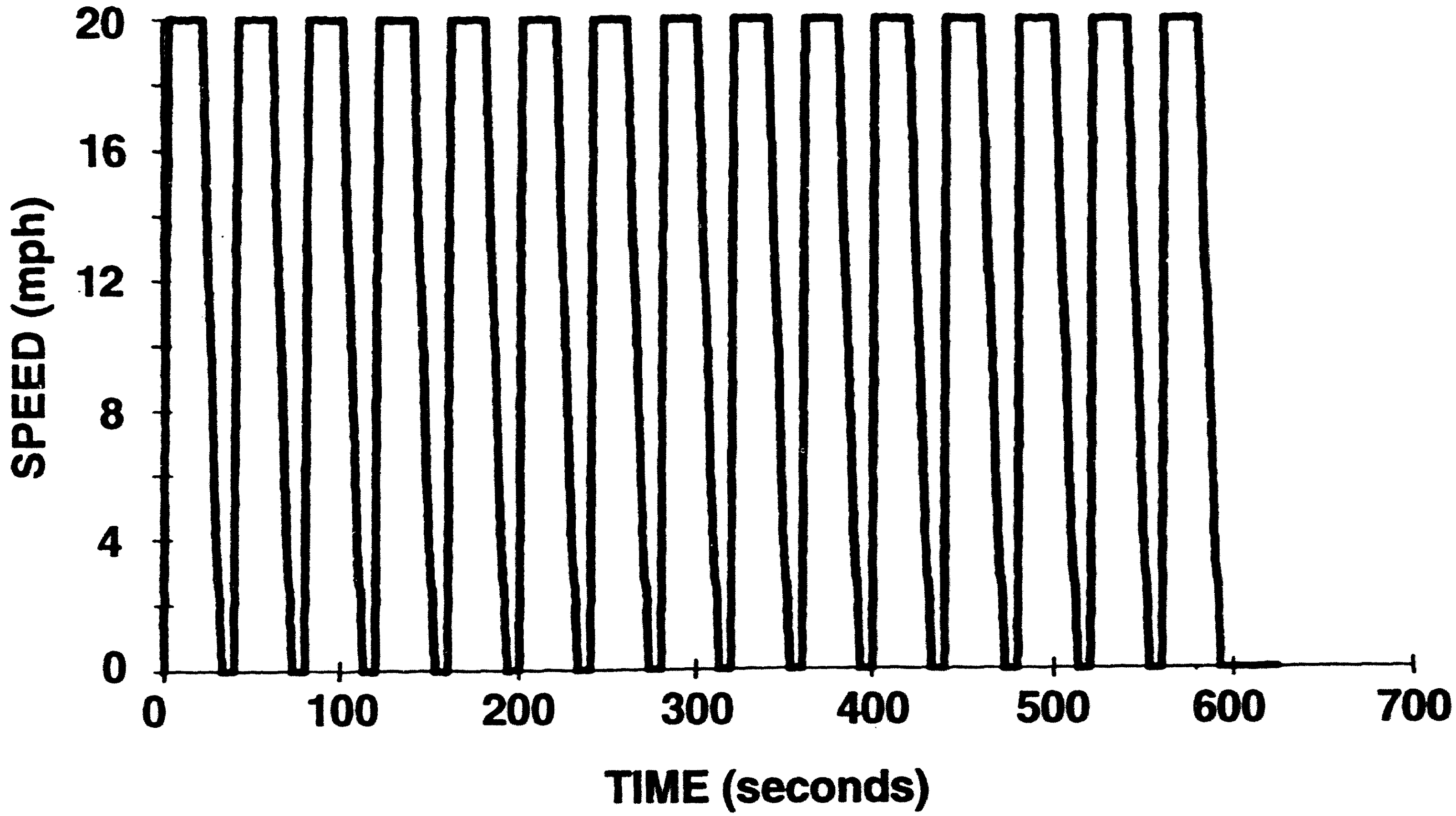
Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

EPA HEAVY-DUTY CHASSIS TRANSIENT CYCLE



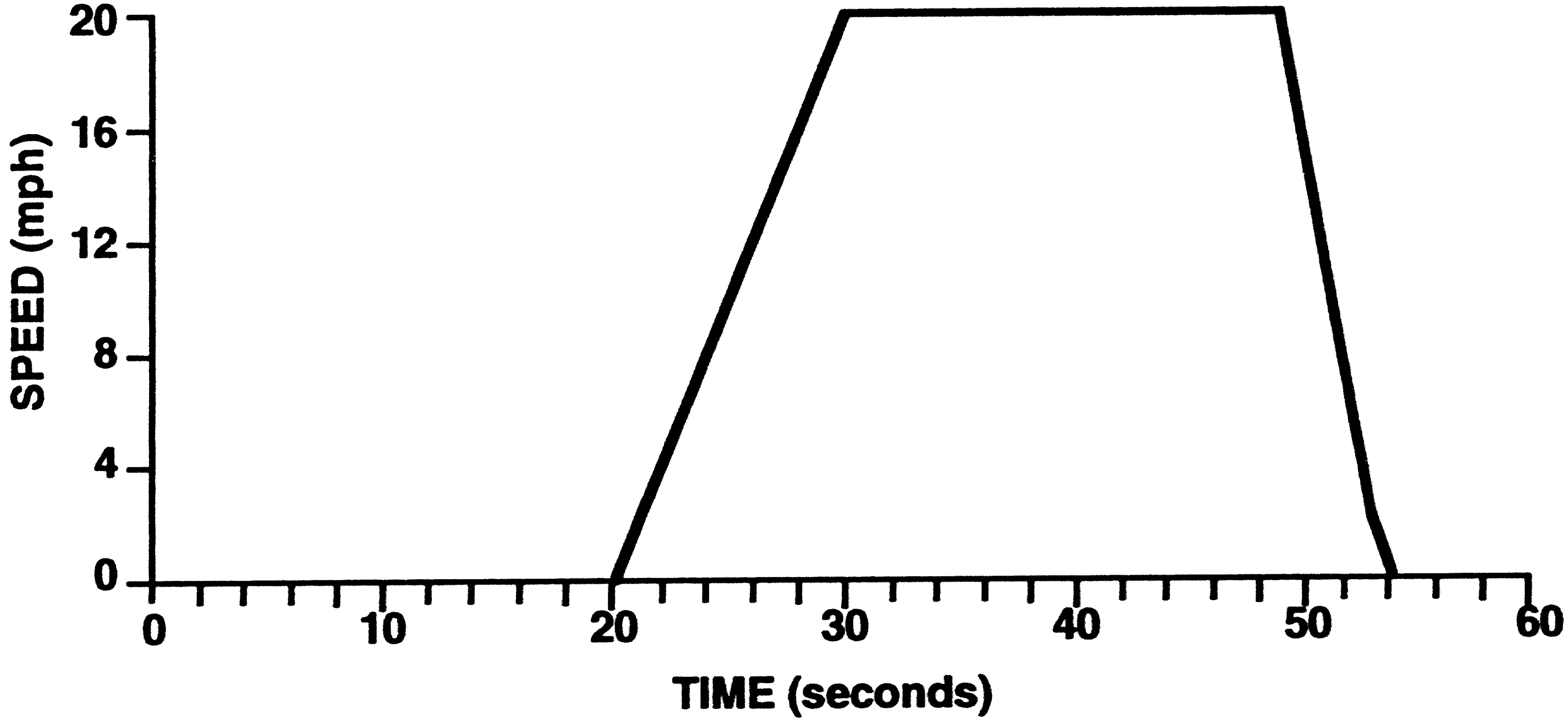
Ontario TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

