Conf-930696 -- --

1993 WINDSOR WORKSHOP *on* ALTERNATIVE FUELS

Proceedings

October 1993

June 14 - 16, 1993

Holiday Inn
Toronto Downtown - City Hall
Toronto, Canada

Sponsored by:
Energy, Mines & Resources Canada - CANMET
US Department of Energy

Presented by:
ORTECH International

ORTECH
INTERNATIONAL

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

Conf-930696

Proceedings of the

1993 WINDSOR WORKSHOP

on

ALTERNATIVE FUELS

June 14-16, 1993

Toronto, Ontario

October 1993

Sponsored by:

Energy, Mines and Resources Canada - CANMET

United States Department of Energy

PREFACE

In the tradition of previous years, EMR's Canada Centre for Mineral and Energy Technology (CANMET), and the U.S. Department of Energy (DOE) teamed up once again to sponsor the Windsor Workshop on Alternative Transportation Fuels. 1993 marked the 10th anniversary of this Workshop which began in 1983 in Windsor, Ontario. We would like to express our appreciation to ORTECH International for a fine job in coordinating this event.

The 1993 workshop attracted 271 participants from 9 countries including, France, Japan, Australia, Hong Kong, Italy, Korea, The United Kingdom, The United States and Canada; continuing to indicate the growing awareness and importance of alternative transportation fuels in the world marketplace.

Following in the footsteps of its predecessors, the 1993 workshop maintained its established approach to encourage an informal exchange of information with a focus on infrastructure barriers, and the readiness of alternative fueled vehicles to enter the marketplace. Participants included engine and vehicle manufacturers, fuel suppliers, public and private research organizations, and academic and regulatory bodies. In keeping with this informal theme, many of the papers presented in these proceedings are not in text format. After each paper a brief summary of the question and answer period is appended, which should serve as a reminder of some of their more salient points.

The development of alternative transportation fuels, and ultimately the quality of the environment, can only be enhanced by the exchange of information on worldwide industrial trends and technical progress. 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

Mark your calendars now, the next workshop will once again be held in Toronto, at the Holiday Inn Downtown City Hall, June 13 - 15, 1994. We hope to see you all again in 1994. We would like to extend our warm gratitude to the organizers and participants of the 1993 Windsor Workshop.

Bernie James
Energy, Mines & Resources Canada

John Russell
U.S. Department of Energy

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

JUNE 14-16, 1993

TABLE OF CONTENTS

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

JUNE 14-16, 1993

TABLE OF CONTENTS

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

JUNE 14-16, 1993

TABLE OF CONTENTS

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

JUNE 14-16, 1993

TABLE OF CONTENTS

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

OPENING ADDRESS

Norman Moyer
Assistant Deputy Minister, Corporate Policy and
Communications Sector, Dept. of Energy, Mines & Resources Canada

NOTES FOR AN ADDRESS

DELIVERED ON BEHALF OF
BILL MCKNIGHT
MINISTER OF ENERGY, MINES AND RESOURCES CANADA

BY MR. NORMAN MOYER
ASSISTANT DEPUTY MINISTER
CORPORATE POLICY AND COMMUNICATIONS SECTOR

AT THE
1993 WINDSOR WORKSHOP

TORONTO, ONTARIO
JUNE 14, 1993

Thank you, David for that kind introduction, and good morning, ladies and gentlemen. It's an honour to be here today among the top performers of the North American alternative transportation fuel industry. Mr. McKnight was unable to attend due to a previous commitment, and he sends his regrets.

As most of you are no doubt aware, I am privileged to share the stage this morning with Chuck Imbrecht, who I understand is serving his fifth consecutive term as Chairman of the California Energy Commission. Welcome to Toronto! I know many people gathered here today are looking forward to your keynote address.

I would like to start off today by saying a few words about the Windsor Workshop. As most of you know, this workshop has been a tradition in the transportation industry for a decade now. Over the years it has evolved into the most important forum on alternative fuels in North America. Your discussions have progressed from technical papers and discussions on alternative fuel concepts and theories to Original Equipment Manufactured alternative fuel vehicles using propane, natural gas and methanol. In fact, the world's first hydrogen fuel-cell-powered bus was just unveiled on Tuesday.

Indeed, the Windsor Workshop provides an excellent example of technology transfer in action. I think this is extremely important. Your industry is rapidly developing — it is imperative that the lines of communication remain open as to your successes, your emerging opportunities, and the barriers that stand in the way of your goals.

Therefore, Energy, Mines and Resources, through the Canada Centre for Mineral and Energy Technology — CANMET, to many of you — is proud to be a sponsor of this workshop, particularly on this, its tenth anniversary. CANMET firmly supports your efforts to accelerate the commercialization of your technologies through concerted technology transfer. To recognize the major successes that some of you have achieved in this regard, I will be presenting an award later on behalf of CANMET. The award recognizes industry's efforts in commercializing new technologies in the areas of energy efficiency and alternative energy. I'll tell you more about that in a few minutes.

But first, I'd like to talk about some of the barriers that are inhibiting the commercialization of alternative transportation fuels here in Canada. Some of these are institutional, while others are technical. In any case, substantial effort and resources will be required to overcome these obstacles, which poses a challenge in these times of economic restraint.

The question that remains is this: how can we most effectively address these barriers when government and industry are each under pressure to operate as cost-effectively as possible?

I believe the answer is in the formation and maintenance of strategic alliances — alliances that will not only advance alternative transportation fuels, but will boost the competitive prospects of your entire industry. Of course, we do not need to look very far into the past to see successes in this regard. By working together, government, industry and academia have been able to introduce a new fleet on alternatively fuelled vehicles in this country. Over 140,000 propane vehicles and 35,000 natural gas vehicles are on the road in Canada. Domestic sales of ethanol-blended gasoline exceeded 256 million litres last year. And we're road-testing some of the first methanol, ethanol, hydrogen fuel-cell-powered and electric vehicles in the world.

The credit for these achievements must be shared — by industry, by universities and research organizations, and by government at all levels. Our successes in the alternative transportation fuels industry clearly demonstrate what strong partnerships can achieve in this country. Let me say a few words about that now.

Federal R&D Program

As many of you know, the Government of Canada has supported the alternative transportation fuels industry since 1980. In recent years, responsibility for federal R&D activities in this area has been that of CANMET, the main S&T arm of EMR. CANMET's objectives in the alternative fuels area are three-fold: first, we are dedicated to working with your industry to commercialize technologies with near-term market potential, like propane, natural gas and alcohol fuels. Second, we support the development of longer-term alternatives with significant market prospects, including hydrogen-powered and electric vehicles. And third, we are committed to assisting with the development of an infrastructure that will facilitate the market entry of proven alternative fuels.

Our experience has shown that cost-shared research and development is the best way to meet our technology goals. In keeping with this policy, CANMET is working in cooperation with a wide number of stakeholders from both government and industry.

To promote the commercialization of short-term technologies, we have struck R&D agreements with a number of industrial partners, as well as the Canadian Gas Association, the Propane Association of Canada, and the Canadian Oxygenated Fuels Association. Our goals? Technology improvement and cost reduction. At the same time, we are assisting these groups with the development of technical and safety standards needed to encourage the acceptance in the market place.

To promote the development of longer-term alternatives like hydrogen and electric vehicles, we are supporting R&D by several Canadian universities, research organizations, and groups such as the Electric Vehicle Association of Canada and the Hydrogen Industry Council. Our shared objectives for these technologies include cost-performance improvements that will permit eventual manufacturing. For although hydrogen and electric vehicles are expensive, they are also the most environmentally friendly transportation alternatives available to us. Their future market prospects are therefore enormous.

Finally, CANMET is working closely with your industry, other groups within EMR and concerned federal departments to further develop the regulation and fuel infrastructure that is so critical to the commercial penetration of these fuels. I'm pleased to say that a great deal of progress is being made in this regard. Harmonization of standards for emissions, safety and fuel consumption has been achieved for conventionally fuelled vehicles at the national level. Efforts are underway to achieve the same regulatory milestones for new fuels. I want to acknowledge the importance of the strong industry assistance that delegates in this room and your colleagues provide to us through the technical organizations and committees that you have spent many hours serving.

In terms of the refuelling infrastructure, I believe the Government of Canada has played a useful role in funding the construction of natural gas fuelling stations. To date, we have contributed to the development of more than 140 such stations in cities across the country. We are also working with your industry to expand the methanol refuelling network. We hope these will follow the trend of growth already set by propane fuelling stations.

Government and industry alike should be proud of the teamwork that is fostering the successful development of alternative transportation fuels. It has been a tough climb for the past dozen years or so — but I believe we have recently begun to see evidence of our progress.

Market Place for Alternative Fuels

We need only examine the conditions of the transportation market place to recognize that these fuels do have an important role to play. As a result of the initiation of new environmental policies in countries around the world, enormous new markets have been created for alternative fuels. California, for example, is calling for quotas of zero-emission vehicles by 1998. In the interim, demand is going to increase for cleaner transportation technologies. Infrastructures will continue to develop. And the public confidence in these new technologies will grow.

Here in Canada, we have had great success in the sale of natural gas and propane conversion kits for vehicles. Today, there are over 150,000 converted cars and trucks operating on Canadian roads. The recent announcements of OEM vehicle production by the 'Big Three' has added a new factor in the way we do business. The transition zone to our evolution to alternative fuels has expanded. While this development has the benefit of providing added choice for the consumer, it magnifies the requirement for technology development — toward both competitive conversion technologies and leading-edge Canadian technology for OEMs.

In short, we are entering a new era in the development of alternative transportation fuels — one with significant commercial opportunities for your industry. It is interesting to note that other countries are now recognizing what we have known for some time — that alternatively fuelled vehicles have a major role to play in meeting global environmental objectives. As a result, we are facing increased competition. And we must work harder to maintain our technical edge and take advantage of emerging world markets.

As technology developers in the alternative fuels industry, Canadians are among the best. To exploit the full potential of our technologies, we must maintain these strategic alliances between government, industry and academia. They have been the key to our successes in the past. And they will ensure a prosperous future for our technologies.

However, we should not take our partnerships for granted. We need to consult with each other to review the cooperative structures that are in place right now. And we need to identify the issues that most require our attention. However, to do so, we must ensure that everyone is at the table — from all levels of government, and from all sides of the industry. That's the essence of consultation — information sharing. The Windsor Workshop provides an excellent starting point each year for discussion, and we must carry this momentum throughout the year.

Award Announcement

On that note, I'd like to talk a little more about the announcement I made earlier regarding a new CANMET technology transfer award. CANMET has long recognized the value of technology transfer efforts and the role they have played in expanding the contribution of alternative energy and energy efficiency. To show our appreciation, an award will be presented every year in recognition of outstanding contributions in transferring energy efficiency and alternative energy technologies to the market place. This first award is being given for outstanding achievement in alternative transportation fuels. I think this is a clear demonstration of the importance we assign to developments in this key sector.

To select this year's winner, we asked representatives of your industry to provide us with nominations. It was a very close race. The runners up included Mr. Elson Fernandes of Clemmer Industries for the development of a methanol fuel dispensing system, and Mr. Don Henry of Imperial Oil for work on specially formulated motor oil for gaseous fuelled vehicles. Both of you are to be commended for your achievements.

I am now honoured to announce that this year's award has been won by the Engineering Division of Chrysler Canada for your development of vehicles powered by natural gas, propane and methanol which are being mass-produced. Will Mr. Stuart Perkins and his team of John Mann, Jim Lanigan, Larry Robertson and Shawn Yates please come up here to receive these certificates and a small token of our appreciation?