CENTRAL BUSINESS DISTRICT



Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

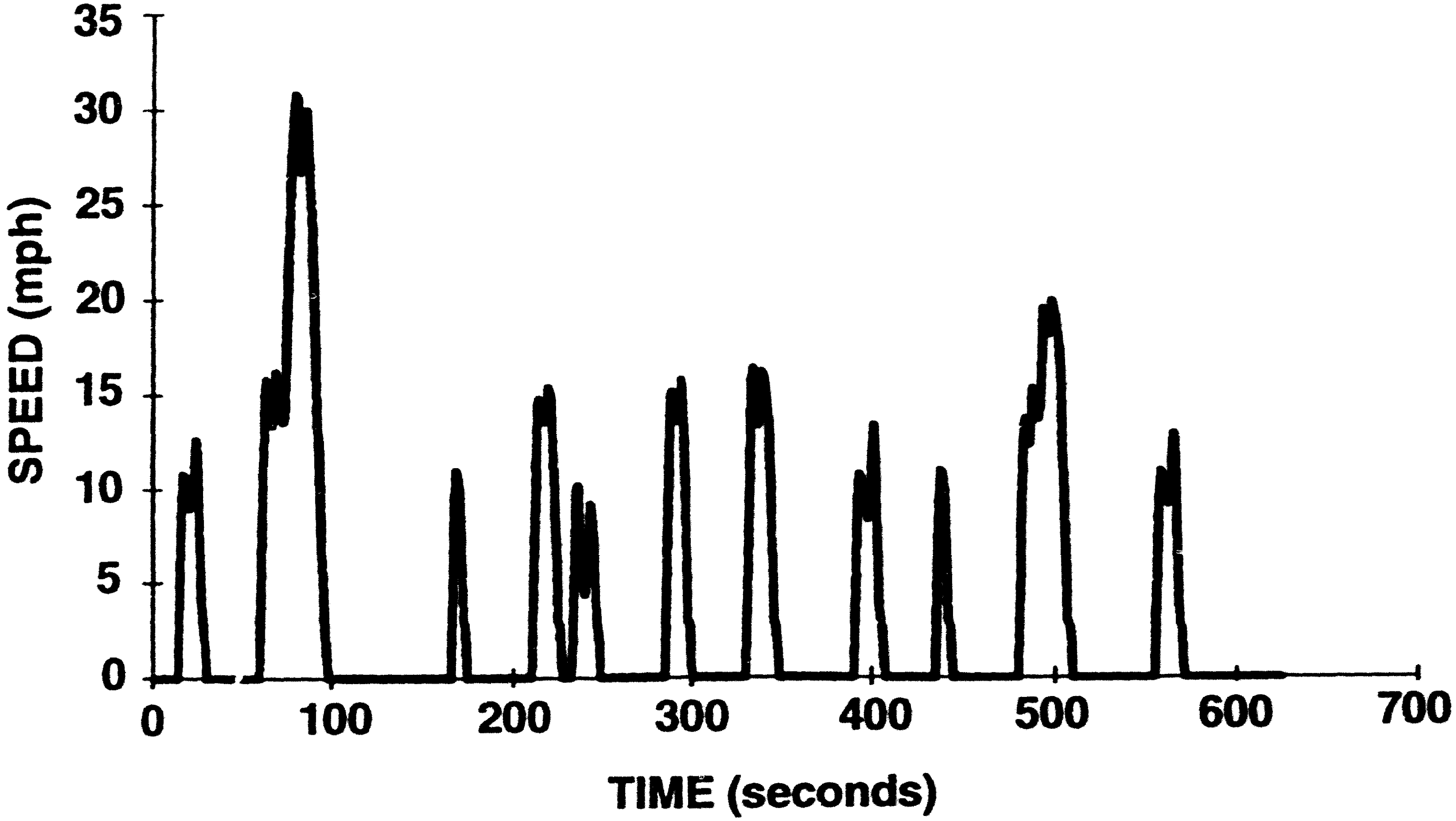
ONE SEGMENT OF THE CENTRAL BUSINESS DISTRICT CYCLE



Ontario

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

NEW YORK BUS CYCLE



TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

SCOPE OF TEST PROGRAM (cont'd)

- **Assess effects of driving cycle:**
  - EPA Heavy-Duty Test Cycle (HDTC)
  - DOT/FTA Central Business District Cycle (CBD)
  - New York Bus Cycle (NYBus)
  - New York Composite Cycle (NYComp)
- **Assess effects of bus weight:**
  - 26,000 to 33,000 lb for 40-ft buses

Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

SCOPE OF TEST PROGRAM (cont'd)

- **Buses included in test program:**
  - **Ontario Bus Industries (OBI) 40-ft CNG powered buses with Cummins L-10 engines and oxidation catalysts**
  - **Motor Coach Industries (MCI) 40-ft methanol powered buses with Detroit Diesel 6V-92TA engines and oxidation catalysts**
  - **MCI and OBI 40-ft and 60-ft buses with DDC 6V-92TA, DDC 6V-71NA, DDC 6L-71T, and Cummins N-10 diesels and Donaldson particulate traps**
  - **OBI and MCI baseline buses**

Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

RESULTS OF THE PROGRAM

- To-date a large number of tests have been completed with each technology
- Test program will continue for several years to provide a more complete assessment
- Presentation will be limited to representative results with low-mileage or new 40-ft buses

Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

COMPARISON OF FUEL/ENGINE/BUS TECHNOLOGIES

(40-ft bus; 33,000 lb inertia weight; CBD cycle)

	Two-stroke Diesel	Four-stroke Diesel	Methanol	CNG
PM (g/mile)	3.32	3.02	0.29	0.12
NO_X (g/mile)	20.36	23.90	11.69	10.26
CO (g/mile)	20.85	27.33	13.02	0.03
HC[1] (g/mile)	0.79	1.43	2.77	0.02
FE[2] (m/USgal)	2.96	3.57	3.09	3.74

[1] for CNG, non-methane hydrocarbons (NMHC)
for Methanol, organic matter hydrocarbon equivalent (OMHCE)

[2] Diesel equivalent fuel economy in mile/US gallon

Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

RESULTS WITH PARTICULATE TRAPS

(40-ft bus with DDC 6V-92TA; 32,000 lb inertia weight; CBD cycle)

	WITHOUT TRAP	WITH TRAP
PM (g/mile)	2.47	0.38
NO_X (g/mile)	23.28	25.73
CO (g/mile)	18.36	25.72
HC (g/mile)	2.44	2.17
FE (m/USgal)	2.74	2.80
Trap efficiency (%)		85

Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

EFFECT OF DRIVING CYCLE

(40-ft bus with DDC 6V-92TA; 33,000 lb inertia weight; CBD cycle)

	HDTC[1]	CBD	NYBUS
PM (g/mile)	2.18	3.32	4.79
NO_X (g/mile)	12.85	20.36	51.89
CO (g/mile)	7.56	20.85	57.23
HC (g/mile)	0.53	0.79	2.01
FE (m/USgal)	3.92	2.96	1.50

[1] Warm-start cycle

Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

EFFECT OF INERTIA WEIGHT

(40-ft bus with CNG engine; CBD cycle)

	26,000 lb INERTIA	33,000 lb INERTIA
PM (g/mile)	0.09	0.12
NO_X (g/mile)	6.83	10.26
CO (g/mile)	0.01	0.03
NMHC (g/mile)	0.00	0.02
FE (m/USgal)	4.16	3.74

Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

CONCLUSIONS

- New and emerging technologies offer major exhaust emissions improvements relative to the "standard" diesel
- CNG powered buses appear to approach the status of zero emission vehicles with respect to all regulated emissions, except NO_x
- The fuel economy of the CNG bus with the Cummins L-10 engine is comparable to its diesel conterpart at the same inertia weight and under identical driving conditions

CONCLUSIONS (cont'd)

- The Donaldson particulate trap achieves an 85% trapping efficiency under typical bus driving conditions
- The bus duty cycle has a profound impact on fuel economy and exhaust emissions with all technologies
- The weight of the bus has a major effect on fuel economy and exhaust emissions
- The test program will be continued to provide a better assessment of the long-term potential of emerging technologies

Ontario TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

EXHAUST EMISSIONS AND FUEL ECONOMY OF TRANSIT BUSES - CHASSIS DYNAMOMETER TEST RESULTS

T. Topaloglu, D. Elliott, J. Turner, D, Petherick, and C. Kaskavaltzis, Ministry of Transportation of Ontario

Q. Dan Fong, California Energy Commission: Were the engines certified, and to which standard?

A. The diesel engine was certified to the U.S. EPA standard and the CNG engine was certified essentially identical to the CARB standard.

Q. Anonymous: Would you clarify the heavy duty cycle?

A. The heavy duty test cycle is first driven from a cold start and is repeated with a hot start. The test results reported were for the hot start portion only.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

CARS AND CLIMATE CHANGE

L. Michaelis
International Energy Agency

CARS AND CLIMATE CHANGE

EXECUTIVE SUMMARY[1]

The transport sector is an essential element in the process of creating and consuming wealth. Popularisation of the motor car in particular has been important in the process of industrialisation and economic growth. At the same time there is an emerging consensus among OECD governments that policies are required to address some of the adverse social and environmental effects of motor vehicles. Traffic can be detrimental to quality of life, especially in cities, through the risks, noise and air pollution it causes. Vehicles are also a major source of greenhouse gas emissions. In the context of continuing growth in car use, stabilisation of the emissions poses a major challenge.

Cars and Climate Change contributes to the analysis of the technical potential, economic potential and market potential for emission reduction in the transport sector through increased efficiency and fuel substitution. The car market and its related fuel supply and infrastructure systems are examined, along with policies that might effect beneficial changes in the market.

Energy Use and Emissions

Energy use in OECD transport nearly tripled between 1960 and 1990. The growth rate for emissions of carbon dioxide (CO_2) was virtually the same, though other transport emissions have been decreasing. Transport, including international marine bunker fuel use, is now responsible for more than one-third of OECD final energy use. It is the largest final energy use sector and the share is growing. It is also the sector that has been the least responsive to policy makers' attempts to encourage energy efficiency and fuel flexibility.

Over the last 20 years, all transport modes except seagoing ships carried increasing levels of passenger traffic. The increase in rail and bus travel has been slight, and most of the additional land-based travel is by car. Of the passenger transport modes, air travel, which has the highest energy use and greenhouse gas emissions per passenger-kilometre, has increased fastest. Its growth rate is matched by that of road freight traffic. Air travel and road freight, which are causing increased concern in terms of both energy use and the environment, will be the focus of future IEA studies.

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[1] Extract from: International Energy Agency; *Cars and Climate Change*. OECD, Paris 1993. (61 93 02 1) ISBN 92-64-13804-8.

Of the land-based passenger transport modes, car travel is the most energy intensive. At typical seat occupancy levels, buses and trains use less energy per passenger-kilometre. Gasoline-powered cars, in aggregate, consume more energy than any other type of vehicle, and produce more greenhouse gas emissions.

Reducing Greenhouse Gas Emissions from Cars

For this study the IEA has used a life-cycle emission model that takes into account upstream emissions in considerable detail. Fuel supply is analysed, including raw material extraction, transport, processing and fuel distribution. Similarly, the model calculates emissions in vehicle production, from raw material extraction, transport and processing to vehicle manufacture. The model can be used to examine the effects on emissions of vehicle and engine design, of switching to alternative fuels and of using electric vehicles. The model also takes account of emissions other than CO_2, weighting them according to their greenhouse forcing[1] and how long they stay in the atmosphere.