Congratulations!

Thank you, and all the best for a successful workshop.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

OPENING ADDRESS
N. Moyer, Assistant Deputy Minister, Corporate Policy and Communications, Energy, Mines & Resources Canada

No discussion took place after this presentation. However, an annual award by CANMET was announced for alternative energy technology transfers to the marketplace. The Engineering Division of Chrysler Canada was chosen for the 1993 award from a group of several candidates who had been nominated.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

KEYNOTE ADDRESS

(unavailable at time of printing)

Charles R. Imbrecht
Chairman, California Energy Commission

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

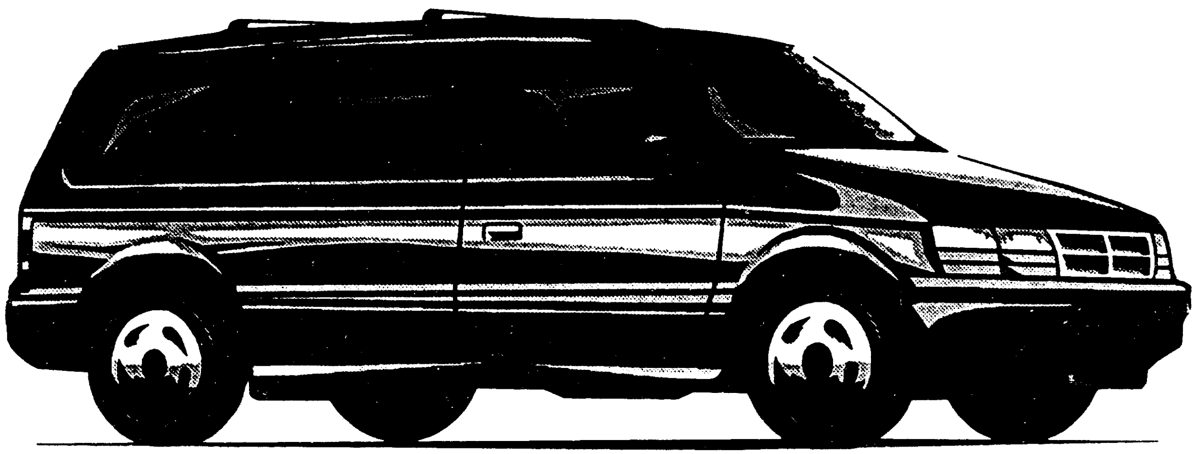
MARKET PLACE IMPLICATIONS IN THE CHANGING WORLD OF MOTOR FUELS POLICY PANEL DISCUSSION

Panel Moderator: Frederick Potter

NEW IDEAS FOR FEDERAL ROLE IN MARKETING AFVs

D. Rodgers
U.S. Department of Energy

New Ideas for Federal Role in Marketing AFVs



TRANSPORTATION TECHNOLOGIES

Office of Transportation Technologies
U.S. Department of Energy

New Ideas

Federal Mandates to Leverage Alternative Fuel Vehicles

- Clean Air Act Amendments of 1990
- Intermodal Surface Transportation Efficiency Act of 1991
- Energy Policy Act of 1992

p:\doeott\task2\overhds\leverage.drw

EPACT Implementation Plan for Alternative Fuels

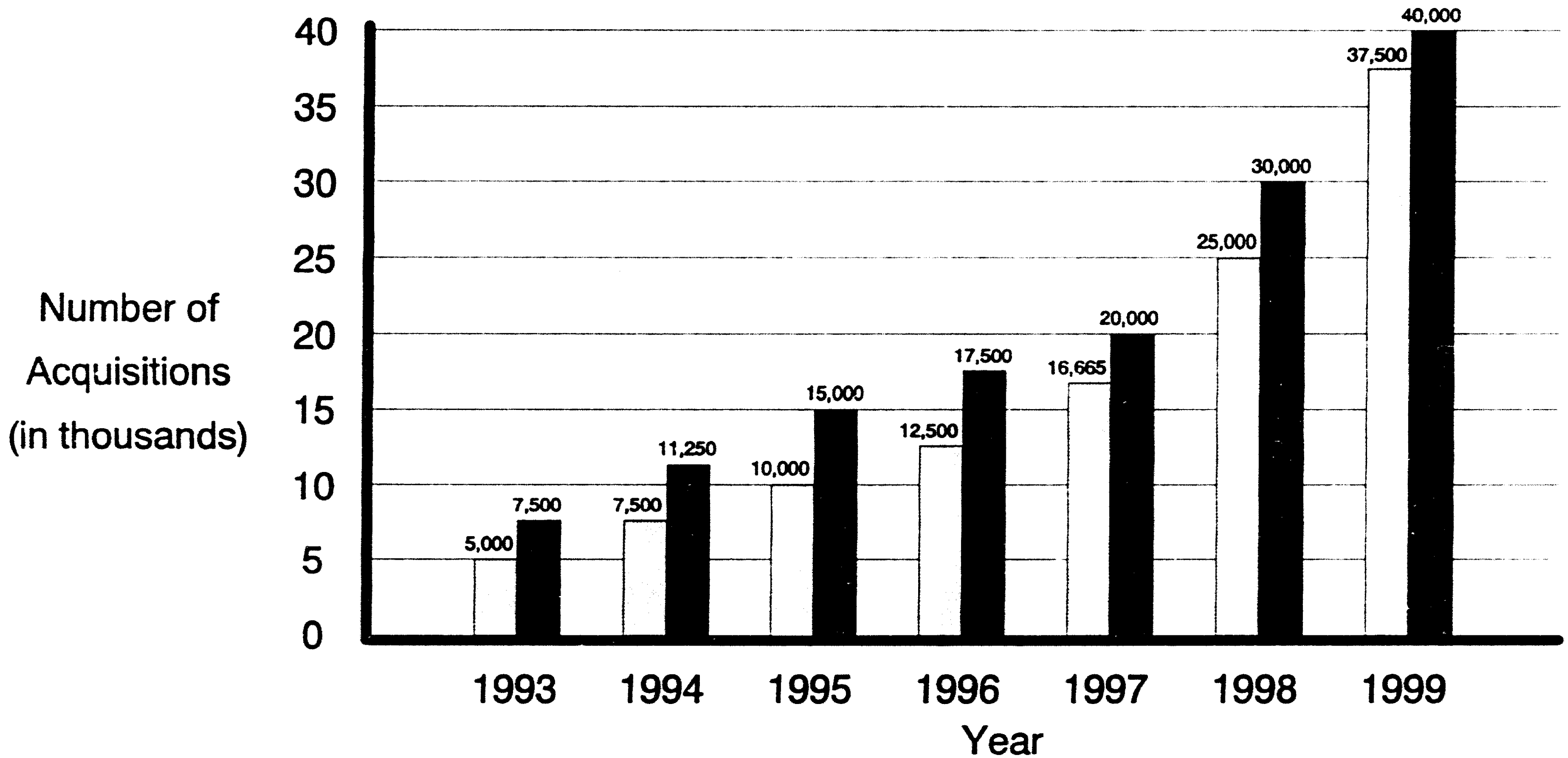
Strategy

Program Elements

- Fleet Mandates
- Fuel Supply
- Consumer Awareness/Education
- Incentives/Financial Assistance
- Misc. Regulations/Guidelines
- Reports/Analysis