About 72% of greenhouse gases from cars are emitted from the tailpipe during vehicle operation; 17-18% of car life-cycle emissions arise from fuel extraction, processing and distribution; a further 10% come from vehicle manufacture[2]. For cars with below-average annual kilometrage, the emissions in vehicle manufacture become more significant as a proportion of life-cycle emissions. The reverse holds for cars with above-average kilometrage.

Exhaust emission control devices are expected to be installed on most cars throughout the OECD by about 2005. Catalytic converters reduce emissions of carbon monoxide, volatile organic compounds (VOC) and nitrogen oxides (NO_x). However, they increase emissions of CO_2 and nitrous oxide (N_2O).

Greenhouse gas emissions can be reduced through:

- **Energy efficiency improvements.** Lower fuel use — for example, as a result of improved aerodynamic design — can reduce emissions throughout the fuel and vehicle life-cycle.

- **Fuel switching.** Alternative energy carriers can result in lower life-cycle CO_2 emissions because they contain less carbon, or because they contain carbon absorbed by plants from the atmosphere. Some alternative fuels can give higher engine efficiency than gasoline. Life-cycle analysis is particularly important in examining the potential benefits of alternative fuels.

---

[1] Effect on global radiative balance per unit mass.

[2] Emissions of chlorofluorocarbons (CFCs) and emissions associated with vehicle disposal vary widely between countries and are not treated in this report.

These two measures can complement each other. Improvements in gasoline vehicle design are clearly applicable to most alternative-fuel vehicles. Similarly, the vehicle design improvements that will be necessary to develop a viable electric vehicle can be used in gasoline vehicle production.

Energy Efficiency Improvements

Technical Potential. Technology is available that would improve car fuel economy by a factor of three or more. This could not be done without reducing performance or raising costs, however. Few of the resulting cars would be competitive in today's market.

Economic Potential. Analysis of the energy efficiency distribution of the current fleet can be used to indicate the economic potential for energy efficiency improvements: the fuel economy that would be achieved if car purchasers were to choose the model that satisfies their needs at the least overall cost. Studies in the United States and the United Kingdom indicate that the economic potential is probably at least 20% better than the current average fuel economy.

Market Potential. Many analysts have attempted to identify the market potential for fuel economy improvements — that is, the improvement that the market will produce without additional intervention. This can be done by:

- making techno-economic assessments of changes that do not affect vehicle size, performance or comfort level;
- mapping the energy efficiency distribution of cars currently being purchased and using the top 10% or 20% to indicate the potential for the fleet as a whole over the next ten to 20 years;
- using macroeconomic models to generate scenarios of the future that include energy efficiency indicators as an output.

All these approaches suggest that fuel economy may improve by 10-20% between now and 2005.

Alternative Fuels

Some alternative fuels — diesel, LPG[1] and CNG[2], for example — can be produced with less processing than gasoline from crude oil. Synthetic fuels such as alcohols generally require more energy and more capital-intensive plant for processing. Switching fuels generally results in lower tailpipe emissions of CO_2 and pollutants but may result in higher emissions from fuel supply. Where alternative liquid fuels are produced from gas or coal, life-cycle greenhouse gas emissions can exceed those due to gasoline use. Fuels from biomass or other renewable sources can in principle have zero life-cycle emissions. Manufacturing of vehicles using gaseous fuels that require heavy cylinders, or electric vehicles with heavy batteries, involves more energy use and emissions than that of more conventional cars.

Technical Potential. **Figure 1** shows an example of the calculation of life-cycle emissions for a variety of alternative fuel options for use in North America. The options can be divided into four main groups:

- Fuels which offer little or no greenhouse gas abatement but may be attractive from the perspective of other areas of government policy. Synthetic liquid fuels using fossil fuel inputs, including some biomass-derived fuels, fall into this group, as do CNG used in existing vehicles (not shown in the graph) and electric vehicles using power from some existing generation mixes;

- Alternatives available now, or expected to become available by 2005, including diesel, LPG, CNG in optimised engines and electric vehicles using power from existing generation mixes; these options can reduce greenhouse gas emissions by 10-25%;

- Synthetic fuels from wood or other low-input biomass feedstocks, which are not yet technically demonstrated but could offer 60-80% greenhouse gas abatement;

- Fuels derived from completely renewable sources, including hydrogen produced by electrolysis of water using electricity generated by renewable sources; synthetic fuels from zero-input biomass feedstocks; and electric vehicles powered by electricity from renewable sources. All would mean large-scale replacement of the existing fossil-based energy system. They can result in over 80% greenhouse gas abatement.

One striking result of the analysis of alternative fuels and electric vehicles is the considerable range of emission levels that could be associated with each option (see **Figure 2**). The results depend on the fuel inputs and emission levels associated with power generation and fuel conversion. Any ranking of the

---

[1] Liquefied petroleum gas.

[2] Compressed natural gas.

options will vary by region and according to the assumptions made about technology that is not yet fully developed. Even currently available options, including CNG and ethanol from maize, have considerable ranges of emissions and may result in higher life-cycle emissions than gasoline.

Economic Potential. The car buyer considering an alternative-fuel vehicle has to consider the cost of the vehicle, its probable operating costs and its expected resale value. In the case of fuels such as CNG or diesel, the vehicle cost is likely to be higher than that of a gasoline vehicle and the fuel costs are likely to be lower. The buyer has to make a trade-off, depending on the cost of capital, expected annual costs and kilometrage and the probable time before the car will be resold.

An earlier IEA study examined the costs and technical feasibility of using several alternative fuels (IEA, 1990b). **Figure 3** shows the cost-effectiveness of using alternative fuels to reduce greenhouse gas emissions, considering only the costs involved in fuel supply.

The current study provides a deeper economic analysis of fuels that may have significant market potential by the end of the 1990s. Costs are calculated for gasoline, diesel and CNG cars in the United States and France in 2000. **Figure 4** shows the estimated ranges of costs in each country of switching from gasoline to diesel and CNG cars at 1992 fuel prices and taxes. The fuel duties in each country have important effects on the economics of fuel switching. In France diesel is subject to lower tax than gasoline, and is likely to remain very attractive for most vehicle buyers. Tax exemptions introduced in the United States by the 1992 Energy Policy Act may make CNG attractive, at least for drivers who are unaffected by a shorter driving range.

Market Potential. Market share projections for alternative fuels are unreliable, as there is little experience on which to base them. Macroeconomic models such as the IEA's World Energy Outlook are not designed to predict fuel switching in the long term. Econometric models with more detailed disaggregation of transport fuel demand may be more helpful in identifying possible niche markets for alternative fuels.

Market surveys have been carried out in California, where alternative fuels are being promoted by the state government. The surveys indicate that disadvantages of alternative fuels, such as uncertainty about availability, outweigh any cost advantage for most consumers. As a result the main users of alternative-fuel vehicles have tended to be fleet operators.

Policies for Greenhouse Gas Abatement

Many OECD Member countries have adopted policies to promote alternative fuels. These policies have usually been motivated by objectives other than greenhouse gas abatement. In the United States alternative fuels are being introduced as a result of legislation that is intended mainly to reduce emissions of carbon monoxide and VOC.

Energy-efficient vehicles are not achieving their economic potential in the car market now, and alternative-fuel vehicles appear unlikely to do so by 2005 without government intervention. This is partly due to aspects of the technologies that make them unattractive to consumers — reduced performance, uncertainty regarding fuel availability, uncertainty about the resale market. It may also be due to market imperfections, such as lack of information about new technologies or the existence of external costs and benefits associated with them.

CO_2 emissions are linked directly to fossil fuel demand. In economic terms the most efficient way to reduce emissions would be to tax all fuels, in all sectors, throughout the world, according to their carbon content. This approach, however, is unlikely to be adopted in the near future. The external cost of CO_2 emissions is not known and may be unknowable, so it is not possible to determine the tax level that would internalise the cost.

Approaches that do not depend on international agreement, such as vehicle fuel economy standards, have been widely adopted. Such standards may have the drawback of resulting in lower driving costs and hence more propensity to drive. Other indirect approaches to reducing fuel demand may have similar drawbacks. Even if they result in fuel savings, they are likely to do so at greater expense in consumer welfare than would have been incurred using carbon taxes.

A case study carried out in the Netherlands analyses the effects on traffic and emissions of several policy measures, including parking controls, fuel pricing, road pricing and public transport investment. The study also examines the effects of combinations of different types of measures. Combined measures have more effect than would be produced by adding the effects of the component measures. The use of such combinations reduces opportunities for consumers to compensate for restrictions imposed by individual measures.

Policies for Sustainable Transport

Although greenhouse gas abatement appears difficult to achieve for passenger cars, there is growing recognition of the range of problems caused by cars. Oil dependence has long been a concern of governments in OECD countries. Other issues rising in the political agenda include traffic congestion, accidents, noise and local air pollution.

These issues have relevance for greenhouse gas emissions. Policies to deal with the other problems caused by transport can also reduce greenhouse gas emissions. For example, in Europe the fitting of speed limiting devices to heavy-duty vehicles reduces not only accidents but also energy use. In California the promotion of CNG vehicles to reduce local air pollution may also result in reduced greenhouse gas emissions.