p:\doeott\task2\overhds\epactstg.drw

Requirements for Federal Fleet Alternative Fuel Vehicle Acquisition

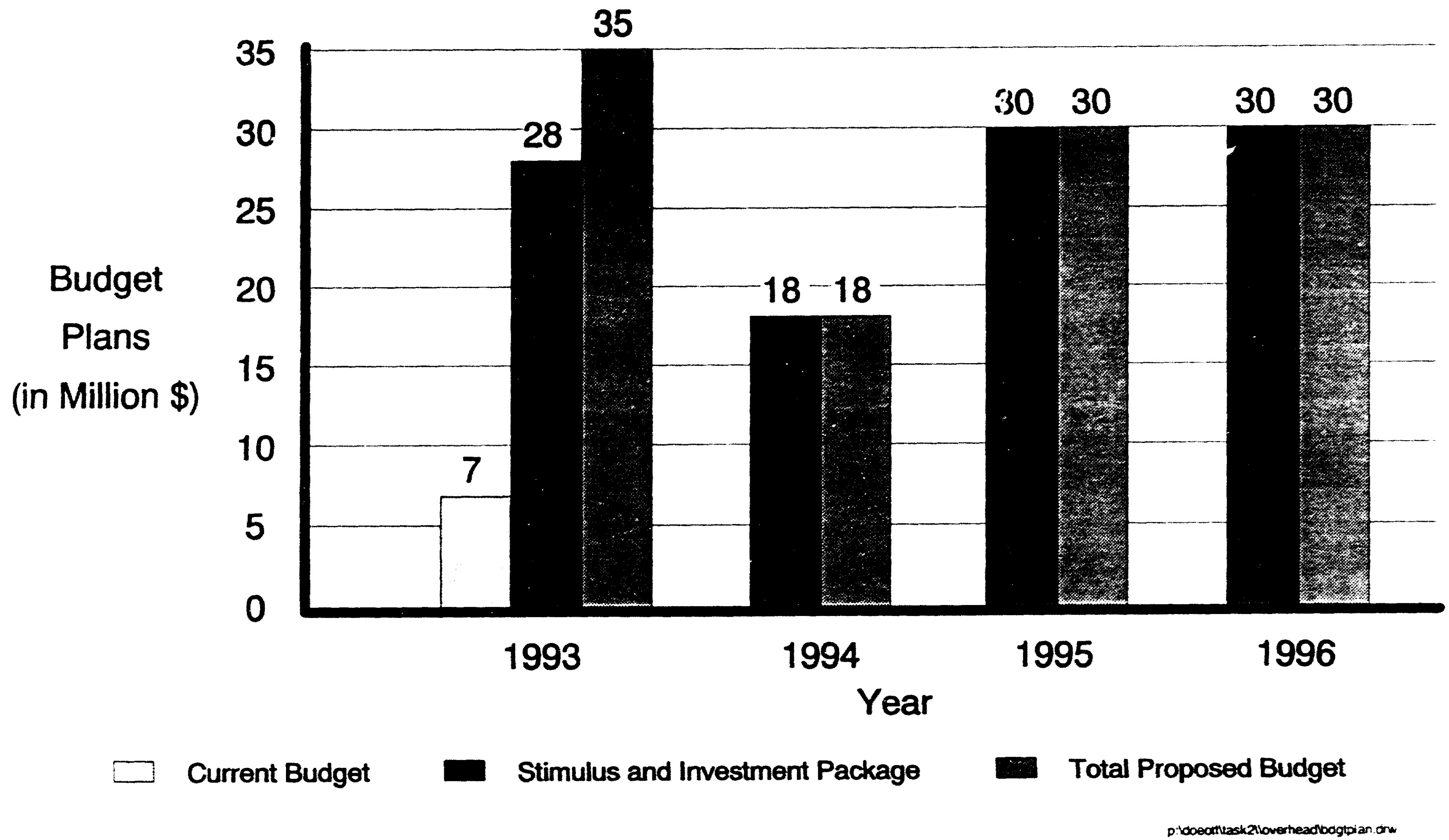


Energy Policy Act of 1992
Executive Order 12844

Based on 50,000 vehicle acquisitions per year

p:\doeott\task2\overhead\gm'stfa.drw

Budget Plans for Federal Fleet Alternative Fuel Vehicle Acquisition



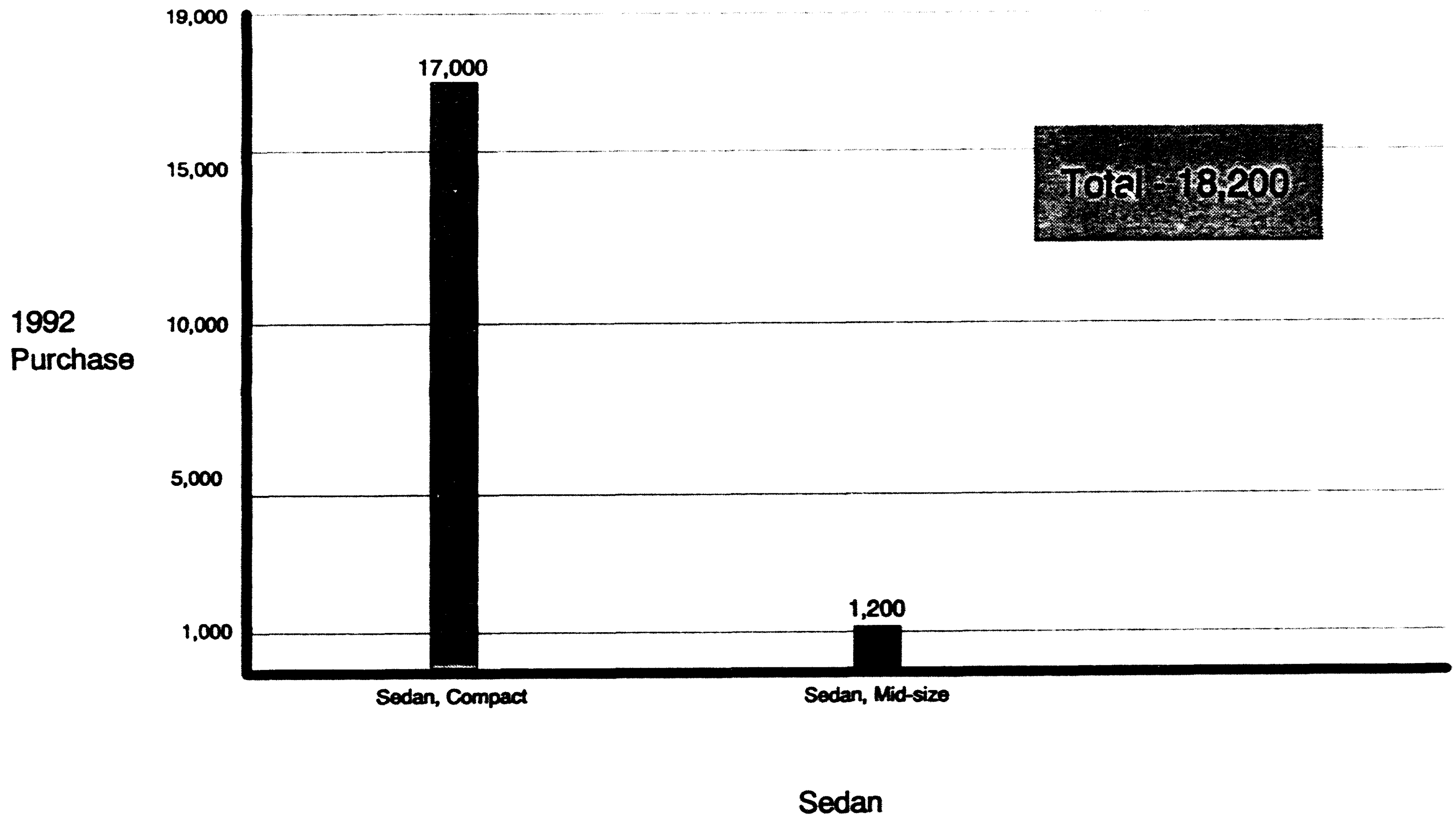
New Ideas

Three Components of Alternative Fuel Vehicle Marketing

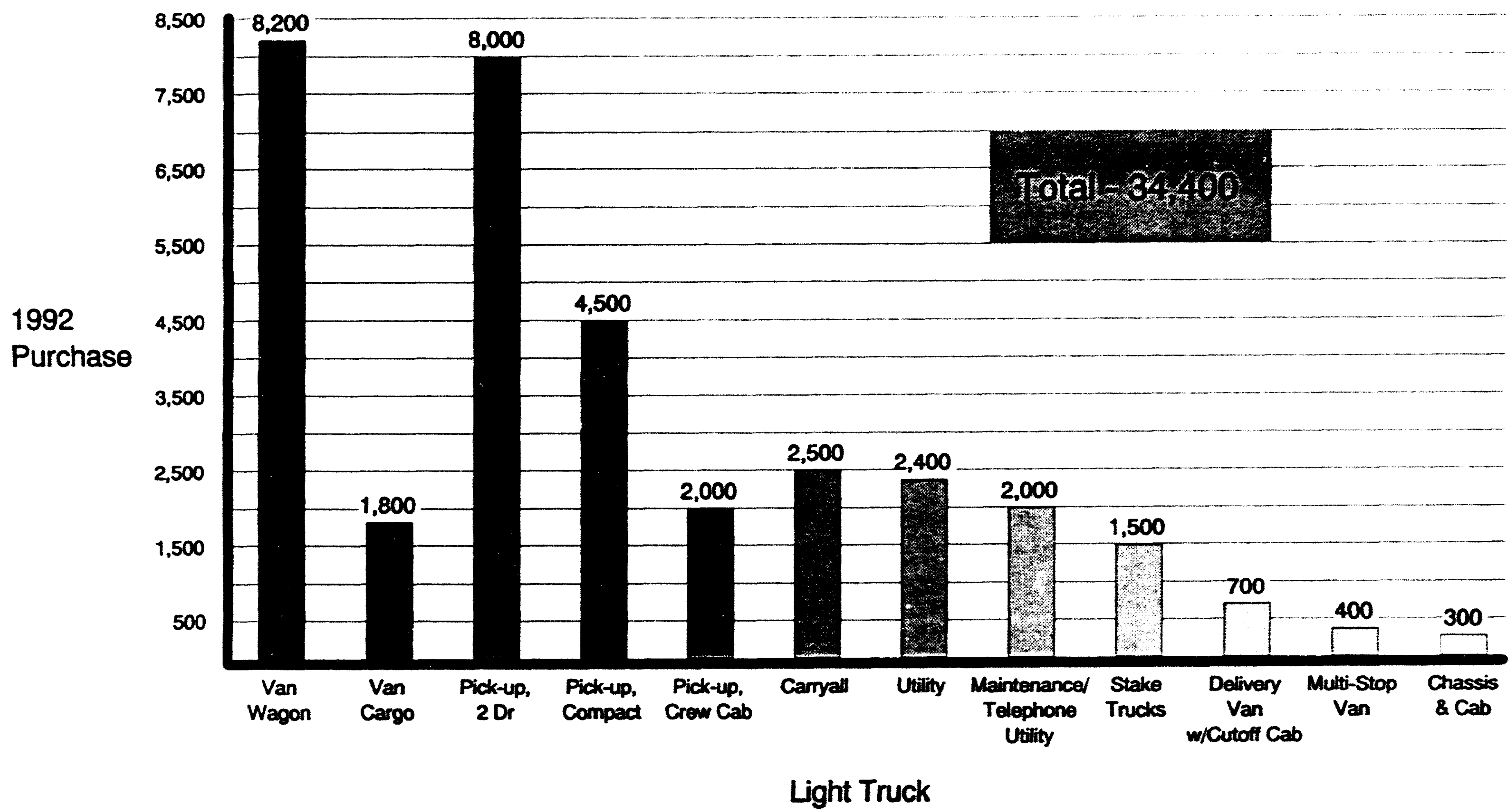
- Concentration
- Concentration
- Concentration

p:\doeoff\task2\overhds\3compnts.drw

Federal FY 1992 Purchases - Sedans
Overview by Category



Federal FY 1992 Purchases - Light Trucks
Overview by Category



p:\doeott\task2\\overhead\prchse92.drw

Federal Fleet Alternative Fuel Vehicle Summary
In Operation April 1993

Vehicle Type	Model Year	Fuel	Quantity
Chrysler Van	1991	CNG	2
	1992	CNG	75
Dodge Spirit	1992	M85	2,500
Ford Taurus	1991	M85	40
Ford Econoline Van	1992	M85	20
Chevrolet C-20 Pickup Trucks	1992	CNG	600
GM/Chevy Lumina	1991	M85	25
	1992	E85	24
LLV & Jeep (USPS)	1984 - 1993	CNG	1,075
Total			4,361

Source: GSA-IFMS, USPS, and DOE data

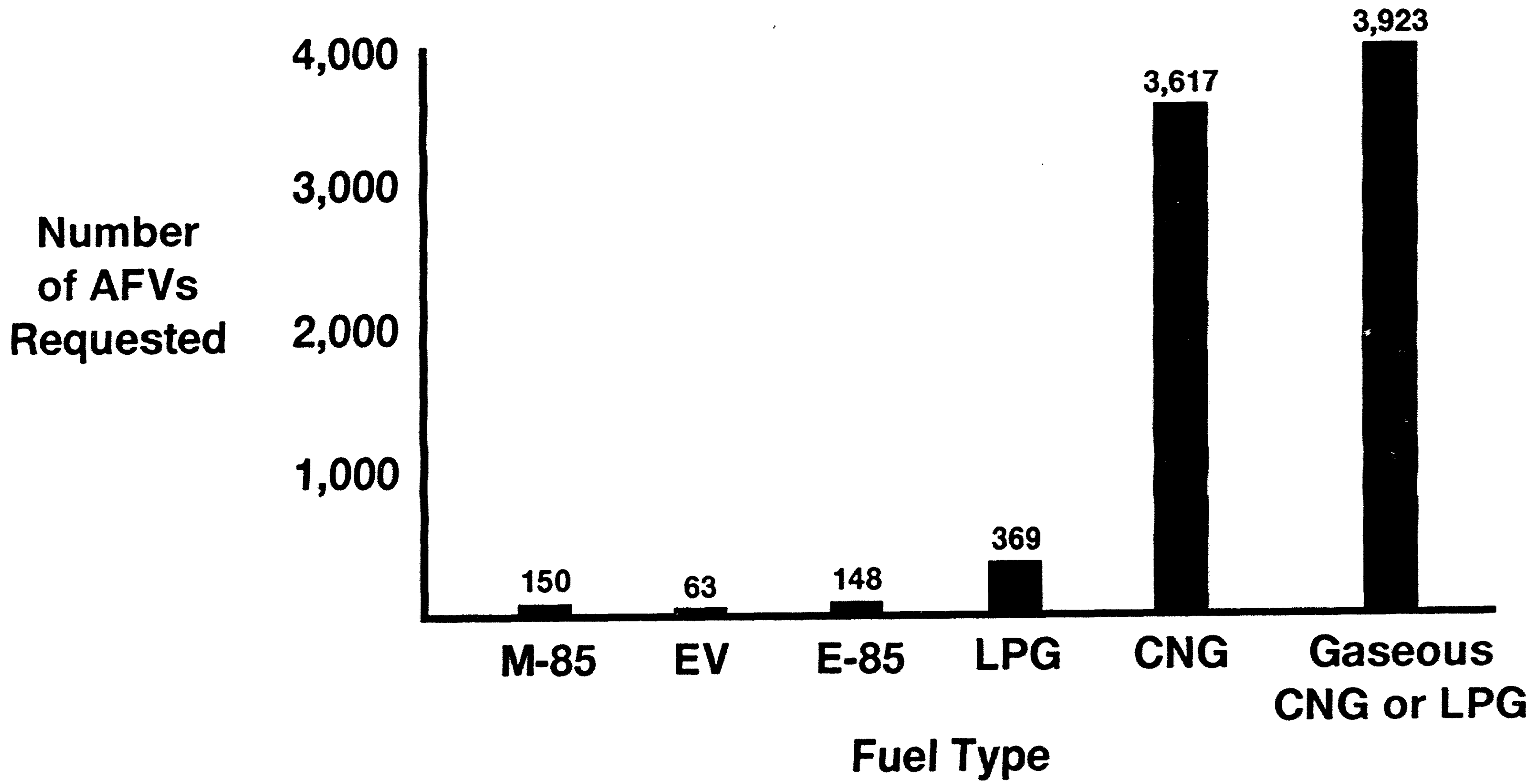
p:\doeotttask2\overhead\tafv493.drw

Federal Fleet Alternative Fuel Vehicle Summary
Estimated FY 1993 Acquisitions
(Includes Postal Service/DOD)