Concern about global warming adds weight to the arguments for governments to reconsider their transport policies according to the "polluter pays" principle. They should try to reduce the damage caused by transport as far as possible. Where damage cannot be reduced, transport users should be required to pay the full cost of their mobility. Yet the considerable existing government intervention affecting transport makes this task difficult.

Responsibility for acting on many problems associated with transport tends to be split between government departments. National administrations are beginning to address transport sector issues as a whole, by consultation between departments. The process is important in helping policy makers see the synergy among the different issues, and should result in more effective action to deal with each problem.

This report cannot prescribe polices or policy packages for governments. The main recommendation arising from the study is that governments should carry out and act on their own careful, comprehensive analyses of transport policy options.

Figure 1. Life-Cycle Greenhouse Gas Emissions from Alternative Fuel Cars in North America, 2000

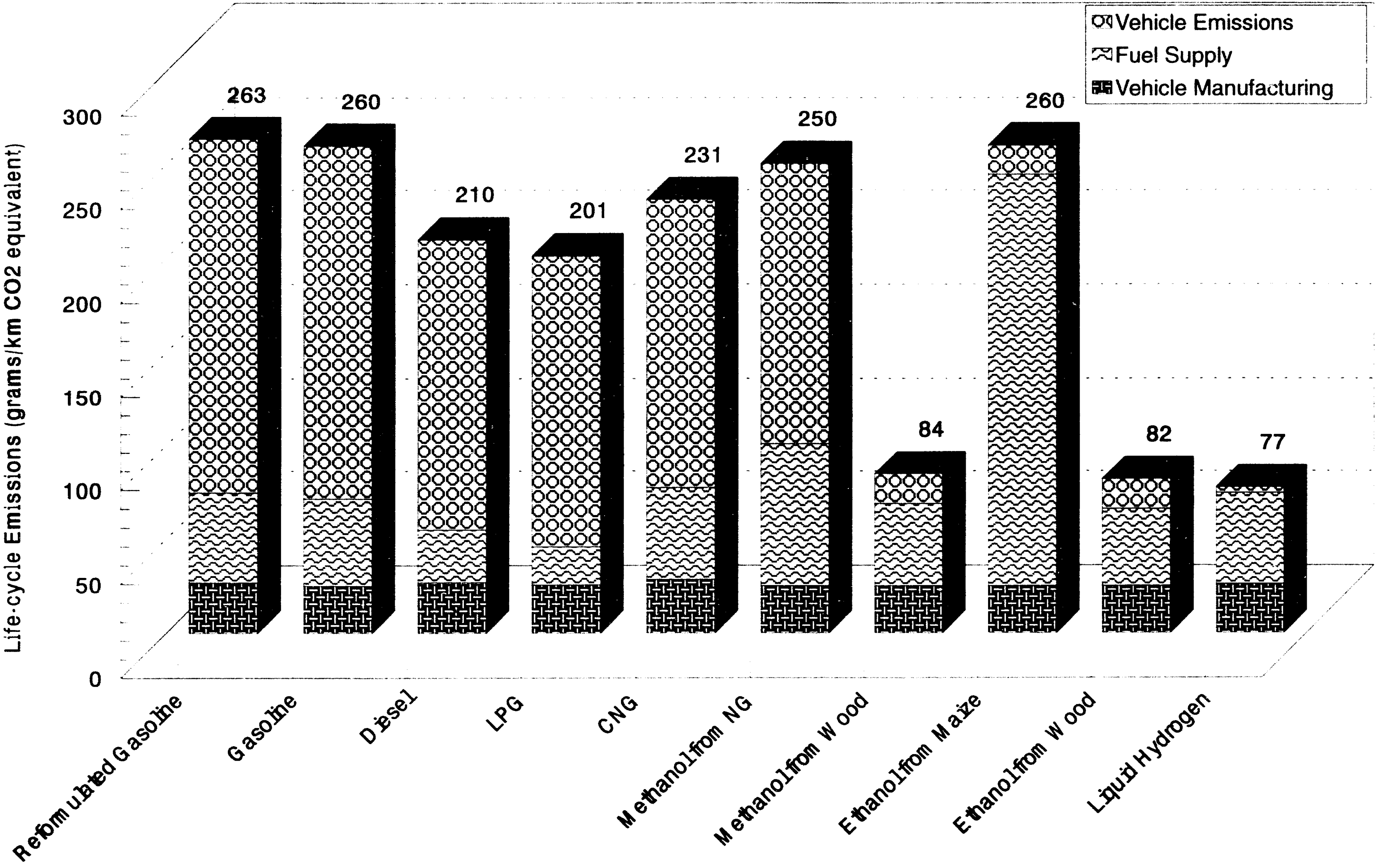


Figure 2.
Greenhouse Gas Emissions from Alternative Fuels
(Reformulated Gasoline=100)

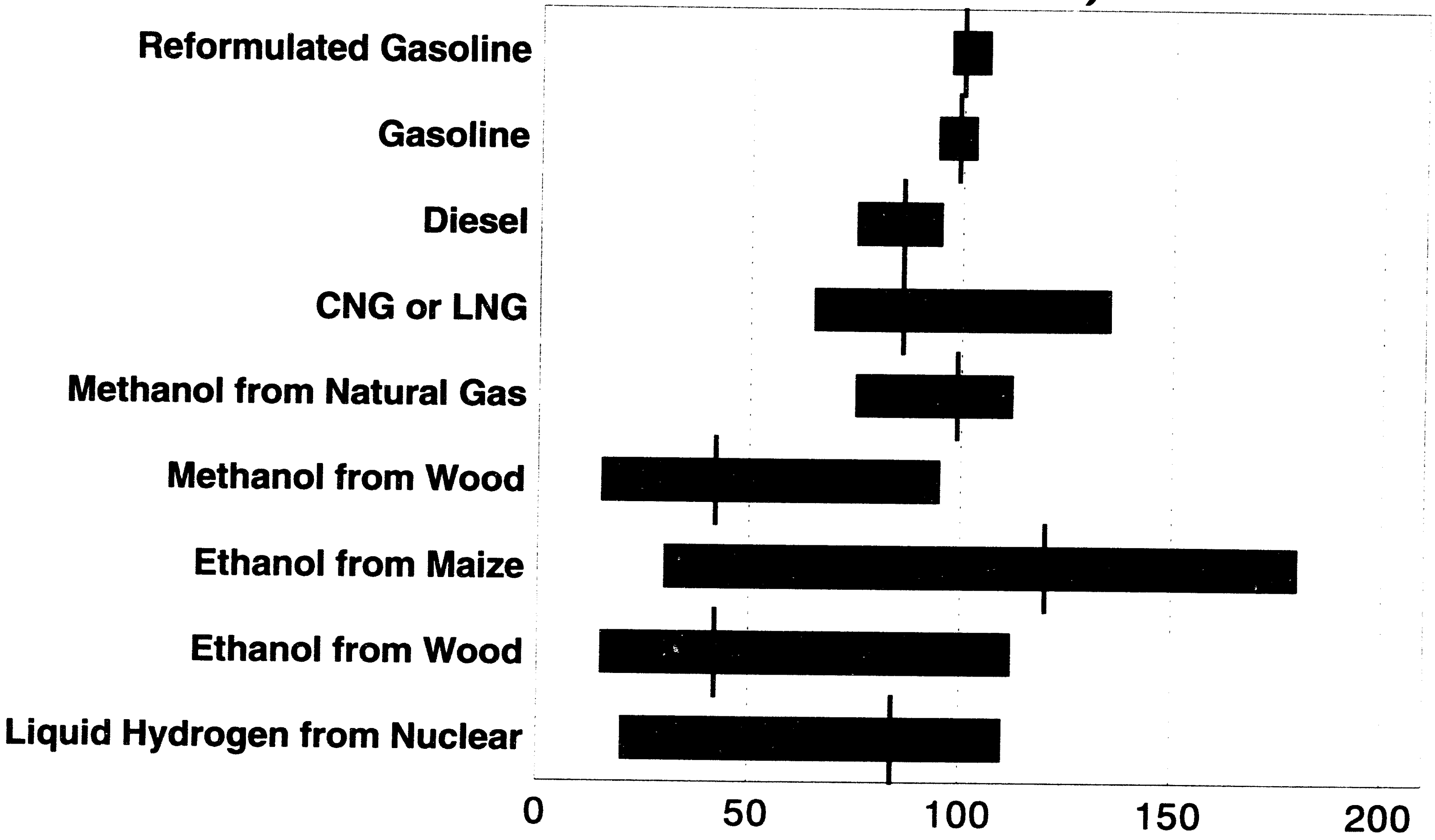
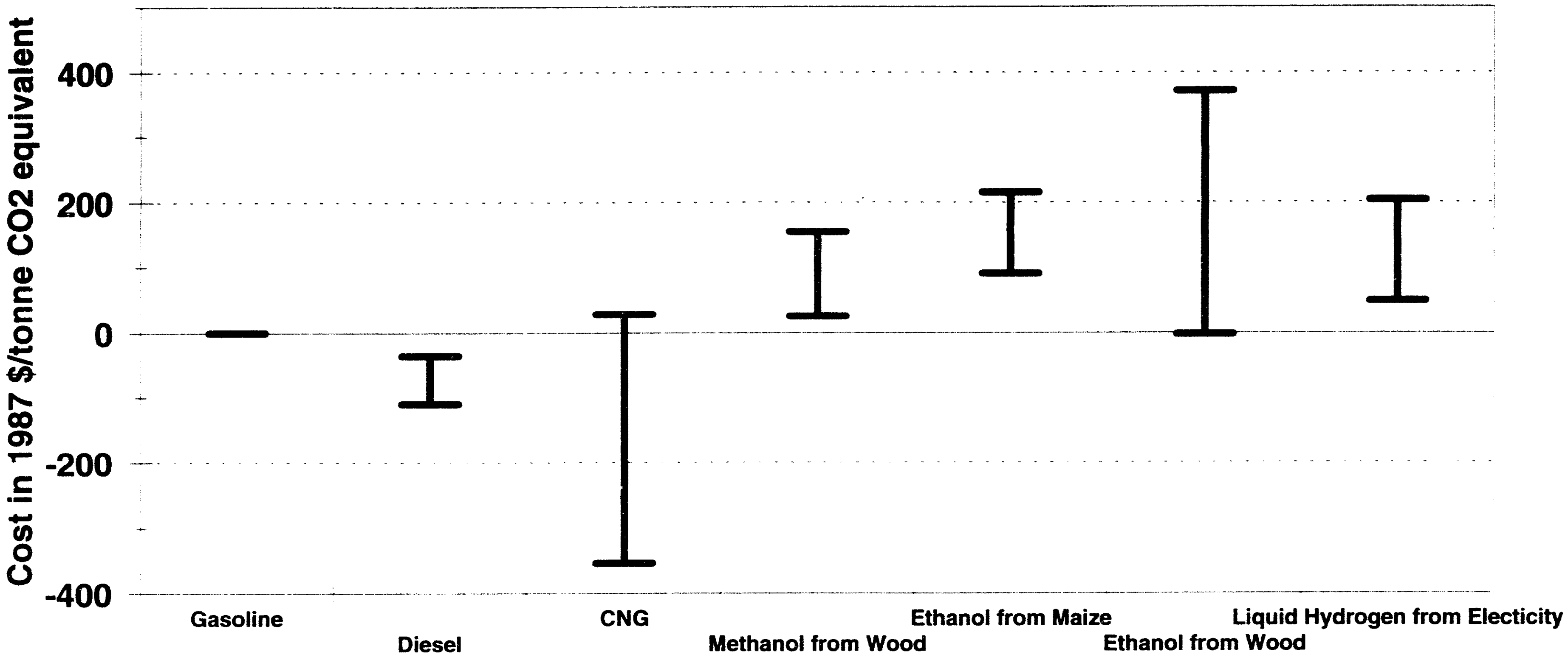