Vehicle Type	Model Year	Fuel	Quantity
Chrysler Van	1993	CNG	100
Dodge Spirit	1993	M85	2,555
Ford Taurus	1993	M85	300
Ford Ecostar Van (USPS)	?	Electric	6
Chevrolet C-20 Pickup Trucks	?	CNG	45
GM/Chevy Lumina	1993	M85	50
	1993	E85	50
Conversions (DOE/NREL)	-	CNG	1,800
		LPG	
Conversions (USPS)	-	CNG	1,400
Conversions (ARPA)		CNG	?
Total			6,256

p:\doeott\task2\overhead\ffaivsum.drw

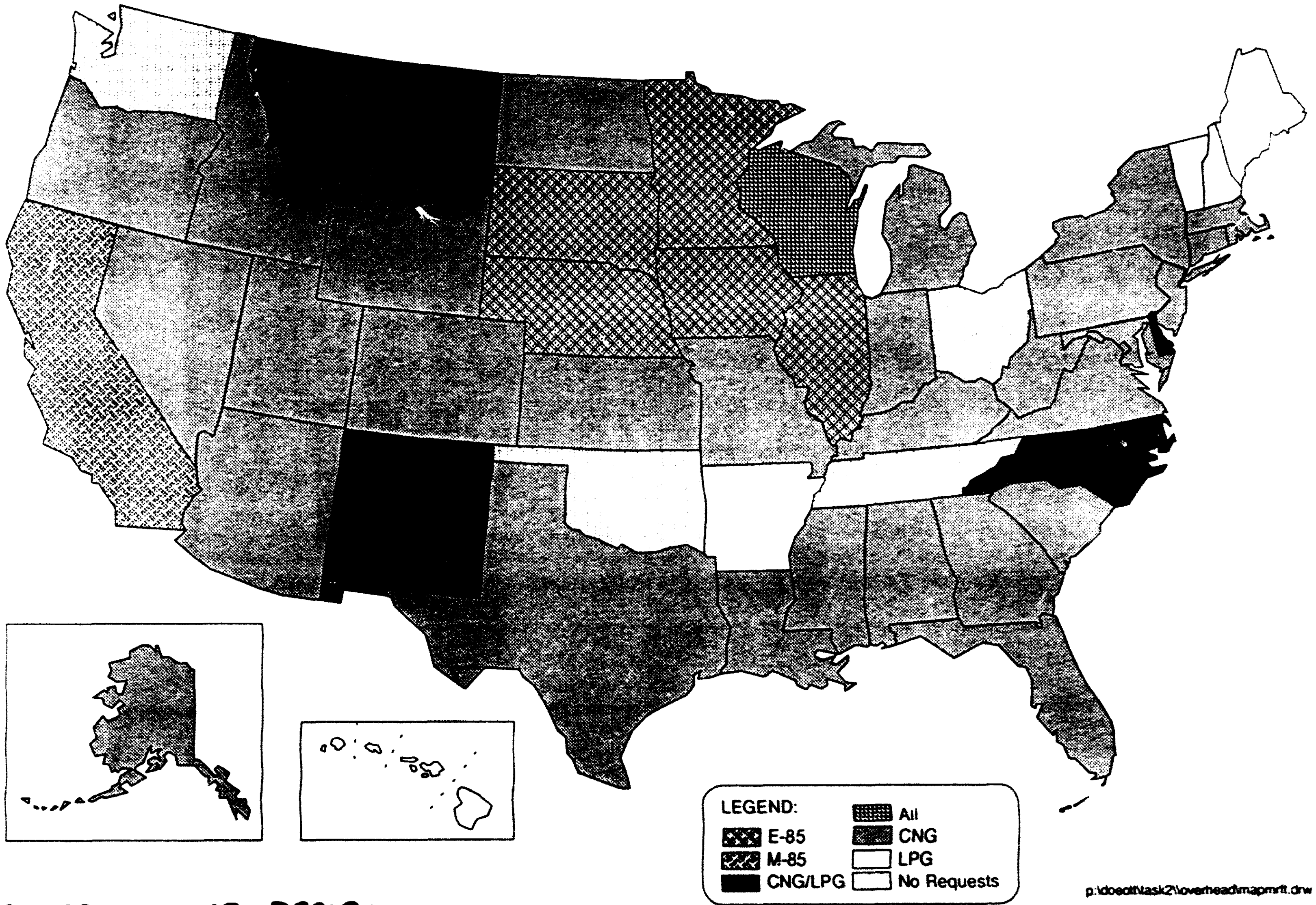
FY93 State Requests for AFVs



SOURCE: DRAFT DOE REPORT

p:\doeott\task2\\overhead\barafvs.drw

Most Requested Fuel Types



p:\doeotf\task2\overhead\mapmrft.drw

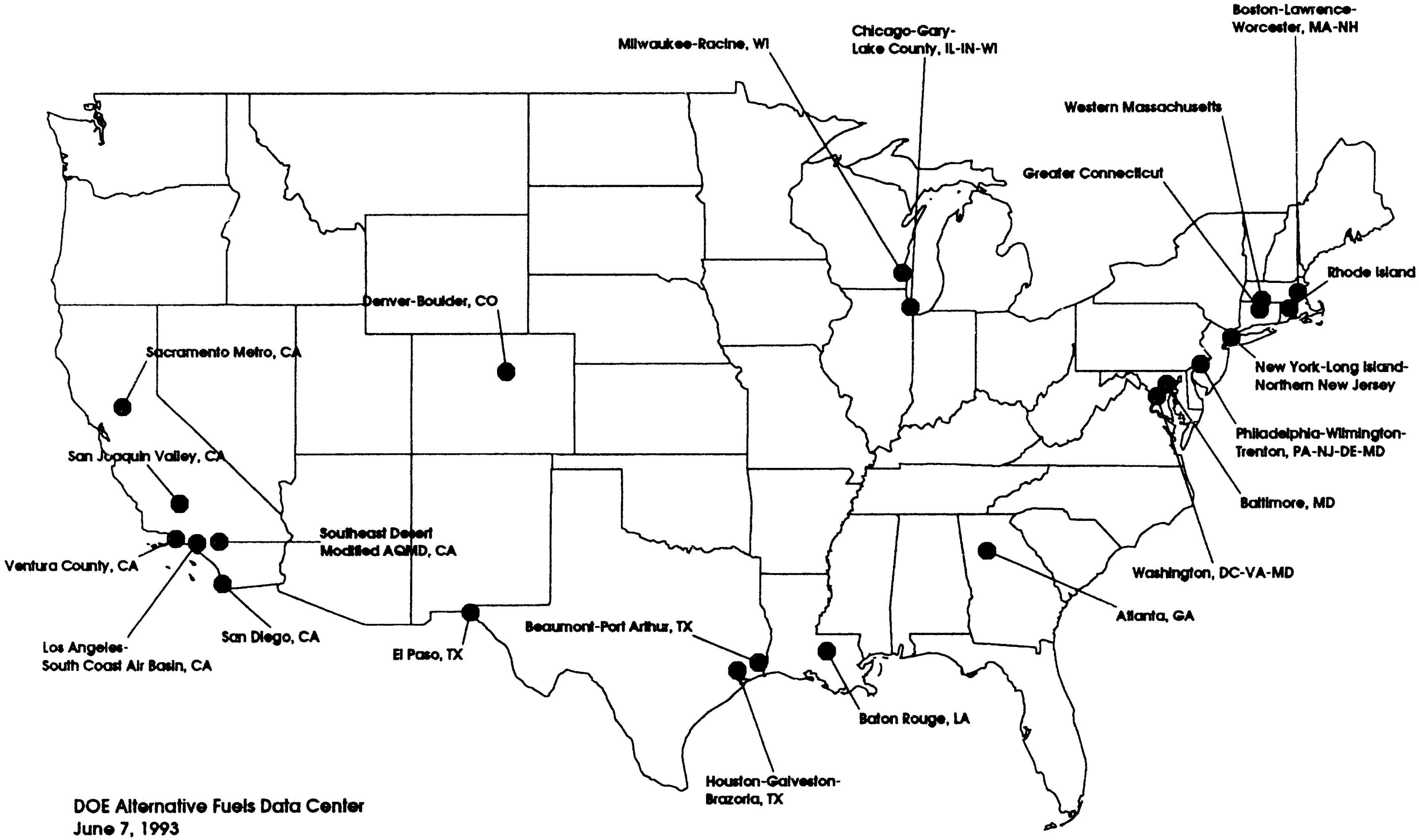
SOURCE: DRAFT DOE REPORT

Top Five Problems/Concerns Expressed by the States

1) Funding the incremental cost of AFVs.
2) Availability of alternative fuels and AFVs.
3) Limited range of dedicated AFVs in large states.
4) Lack of information on alternative fuels and AFVs.
5) Lack of vehicle/facility standardization.

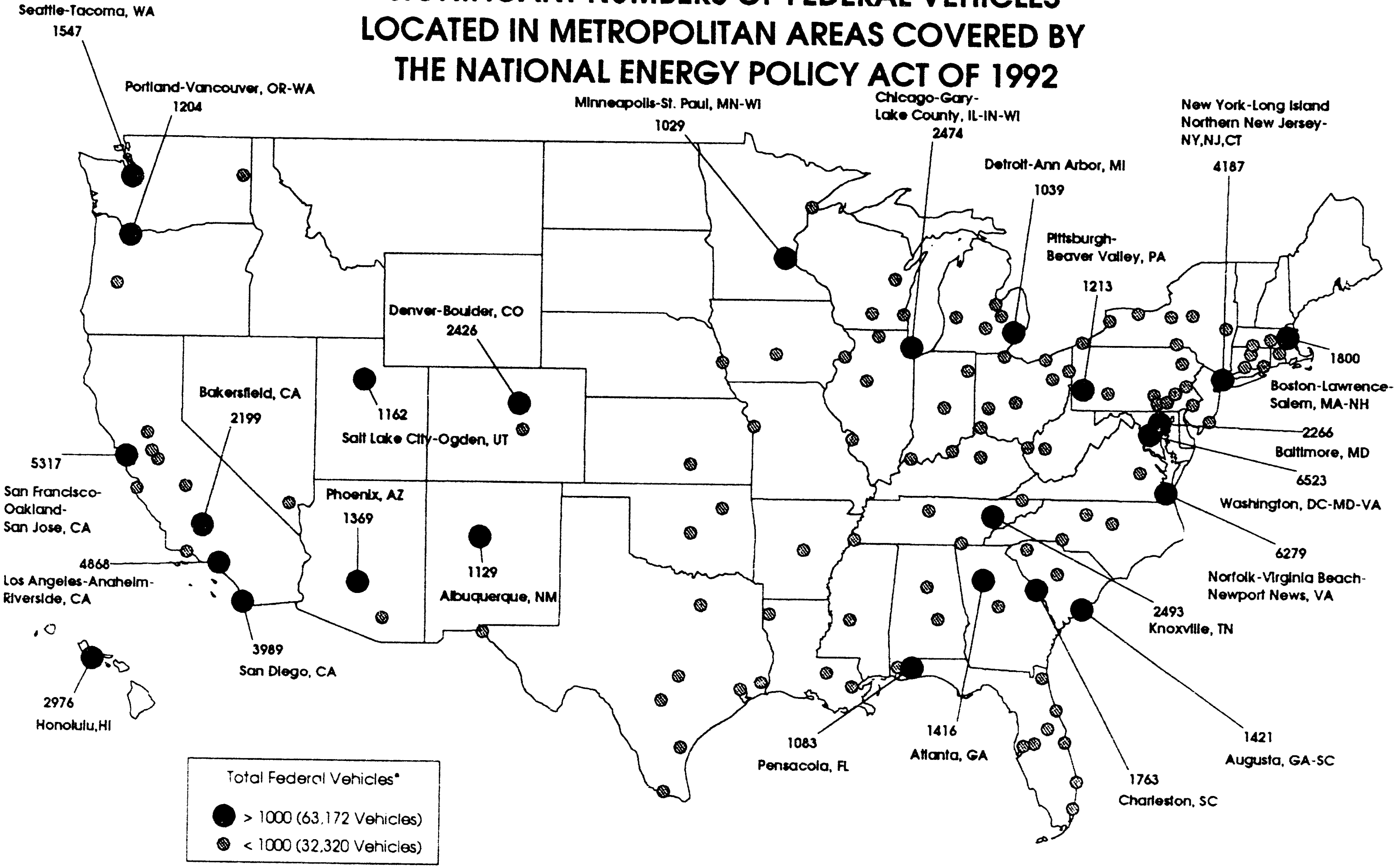
p:\doeott\task2\overhead\topfive.drw

22 Non-Attainment Areas Covered By The Clean Fuel Fleet Program



DOE Alternative Fuels Data Center
June 7, 1993

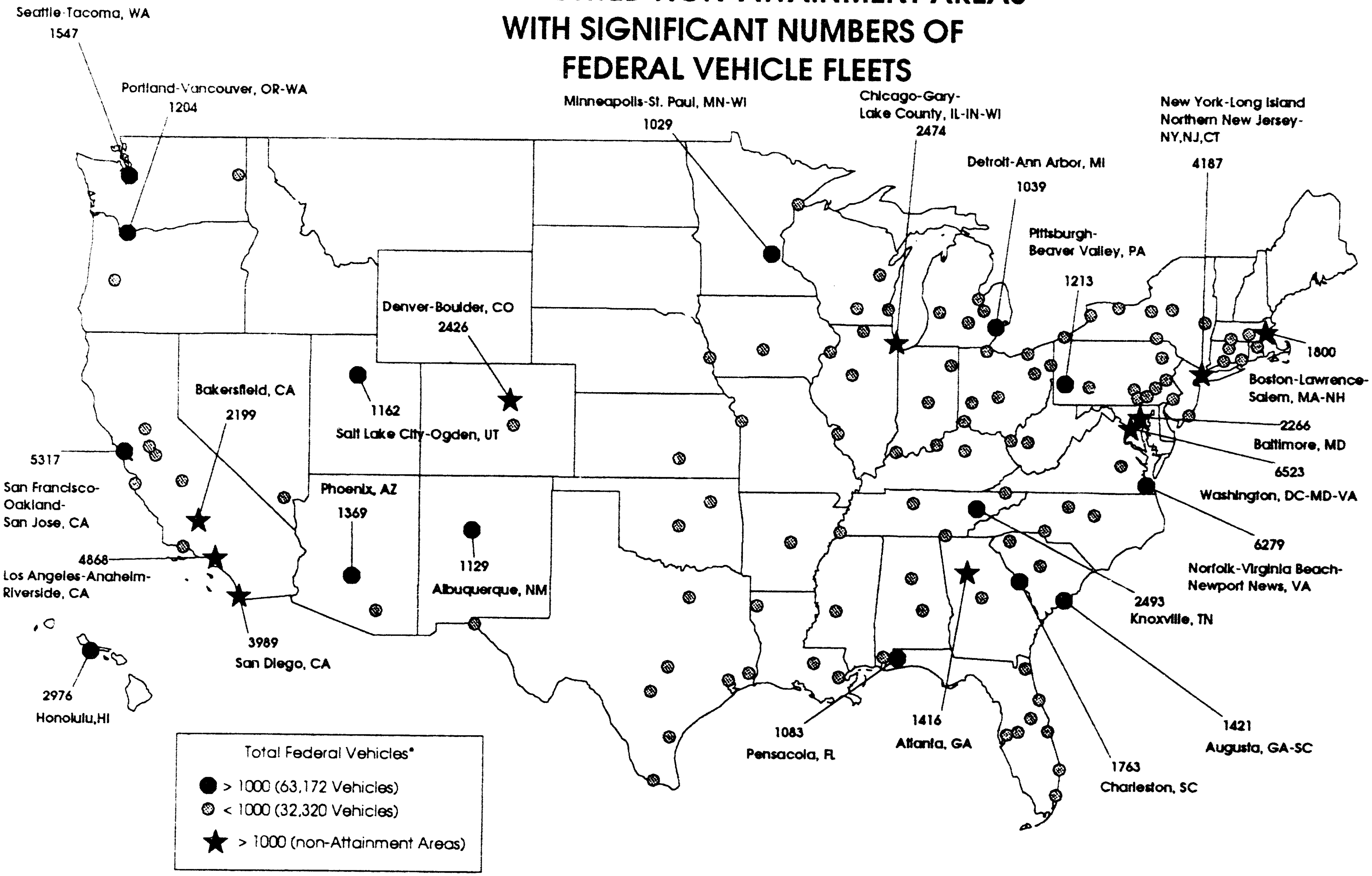
SIGNIFICANT NUMBERS OF FEDERAL VEHICLES LOCATED IN METROPOLITAN AREAS COVERED BY THE NATIONAL ENERGY POLICY ACT OF 1992



*Does not include Post Office and
DOD civilian, Air Force and Marine Corps vehicles

DOE Alternative Fuels Data Center
June 7, 1993

HIGHLIGHTED NON-ATTAINMENT AREAS WITH SIGNIFICANT NUMBERS OF FEDERAL VEHICLE FLEETS



*Does not include Post Office and
DOD civilian, Air Force and Marine Corps vehicles

DOE Alternative Fuels Data Center
June 7, 1993

Clean Cities Program

P120-G1084701

Clean Cities

Purpose

- Concentrate alternative fuel types
- Create "grass roots" market demand
- Promote coordination of city, state, federal, industry

P120-G1084703

Clean Cities

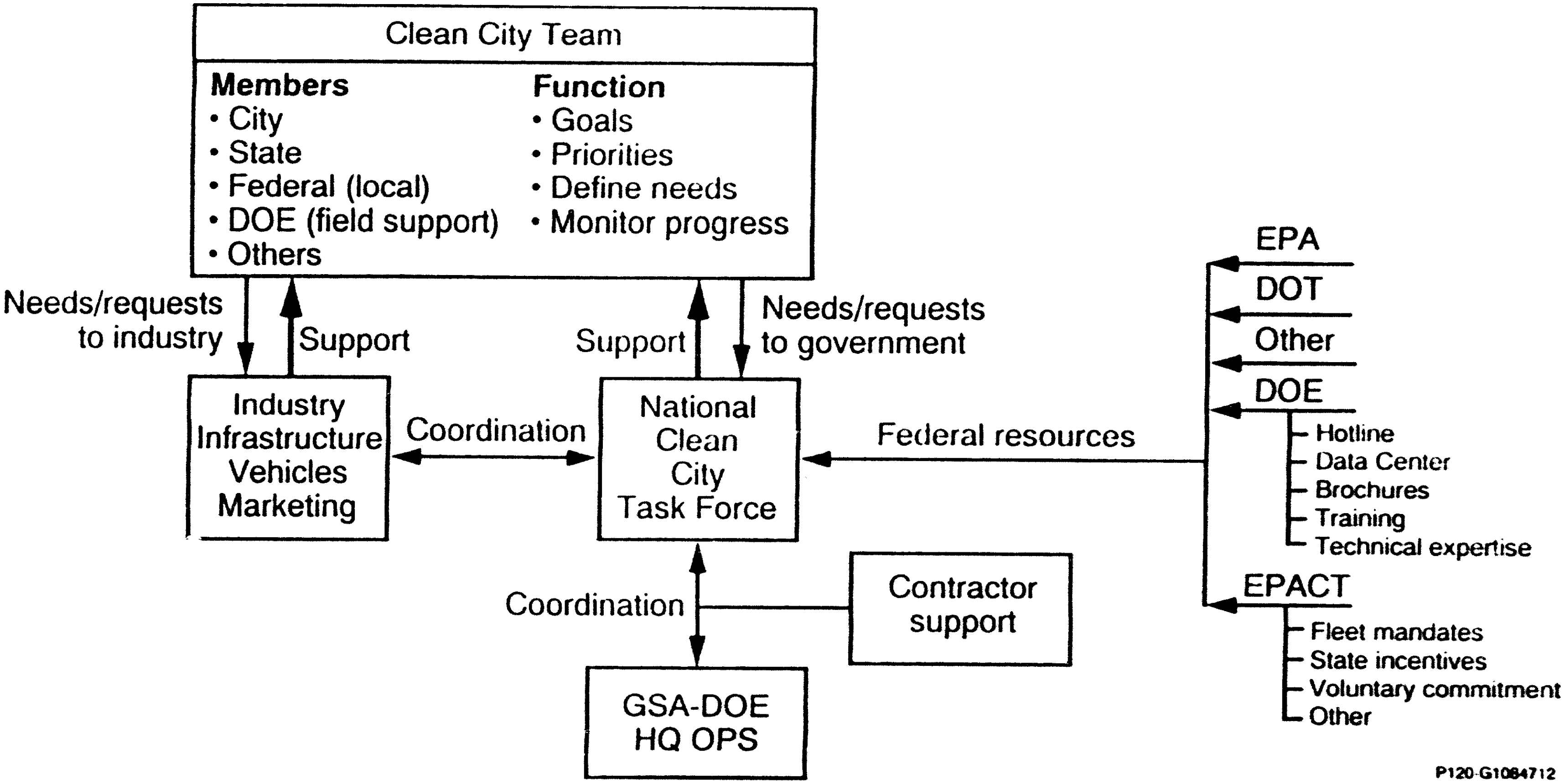
How Does It Work?