Figure 3
Alternative Fuels Cost-Effectiveness for Greenhouse Gas Abatement

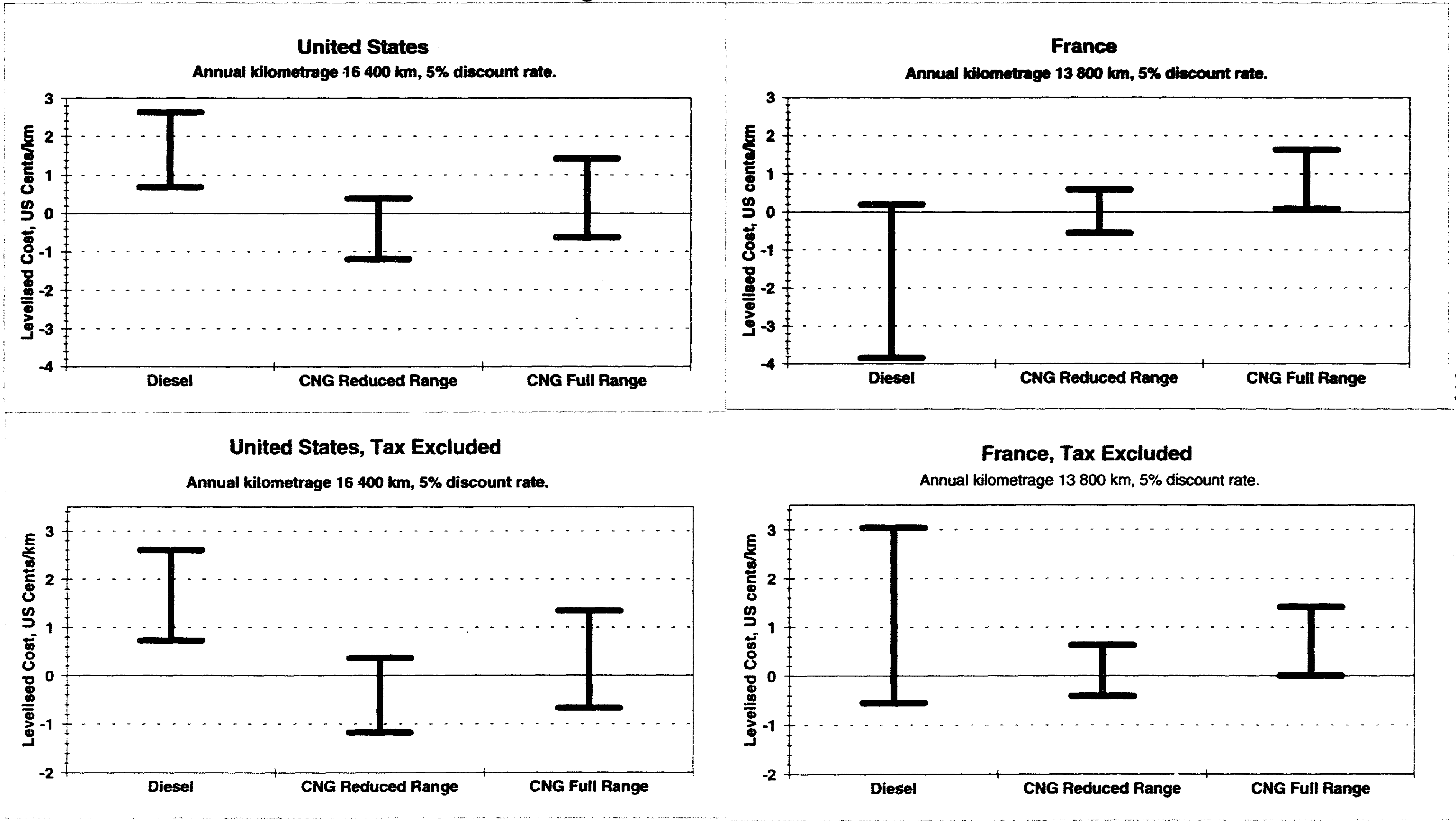
(Fuel cost relative to gasoline in 1987 US $/metric ton CO2 equivalent not emitted)



Sources: IEA 1990
Department of Energy 1990
CEC 1992

figs7.wb1

Figure 4
Cost of Switching from Gasoline to Diesel or CNG



United States

Annual kilometrage 16 400 km, 5% discount rate.

France

Annual kilometrage 13 800 km, 5% discount rate.

United States, Tax Excluded

Annual kilometrage 16 400 km, 5% discount rate.

France, Tax Excluded

Annual kilometrage 13 800 km, 5% discount rate.

Cars and Climate Change

Study Objectives

Greenhouse gas emissions inventory

Assessment of abatement technologies

Assessment of policy instruments

Passenger Car Technologies Covered

Energy Efficiency

Alternative Fuels

Electric Vehicles

Emission Abatement Potential

Technical

Economic

Market

True Technical Fix

Reduces greenhouse gas emissions

Costs no more than current technology

Performs as well as current technology

Lifecycle Emissions Analysis

Several greenhouse gases

Rigorous tracing of upstream emissions

Spreadsheet format allows variation in assumptions

Cost Effectiveness - Spreadsheet Analysis

Options for first owner

Consumer vs national perspective
(i.e. with/without taxes)

Detailed analysis - annual kilometrage

Cars and Climate Change

Further work needed:

National analyses

Shadow pricing to reflect
non-monetised
costs and benefits of technologies

Interaction with econometric
modellers of car market

AIE l'énergie et l'environnement ● ***IEA Energy and Environment***

Conclusions

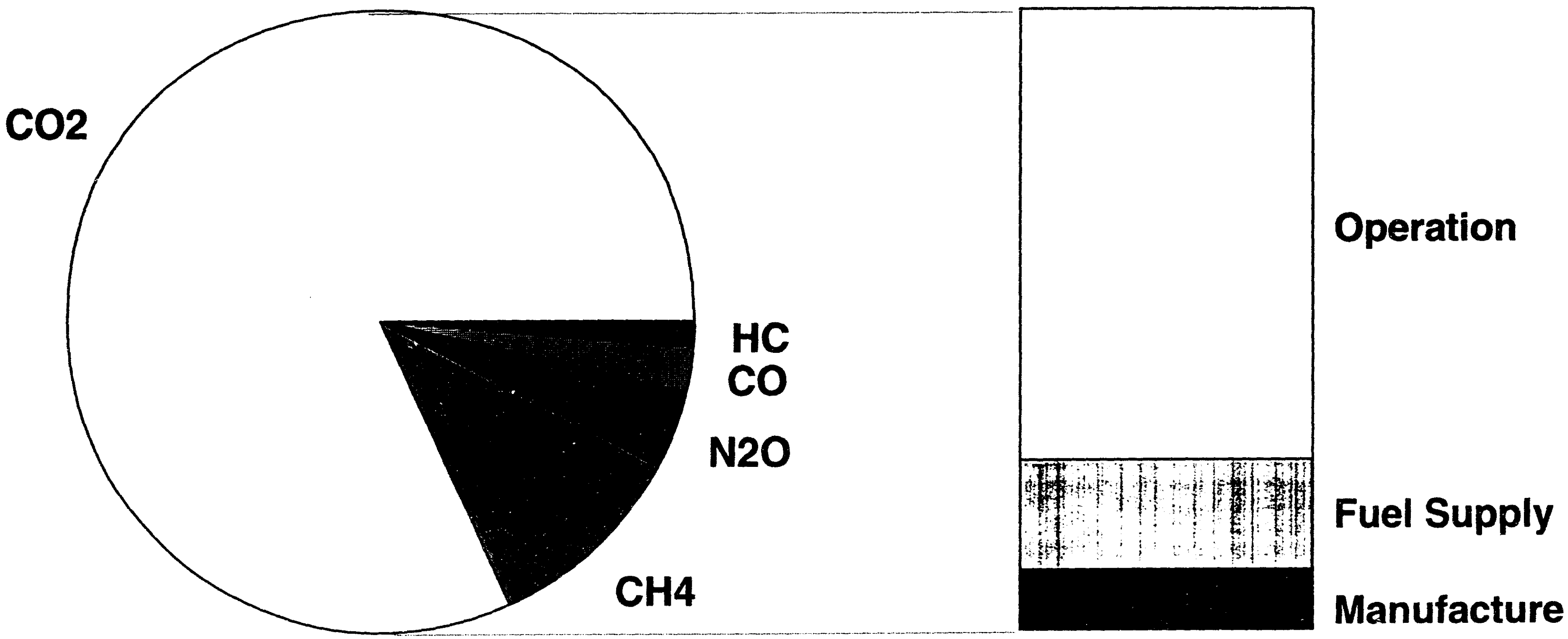
Technical potential is considerable:
could reduce emissions per VKT by 80%

Economic potential much smaller:
20% from energy efficiency
10-20% per VKT from switching to CNG, diesel, LPG

Market potential even smaller:
OECD-wide 10-20% from energy efficiency by 2005
<5% from switching fuels

CNG Car: Lifecycle Emissions

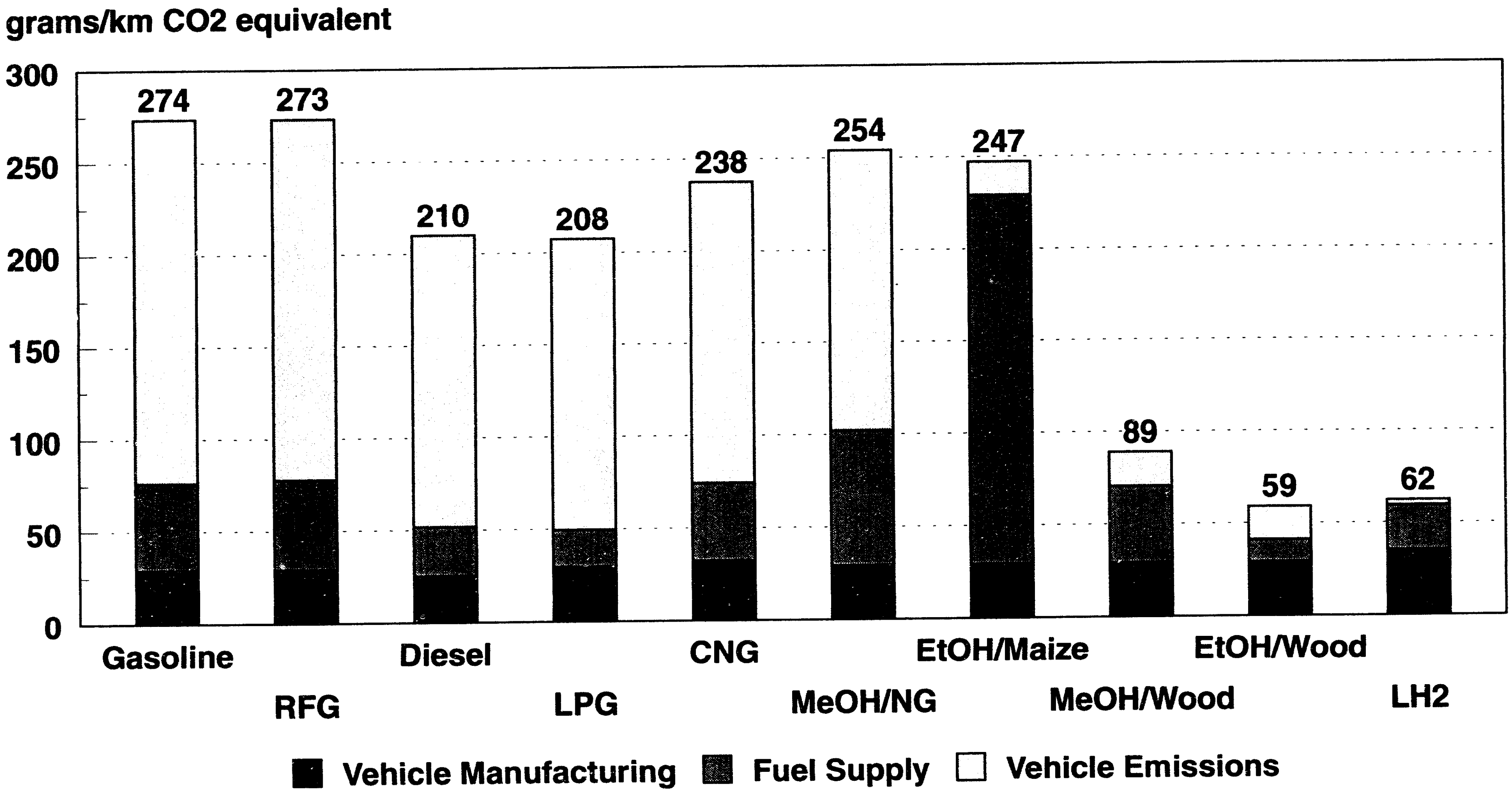
Greenhouse Forcing by Gas, and by Lifecycle Stage