- City makes choice and commitment
- State honors commitment
- Federal agencies (local) honor commitment
- Federal agencies (Headquarters) provide support activities
- Industry meets commercial needs
- Public joins in

P120 G1084704

Clean Cities

Clean Cities Organization



P120-G1084712

Clean Cities

Unique Focus

- Grass roots leadership
- "A person" (city) becomes responsible for success
- Partnerships with clear goals and leadership

P120 G1084705

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

POLICY PANEL DISCUSSION:
MARKET PLACE IMPLICATIONS IN THE CHANGING WORLD OF MOTOR FUELS
D. Rogers, U.S. Department of Energy

Q. Frederick Potter, IRI: Would you comment on the President's Task Force for fleet conversion?

A. Executive Order 12844 calls for federal fleets to accelerate their acquisition of alternative fuel vehicles beyond the plan in the Energy Policy Act of 1992. It established a task force to help the implementation of the executive order. The appointed chairman is Garry Mauro of the Texas General Land Office, and Dr. Susan Tierney of the Department of Energy is the vice chair. The task force goal is to produce recommendations by August 1, 1993 on how the federal government can maximize development of alternative fuels. The first meeting was in Austin, Texas on June 7, 1993 with members from automobile manufacturers, fuel suppliers, fleet operators, and state and local governments.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

MARKET PLACE IMPLICATIONS IN THE CHANGING WORLD OF MOTOR FUELS POLICY PANEL DISCUSSION

Panel Moderator: Frederick Potter

POLICY ISSUES FOR ALTERNATIVE FUELS IN CANADA

A.C. Taylor
Energy, Mines & Resources Canada

(Other presentations made during this Panel Discussion are unavailable)

POLICY ISSUES FOR ALTERNATIVE FUELS IN CANADA

A.C. TAYLOR

ENERGY, MINES AND RESOURCES CANADA

NOTES FOR PRESENTATION

WINDSOR WORKSHOP
14 JUNE 1993

WHERE IS CANADA IN ALTERNATIVE FUELS ?

Are we still "ahead of the U.S." in Alternative Fuels ?

..... probably not

This is good news - we need the help

bad news - maybe our approach needs a fresh look

EMR is working with others to

clarify our goals in alternative fuels

examine our policy and activities

NEED FOR A REVIEW

There are several reasons for a review

- technology has changed
- fuel and vehicle markets and regulations are changing
- increased U.S. activity presents opportunities for Canada
- several provincial governments are reviewing policy and activities
- a number of federal ATF programs expire in 1994
- the ATF industry and vehicle manufacturers are seeking clarification of government's commitment to alternative fuels.

SCOPE OF OUR REVIEW

1. Clarifying our Goals

We're learning more about the benefits

- environment
- user costs
- industry opportunities
- fuel markets
- energy security

But the real question is what are we trying to achieve

- different goals bring different roles

eg. how important is
- new technology
- export markets
- factory-produced vehicles
- government fleet use ?

SCOPE OF OUR REVIEW (continued)

2. Examining policies and activities

   Financial support

      fuel taxation
      support to associations
      grants for conversions
      vehicle taxation incentives

   Information

      information to users
      marketing and promotion
      standards
      feasibility studies

   Technology

      longer term research
      technology transfer
      export markets

SCOPE OF OUR REVIEW (continued)

3. Consultation

- some aren't shy
- discussion paper
- informal channels
- formal processes
- plenty of controversy !

HOW HAVE WE BEEN APPROACHING ALTERNATIVE FUELS ?

1. Assist with the development of technology

    - federal R&D
    - contributions to industry
    - demonstration projects

2. Remove market barriers

    - regulatory
    - infrastructure
    - conversion costs
    - fuel supply costs
    - lack of information

3. Let the market develop

WHAT HAS BEEN ACHIEVED WITH THIS ?

British Columbia

NGV
- showcase for NGV development
- fleet and private (light duty vehicles)
- public fueling network
- demonstration of transit buses
- ferries

Propane
- strong fleet auto propane market
- extensive fueling infrastructure

Methanol
- two stations operating
- interest in light duty vehicle demonstration in 1993/94

Hydrogen
- Ballard fuel cell bus

Alberta, Saskatchewan, Manitoba

Propane
- strong auto propane market
  very favourable propane prices
- extensive fueling infrastructure

NGV
- little NGV use except Alberta
- some success in fleet use in Alberta
- transit bus demo planned for
  Edmonton and Calgary
- development of composite on-board
  NGV cylinder in Alberta

Methanol
- one station operating in Calgary
- interest in light duty vehicle
  demonstration in 1993/94
- transit buses in Medicine Hat

Ethanol
- production and marketing (as a blend)
  in Saskatchewan and Manitoba

Ontario

Propane

- strong auto propane market
- extensive fueling infrastructure
- factory production of vans and/or pickups is a possibility

NGV

- good light duty market, esp. in S.W.
- over 50 public stations, private as well
- 1000 VRAs, with production in Toronto
- production of NGV vans in Windsor
- over 50 transit buses in operation
- bus production with export potential
- production of steel cylinders

Methanol

- one station in Toronto, another soon
- several makes of vehicles produced
- vehicle demo through car rentals
- interest in light duty vehicle demonstration in 1993/94
- transit bus demo in Windsor

Ontario (continued)

Ethanol

- one plant with production increasing
- considerable interest in other plants
- successful marketing of blends

Electric Vehicles

- development work and production of a test quantity of vans in Windsor
- battery development in Toronto

Quebec

Propane

- some propane vehicle activity
- reasonable fueling infrastructure

NGV

- was an original leader in public fueling
- reasonably loyal vehicle market
- focus has moved from public to private fueling in recent years

Atlantic Canada

Propane

- very limited use of propane vehicles owing to high fuel cost
- market demonstration underway in Newfoundland, to address barriers
- potential in Maritimes under study

Summary for Canada

- considerable interest in ATF
- considerable R&D activity
- opportunities for ATF use and ATF equipment
- different patterns by region
- growth is slow - it's a hard sell
- success stems from cheap fuel, and in some cases, strong gov't support

SHOULD GOVERNMENT DO MORE TO HELP ?

.... some observations

1. Might not be much more activity without gov't action

- demand for factory vehicles
- will OEM production continue in Canada?
- infrastructure growth
- trade opportunities

2. What could governments do?

- push on fleets, consumers (demos?)
- buy vehicles for own fleets
- fueling infrastructure
- technology

WHAT ARE OUR OPTIONS FOR FURTHER ACTION ?

broad regulation of fleets or fueling not likely

more aggressive subsidies unlikely
- fuels
- fueling infrastructure
- developing technologies
- vehicles and conversions

could increase information programs

be a broker in the market place
(strategic alliances)

convert government fleets

longer term R&D commitments

project-oriented activity

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

MARKET PLACE IMPLICATIONS IN THE CHANGING WORLD OF MOTOR FUELS POLICY PANEL DISCUSSION

Panel Moderator: Frederick Potter

INTERMINISTERIAL COMMITTEE ON CLEAN TRANSPORTATION FUELS

M.D. Harmelink
Ministry of Transportation of Ontario

INTERMINISTERIAL COMMITTEE ON CLEAN TRANSPORTATION FUELS

Co-chaired by
M.D. Harmelink, MTO / B. Beale MOEE

Presented to the
1993 Windsor Workshop
On Alternative Fuels

M.D. Harmelink
Director

ONTARIO

Ministry
of
Transportation

Transportation
Technology and
Energy Branch

June 14, 1993

Mission

- Develop government policy options and strategy options to guide the development and use of clean fuels for transportation
- Coordinate clean fuels activities among provincial ministries

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Objectives

- Assess the potential of clean fuels and develop associated policy options and measures to address:
  - Air quality
  - Health and safety
  - Energy security
  - Transportation efficiency/effectiveness
  - Ontario industry opportunities
- Determine role of and potential for reformulated gasoline/diesel fuel, commercial alternative fuels and advanced technologies

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Clean Fuels

- Modified existing fuels
  - Reformulated gasoline and diesel
- Commercial ATF's
  - Natural gas
  - Propane
  - Methanol
  - Ethanol
- Energy technologies
  - Electricity
  - Hydrogen

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

WORK GROUPS

• WG-1 Vehicle Emissions	MTO/MOEE
• WG-2 Air Quality Analysis	MOEE
• WG-3 Health and Safety	MOL/MCCR
• WG-4 Technology Review	MTO
• WG-5 Industry Analysis	MOEE/MEDT
• WG-6 Market Analysis	MOEE

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

WG-1 Vehicle Emissions

- Initial emission inventories for gasoline
- 5%, 10% , and 16% penetration by each clean fuel by 2010 in combination with gasoline
- 5% ,10% and 16% penetration by a generic clean fuel in combinatio[illegible] with reformulated gasoline in the year 2010

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

WG-2 Air Quality Analysis

- Run ADOM model to establish baseline air quality estimates
- Run ADOM model for 16% penetration by a generic clean fuel in combination with reformulated gasoline in the year 2010
- Work with canyon models to predict local impacts of clean fuels and reformulated gasoline

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

WG-3 Health and Safety

- Review of toxicity characteristics of conventional gasoline and clean fuels
- Toxicity on workers and public to be assessed
- Concerned with aldehydes, benzene and other toxics

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

WG-4 Vehicle Technology Review

- Assess impacts of new car emission standards on benefits of clean fuels
- Assess possible impact of new fuel economy standards
- Review potential of new and emerging technology with respect to emissions and fuel economy

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

WG-5 Industry Analysis

- Assess impacts of gasoline reformulation on petroleum refiners
- Assess impacts of clean fuels on refineries
- Assess industrial opportunities associated with clean fuels

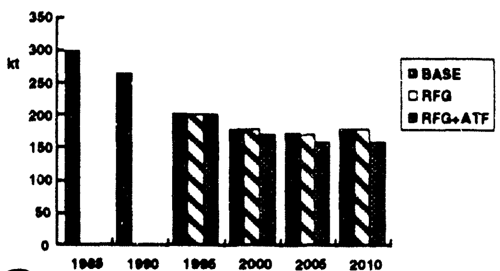
TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

WG-6 Market Analysis

- Review potential for clean fuels in a number of transportation sectors
- Assess the need for market incentives
- Assess government role in promotion of clean fuels

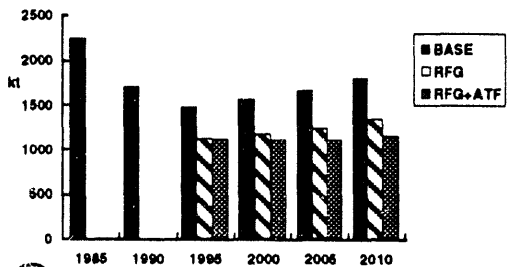
TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Projected NOx Emissions



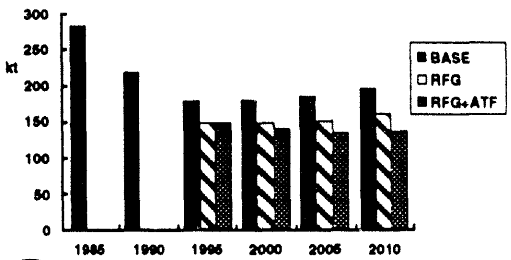
TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Carbon Monoxide Emission Projections



TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Projected Hydrocarbon Emissions



TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Preliminary findings

- **Emissions from on-road vehicles will begin to increase after 1995**
- **Clean fuels can significantly reduce vehicle emissions in Ontario**

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Issues

- **What are the most appropriate means for reducing emissions from on-road vehicles?**
- **What are the roles of reformulated gasoline and diesel fuel?**
- **What is the role of commercial alternative fuels?**
- **What is the appropriate reformulated gasoline recipe for Ontario?**

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

POLICY PANEL DISCUSSION:
MARKET PLACE IMPLICATIONS IN THE CHANGING WORLD OF MOTOR FUELS
M. Harmelink, Ministry of Transportation of Ontario

Q. What reformulated gasoline quality is expected in Ontario?

A. The essential factors will include reduced sulfur content, Reid vapor pressure of 9.5 psi in summer, and oxygenates to provide 2.1 weight percent oxygen.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

POLICY PANEL DISCUSSION:
MARKET PLACE IMPLICATIONS IN THE CHANGING WORLD OF MOTOR FUELS
B. McNutt, U.S. Department of Energy

(Presentation unavailable at time of printing)

Q. Frederick Potter, IRI: Can you comment on trading credits for alternative fuel vehicles that may go below the allowable emission levels?

A I believe that emission results from future vehicles in service may exceed expectations, but the economic benefits for that performance is difficult to assess.

A David Rogers, U.S. Department of Energy: To add to Barry McNutt's reply, there is a concept called ILEV or inherently low emission vehicle. It would meet LEV exhaust emission standards and would have essentially zero evaporative emissions. Vehicles using compressed natural gas or M100 methanol conceivably could meet these standards, and would be eligible for credits under the clean fuel fleet program.

SESSION 1: AVAILABILITY OF ALTERNATIVE FUELED ENGINES AND VEHICLES

Chair: Ron Bright, Ford Motor Company

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

CATERPILLAR'S VIEW OF ALTERNATIVE FUELED MOBILE ENGINES

J.M. Headean
Caterpillar Inc.

Agenda

- Introduction
- Heavy Duty Markets
- Technology Options
    - Fuel Type
    - Engine Technology
- Caterpillar's Technology Selections
- G3306 Mobile Engine
    - Specifications
    - Hardware/Features
    - Performance
    - Product Status
- Summary

Heavy Duty Markets

- Transit Bus
- Refuse Haulers
- Pickup & Delivery
- Line Haul

Technology Options

- Fuel Type
    - CNG
    - LNG
    - HD5
    - Others

Technology Options

- Engine Technology
  - Stoichiometric w/ 3-Way Catalyst
  - Lean Burn w/ Oxidizing Catalyst
  - Dual Fuel (Diesel Pilot)
  - Direct Gas Injection

Caterpillar's Technology Selections

- Factors
  - Current Markets Primarily Intracity
  - Start/Stop Application
  - CNG/LNG/HD5 Regional Opportunity
- Product
  - G3306 Stoichiometric w/ 3-Way Catalyst
    - Lowest Emissions
    - Responsive
    - Fuel Adaptable

G3306 Mobile Engine Specifications

In-line 6, Spark Ignited, 4-Cycle, Turbocharged, Aftercooled

Displacement	638 in^3 (10.5 liter)
Compression Ratio	10.5:1 CNG/LNG
	8.0:1 HD5
Power Rating @ 2100 rpm	250 hp CNG/LNG
	235 hp HD5
Peak Torque @ 1200 rpm	850 lb-ft CNG/LNG
	820 lb-ft HD5

G3306 Mobile New Content

- Center Mount Exhaust Manifold
- Mobile Camshaft
- Altronic DISN Ignition
- Woodward Min/Max Governor
- Deltec A/F Control
- Interface Electronics
- 3-Way Catalyst
- Mobile Gas Regulators
- ATAAC Connections

G3306 Mobile Special Features

- CNG/LNG/LPG Capability
- Low LNG Pressure Capability
  - 25 to 50 psi Operation
- Fuel Tolerance
  - Closed Loop A/F Control
  - Compensates for Seasonal Fuel Changes
  - Compensates for Geographical Fuel Differences
  - Reduces Possibility of Overfueling/Overpowering

G3306 Mobile Engine Emissions
First Transient Cycle Test

	1994 CARB	EPA Cycle	Steady State
NOx	5.0	2.5	0.4
NMHC	1.2	-	-
THC	-	6.7	0.1
CO	15.5	3.5	0.03
PM	0.1	0.02	-

All Units g/bhp-hr

G3306 Mobile Performance Improvements

- Schwitzer S2 Turbocharger
- Woodward Digital Min/Max Governor
- Optimized A/F Response
- Improved Gas Regulator Response
- Added Pre-Catalyst

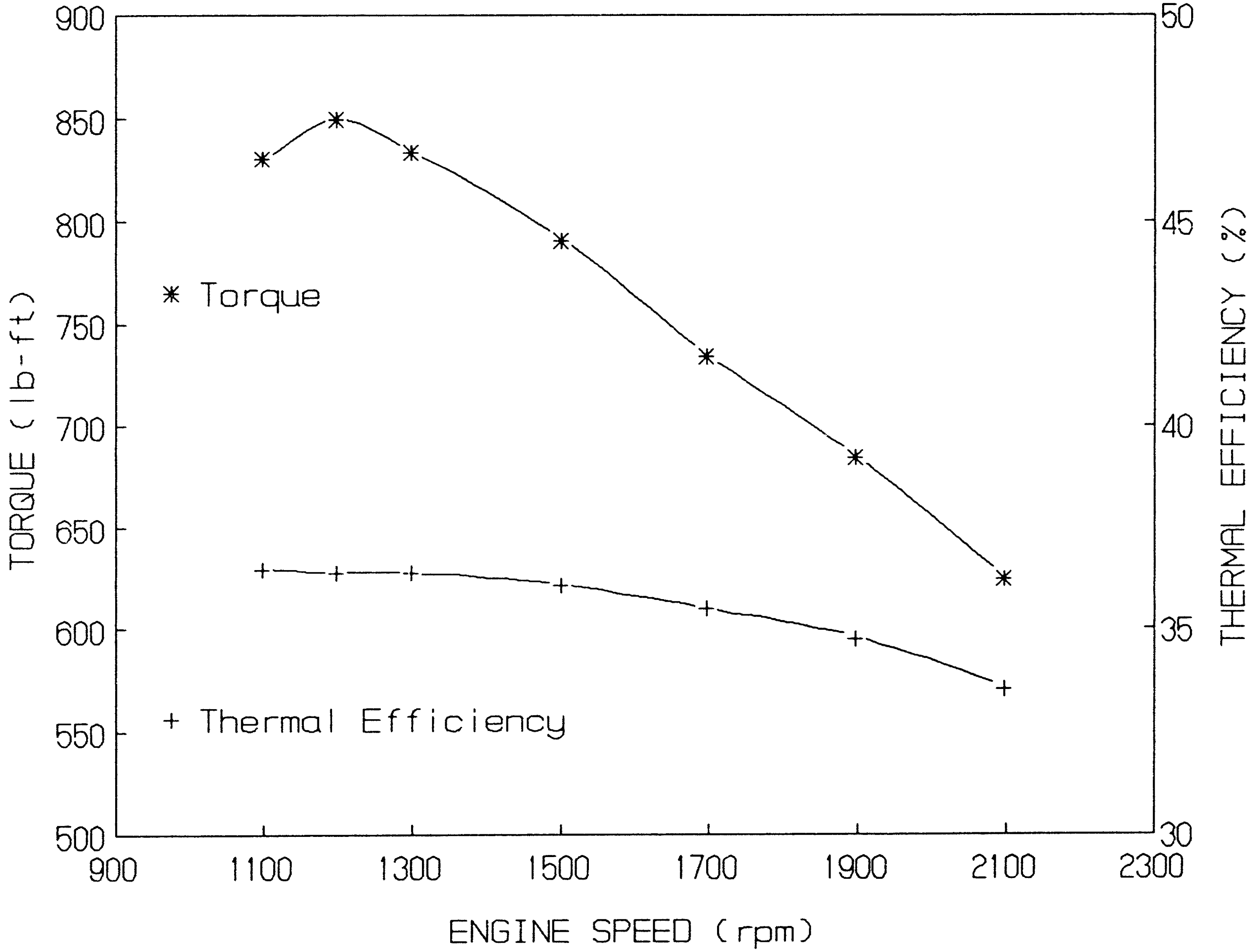
G3306 Mobile Engine Emissions
1993 CARB Certification Test

	1994 CARB	EPA Cycle
NOx	5.0	0.51
NMHC	1.2	0.19
THC	-	-
CO	15.5	4.63
PM	0.1	0.02

All Units g/bhp-hr

G3306 MOBILE ENGINE PERFORMANCE

TORQUE & THERMAL EFFICIENCY



G3306 Mobile Product Status

- 3 Units in Service
  - 2 HD5
  - 1 LNG
- 10 Pilot Units Built for 1993 Delivery
- CARB Certification Testing Complete November 1993
- Planned Production February 1994

Summary

- Heavy Duty Markets Evolving
- CNG/LNG/HD5 Capability Desirable
- Stoichiometric w/ 3-Way Catalyst
    - Robust Technology for Current Markets and Fuels
- G3306 Mobile Engine Developed
    - CARB Certification Underway
    - Optimized Emissions
    - Good Driveability
    - Fuel Flexible
    - Fuel Variation Tolerant
    - Proven Technology

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

CATERPILLAR'S VIEW OF ALTERNATIVE FUELED MOBILE ENGINES
J.M. Headean, Caterpillar Inc.

Q. Mostafa Kamel, Cummins Engine Co.: Why was stoichiometric operation chosen for the engine design?

A. We felt that the stoichiometric design offered more flexibility for the stop-and-cooperation and was more suitable for low NOx emissions in inner city use. We also have lean burn engines being developed for long haul applications where higher NO_X emissions are allowed and fuel economy is more important.

Q. James Grieve, Consultant: How does the durability compare for similar engines operated on diesel fuel, propane, and natural gas?

A. These engines are derived from our diesel engines and use the same components. Since the cylinder pressures are lower for propane and natural gas, the engines are not stressed as much and durability is excellent.

Q. Matthew Bol, Sypher:Mueller International: Can you tell us the cost of these engine compared to diesel?

A. I am mainly concerned with engineering and am not prepared to talk about cost.

Q. Anonymous : Can you give the fuel flow rate for these engines?

A. Fuel flow is about 7,500 BTU per horsepower-hour at rated speed and about 6,900 BTU per horsepower-hour at peak torque.