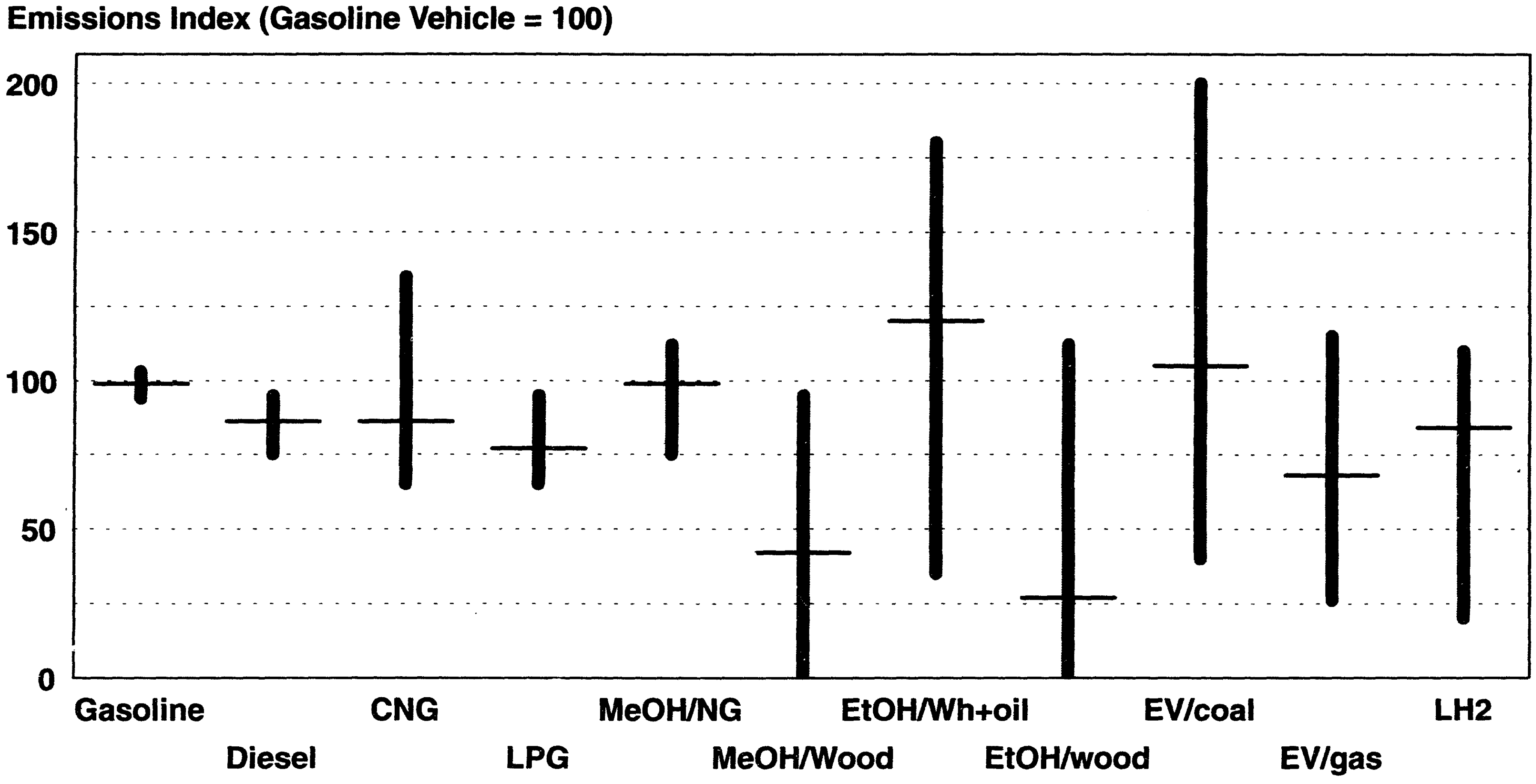
Cars and Climate Change

Alternative Fuel Vehicle

Lifecycle Greenhouse Gas Emissions



Cars and Climate Change

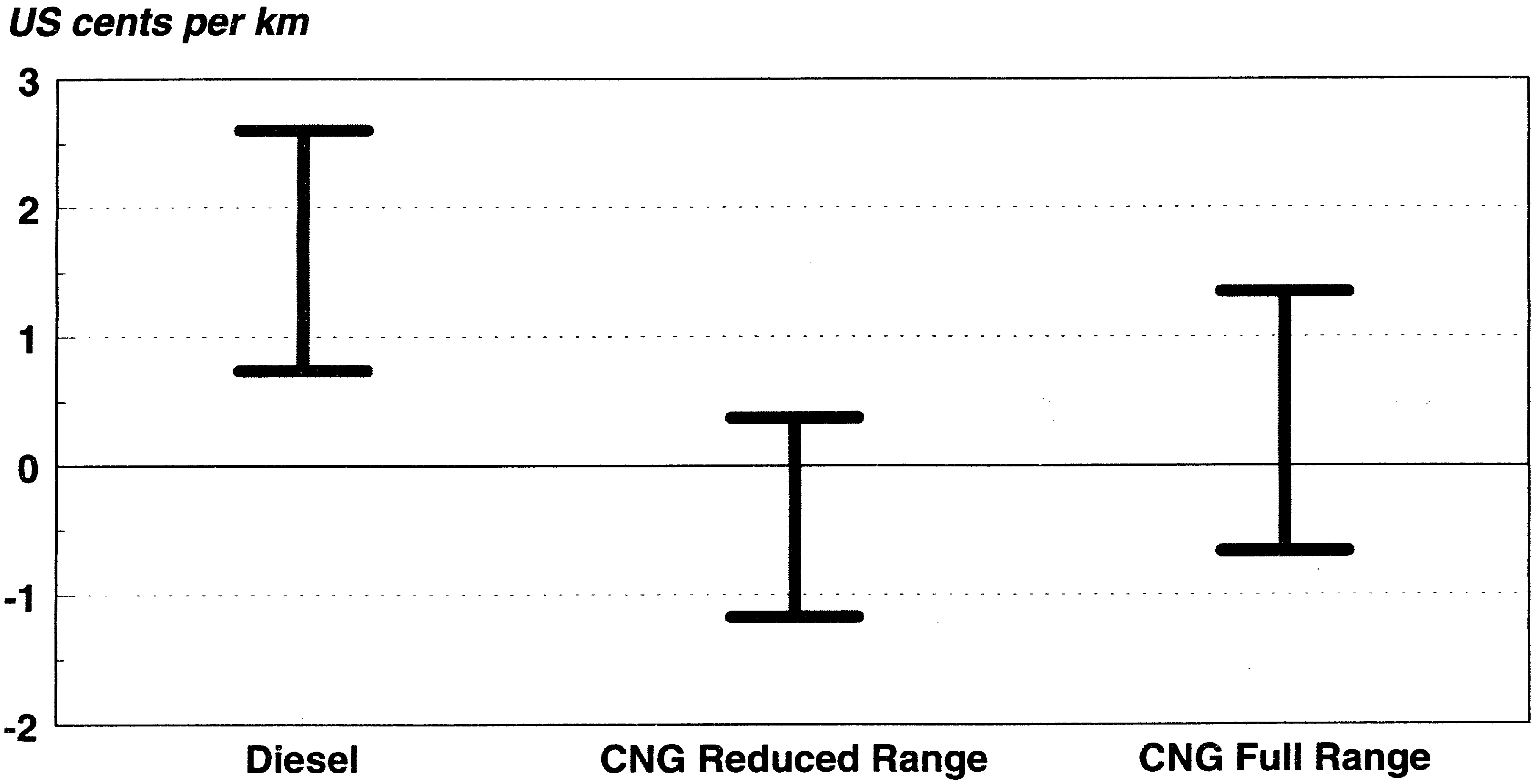


Lifecycle GHG Emissions for LDV Technologies

Ranges and Best Guesses

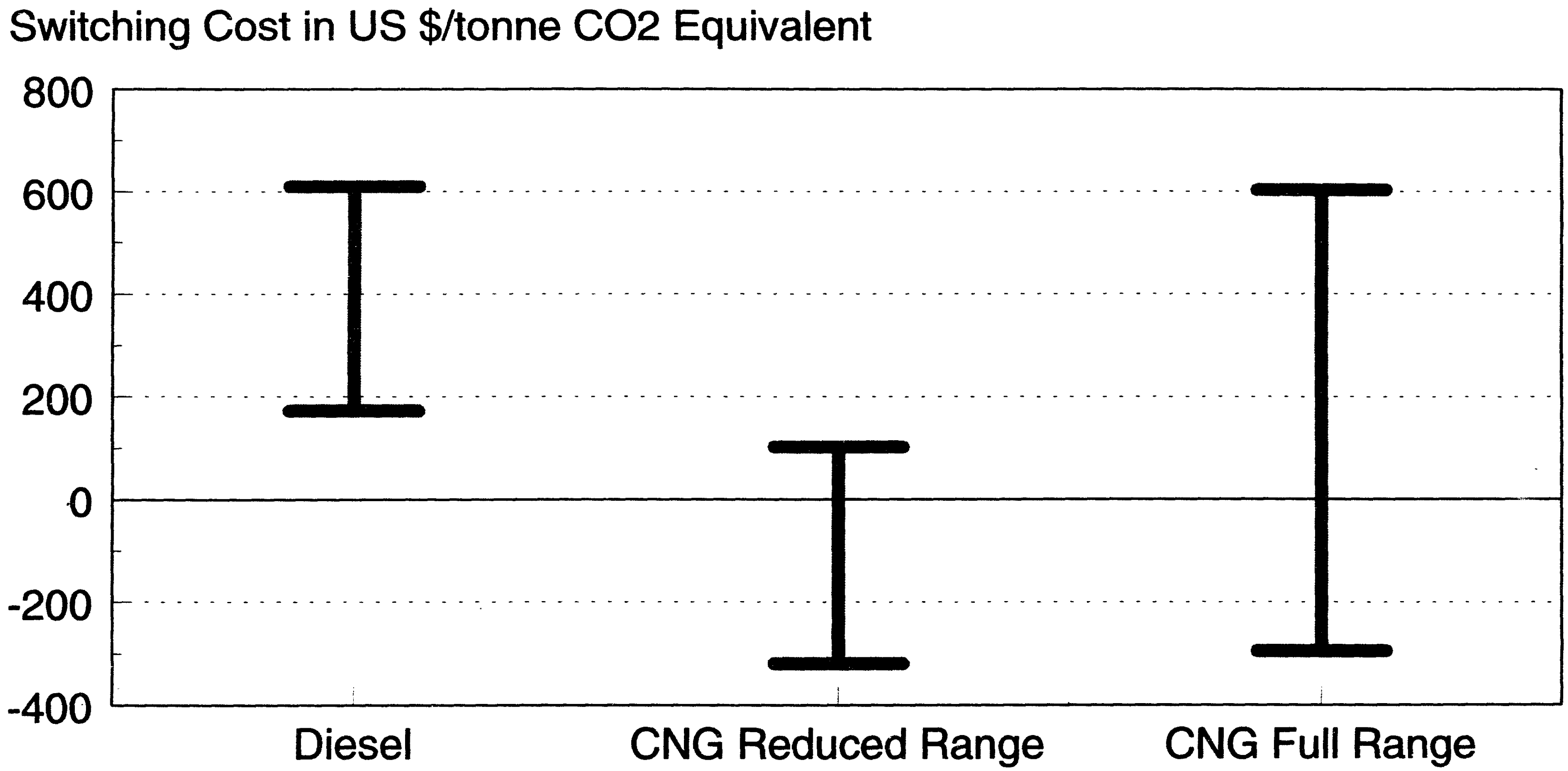
Cars and Climate Change

Cost of Switching from Gasoline in United States



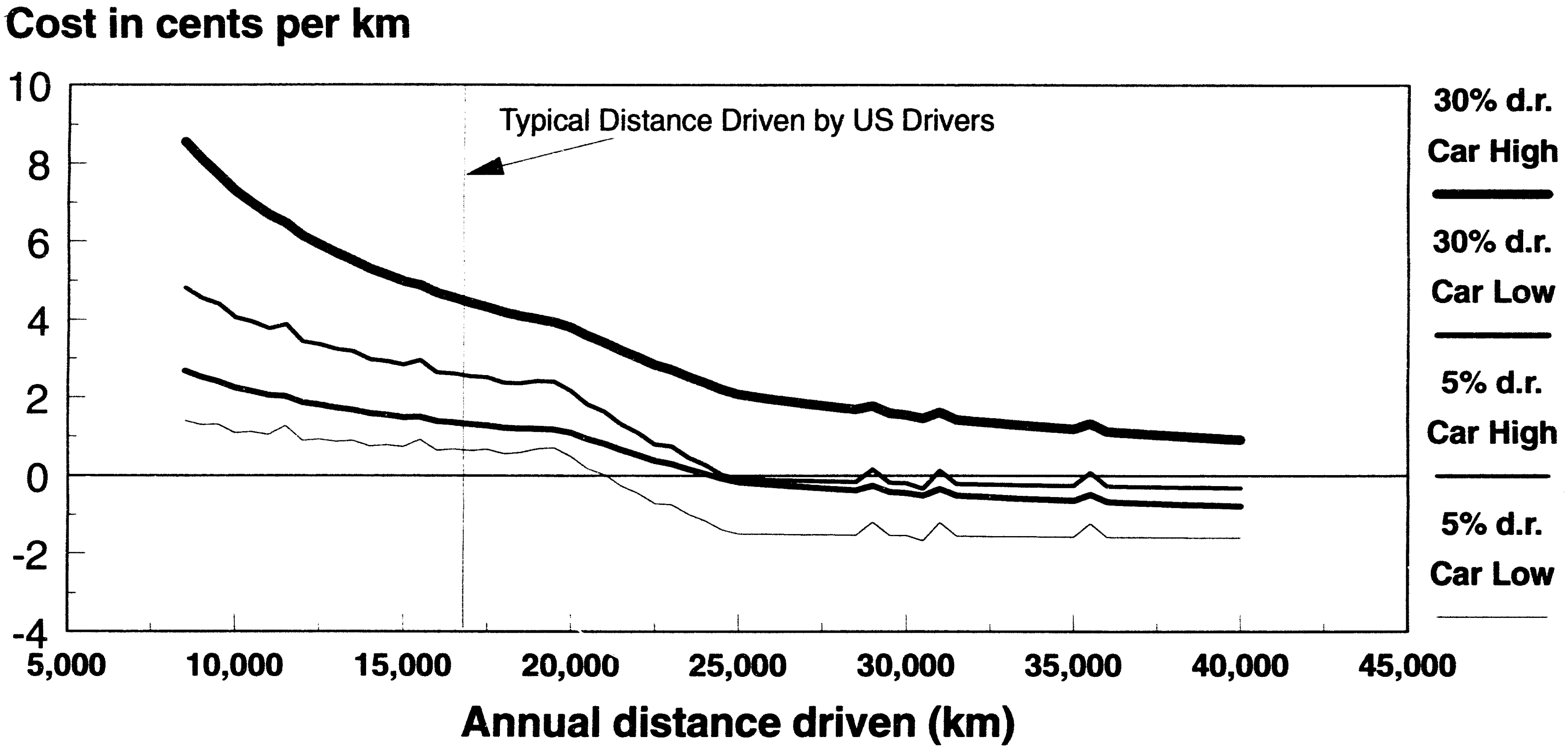
Cars and Climate Change

Cost of Reducing Greenhouse Gas Emissions by Switching from Gasoline in the United States



Cars and Climate Change

Cost of Switching from Gasoline to Diesel in the United States, 2000.



SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

ALTERNATIVE FUELS IN IEA COUNTRIES: A LIFE-CYCLE STUDY

Laurie Michaelis, International Energy Agency

Q. Rene Pigeon, Energy, Mines, & Resources Canada: Propane LPG comes from refineries but also comes from natural gas liquids. How was this handled?

A. In North America, most LPG comes from natural gas liquids. In Europe, LPG is mostly petroleum-derived. We took the data in proportion to the LPG source.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

FUTURE R & D FORUM

Discussion Leader: Malcom Smith, Consultant

FUTURE RESEARCH AND DEVELOPMENT FORUM

Discussion Leader: Malcolm Smith, Consultant

This forum was set up by a written question given, at registration, to all delegates. "What do you think is the most exciting thing happening, right now, in alternative fuels?" Twenty delegates provided written replies. The following summarizes the replies:

- Alternative fuels in face-to-face competition with conventional fuels. Technology must deliver comparable or better user experience with alternatives or this competition will not be sustainable.
- OEM vehicles designed to use alternative fuels; refueling stations that are a reality; real infrastructure.
- Alternative fueled vehicles now available from OEMs.
- Optimized OEM engines for alternative fuels (need M85 and E85 programs too).
- The coming availability of competitive medium and heavy duty dedicated natural gas engines from US OEMs.
- The development of OEM alternative fuel vehicles in response to incentives and legislation.
- OEM involvement/technology improvement/consumer interest.
- OEMs finally realizing the market-desire-for bi-fuel, not just dedicated fuel, vehicles now.
- Especially in the US, alternative fuel vehicles are showing signs of being commercially viable.
- Hydrogen fuel cells are showing that hydrogen might become a realistic transportation fuel.
- Demonstration of the hydrogen fuel cell bus in Vancouver.
- Fuel cell vehicles, low emissions, high efficiency, CO_2 reduction, renewable feedstock.
- Electrical hybrid vehicle development.
- LNG fuel dispensing is viable.
- The rapid emergence of natural gas as a realistic alternative transportation fuel.

- Development of natural gas vehicles able to meet LEV standards.
- Lightweight CNG storage cylinders.
- The use of methanol as a light vehicle fuel seems imminent. To some this represents a challenge/threat.
- The development of biodiesels.
- New US government focus on accelerating alternative fuel use for transportation.
- Efforts to cooperate between Federal, State, City and Industry clean fuel programs.
- THC regulations for NG powered vehicles.
- Clinton administration initiatives to promote (or force) alternative fuel vehicles into the market place.
- The impetus that US legislation and economic nationalism is giving to the alternative fuel industry.

Analysis of the 20 replies showed the following breakdown by topic (several replies contained comments about a number of aspects).

• Alternative Fuel Vehicles Now	50%
• New Beneficial Regulations (US)	20%
• Fuel Cells, Electric and Hybrid Vehicles	20%
• Natural Gas Vehicles	10%
• Methanol	5%

In the Forum itself, the following topics were put up as overheads, with the heading "Topics Worth Talking About".

- OEMs are delivering product.
- The Halo effect.
- Who wants to talk about Propane? Nobody? Concern for a fuel that is here now and has environmental benefits, but not the pizzazz to stimulate discussion.
- Where have Canada's policy makers gone?
- What does "clean" mean? What do you want it to mean?
- Its time to bring in the electrics, fuel cell, and hybrid fueled vehicles.
- What would you like to see in or out of next year's Windsor Workshop?
- The case for public and private sector interaction - ATFs in New Zealand and Australia.

There was considerable discussion on propane, redressing to some extent, the lack of propane/LPG presentations in the main body of the Workshop. The following is the set of "on-the-fly" comments captured during the forum:

- The fuel (propane) isn't really there.
- The real energy cost is hard to get at.
- Fuel quality is a problem. So is availability.
- Canadian pilot programs for heavy duty engines produced useful information, but there's been no follow up.
- Don't expect governments to do the whole thing.
- Fragmentation in the propane industry is a problem.
- Propane has lost its "bloom". It's an old fuel and isn't cutting it in the transportation market.
- The feedstock is too valuable in other markets.
- Pricing instability gets in the way of wider adoption.

Other topics were:

- There's been a shift over the past 8 years. Stability of supply is no longer an issue.

- Can we (afford) to research all alternative fuels?

- The Alternative Fuels shouldn't compete with one another. They should compete with the major fuels.

- Fuel-neutral research organizations can assist if there are dollars available.

- Vehicle Inspection and Maintenance programs have the potential for substantial market impact in conjunction with product availability. More thought needs to be given to this for the alternative fuels.

These comments, as with those culled from the 20 replies to the initial question, are not necessarily inclusive or balanced, but they are reasonably representative of the from-the-floor comments.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

FUTURE RESEARCH AND DEVELOPMENT FORUM

Discussion Leader: Malcolm Smith, Consultant

Q. Vinod Duggal, Cummins Engine Co.: There is a case for propane in Canada and the U.S. because of its relatively low price. But what will the price be in five years? It could take that long to develop the engine technology. Will there be enough demand for engines to pay back the development costs? Also, what is propane, how much is available, and at what cost?

A. Bernard James, Energy, Mines & Resources: There is a specification for fuel-grade propane called HD-5. It has been used in both light duty and heavy duty vehicles in Canada without a great deal of research. The reasons for the small amount of research are not clear. The economics are favorable for use of propane as engine fuel.

Comment: Sheldon Vedlitz, Conoco Inc.: We do have some answers on propane. Grade HD-5 is mostly propane, with not over 2.5 percent butane or 5 percent propylene. On cost, I can get a vehicle converted to propane for $900 to $2,200. A CNG conversion would cost $2,000 to $4,200. Propane has been around for a long time and does not have the appeal of newer CNG technology, but it should be given a chance to compete with the other alternative fuels.

Comment: Anonymous: Propane engine technology can be developed by other entrepreneurs who see it as an opportunity.

Comment: William Chamberlin, Lubrizol Corporation: Our objectives have shifted over the years at this workshop. Methanol was popular in the early days because of its potential for tremendous quantities to replace imported petroleum, not because of its low emissions. Cost is an issue with alternative fuels, but national security is also a concern.

Comment: Chandra Prakash, Environment Canada: We all know that vehicle emissions were not good using old techniques with mechanical systems. The new technology with electronic computer controls accomplish improved results. There is still a concern about supply and price of propane.

Comment: Bernard James, Energy, Mines & Resources Canada: I want to recall that ten years ago these workshops were started by Geoffrey Maund and Eugene Ecklund as an off-shoot of contractor coordination meetings. It has been great to see the progress and technology developments over that period of time. I want to thank Alex Lawson for guiding the program and for his hard work.