Q. Ron Bright, Ford Motor Co. of Canada: How would you rate customer interest in this engine?

A. Currently there is more demand than supply, both for the product and for information from potential users.

Q. Anonymous; What can you tell us about the catalyst formulation?

A. One of our few proprietary items is catalyst technology. We are developing the stoichiometric three-way catalyst with the supplier, and technology is still evolving.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

CUMMINS NATURAL GAS ENGINE PROGRAMS
L10 G ENGINE UPDATE

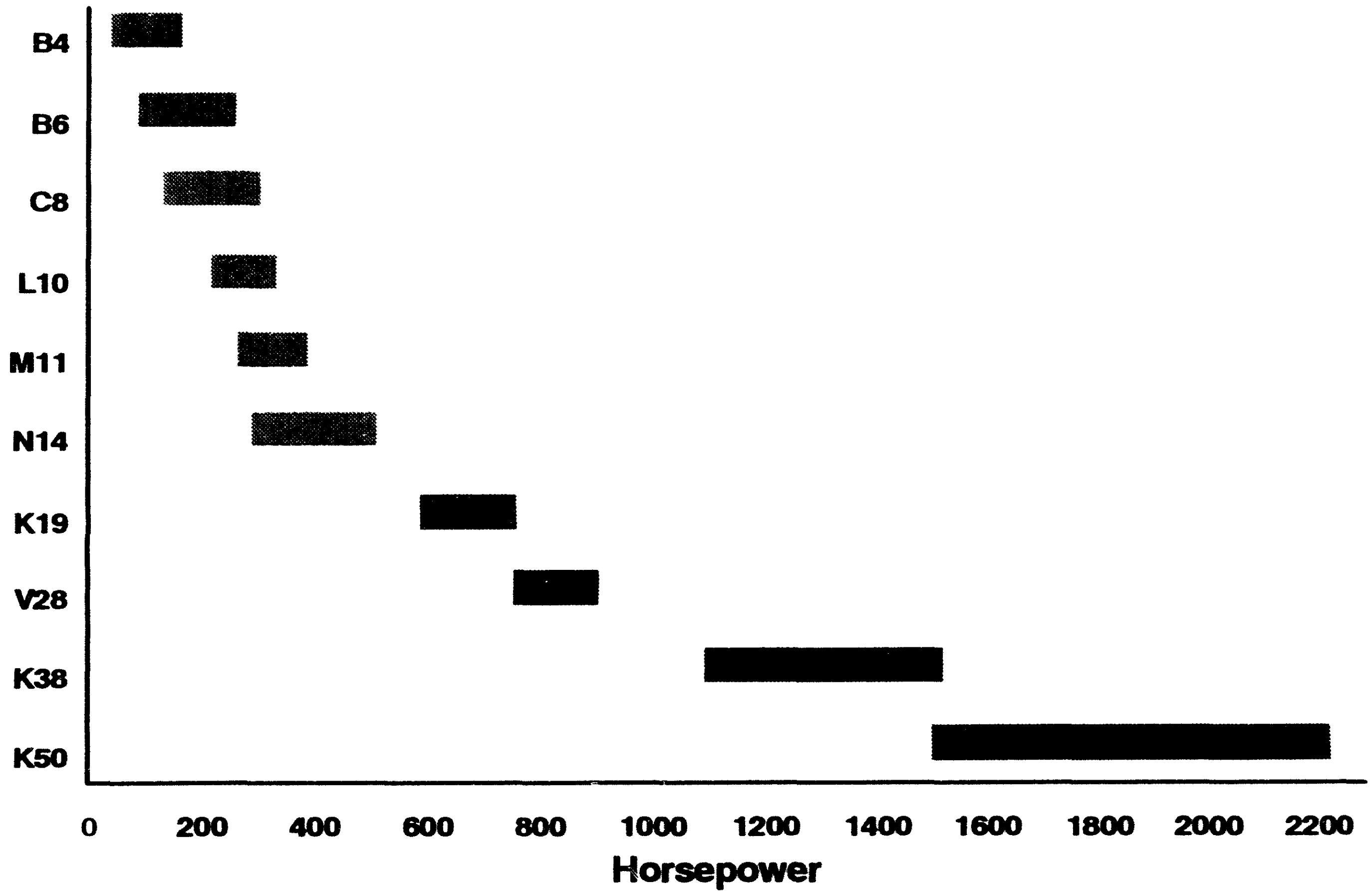
V.K. Duggal
Cummins Engine Co. Inc.

Outline

- Cummins Product Line
- Natural Gas Engine Programs
- Technology and Product Evolution
- L10G Status
  - CARB Certification
  - Field Experiences
  - LNG Application
  - Current and Upcoming Developments
- Summary

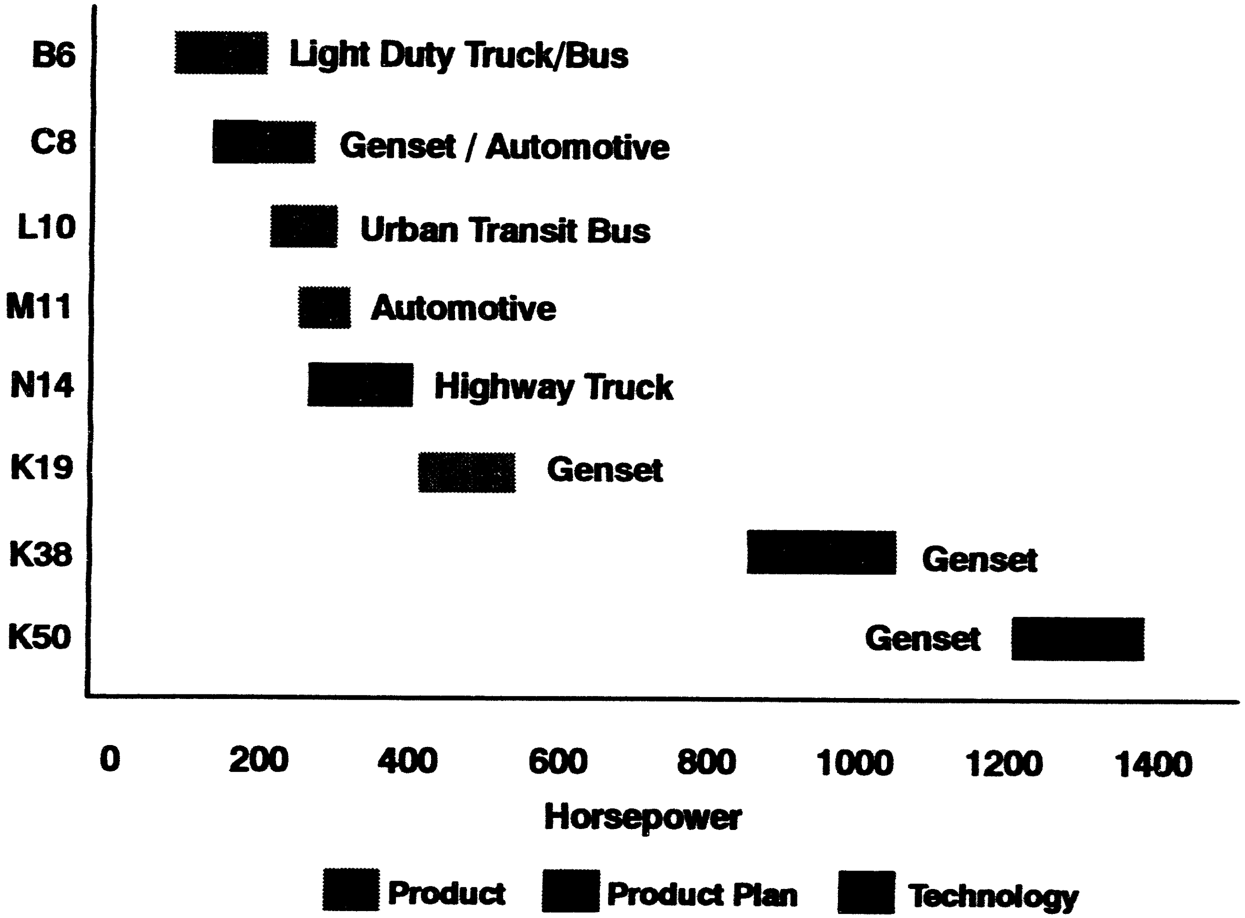
93283s03

Cummins Current Product Line



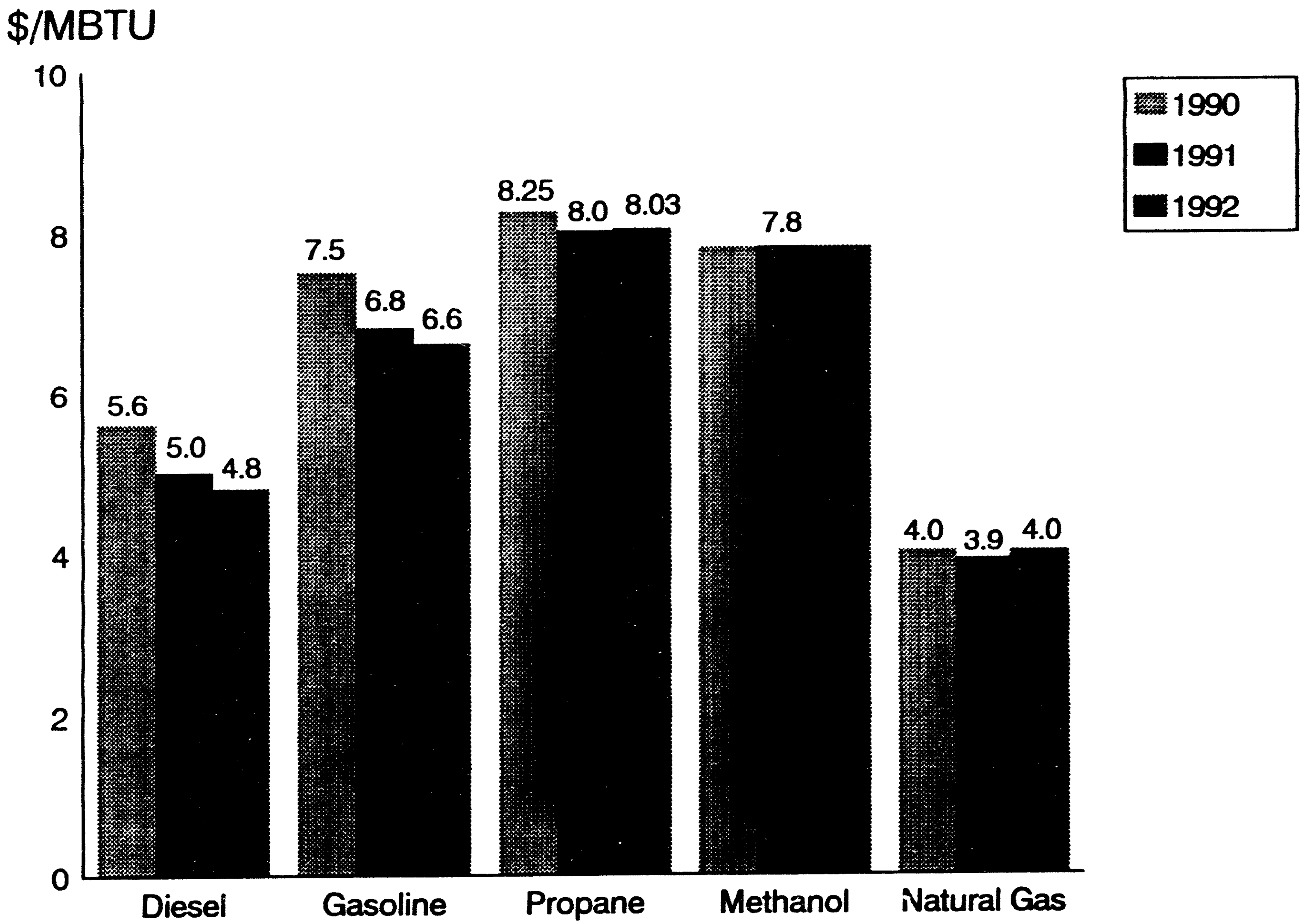
93283t19

Cummins SI Gas Engines
Product and Technology Programs



93283104

Average Refiners Prices (Without Taxes)



Monthly Energy Review - DOE

93214-4

Technology and Product Evolution

- Current product
  - S.I. natural gas
  - Take advantage of high octane properties, broader combustion limits
  - Implemented lean combustion concept
  - Mechanical systems with limited electronic controls
  - Adapt available subsystems
    - ▸Inherent limitations
  - Optimum NOx particulates trade-off
  - Less cost sensitivity

93283s05

Technology and Product Evolution (Cont'd)

- Next generation product
  - Concept solidified (use across engine families)
  - Integral electronic controls
  - Rationalize subsystem function
  - Design/procure to meet spec
  - Commonalty of subsystems/parts
  - ULEV emission target
  - Cost effective

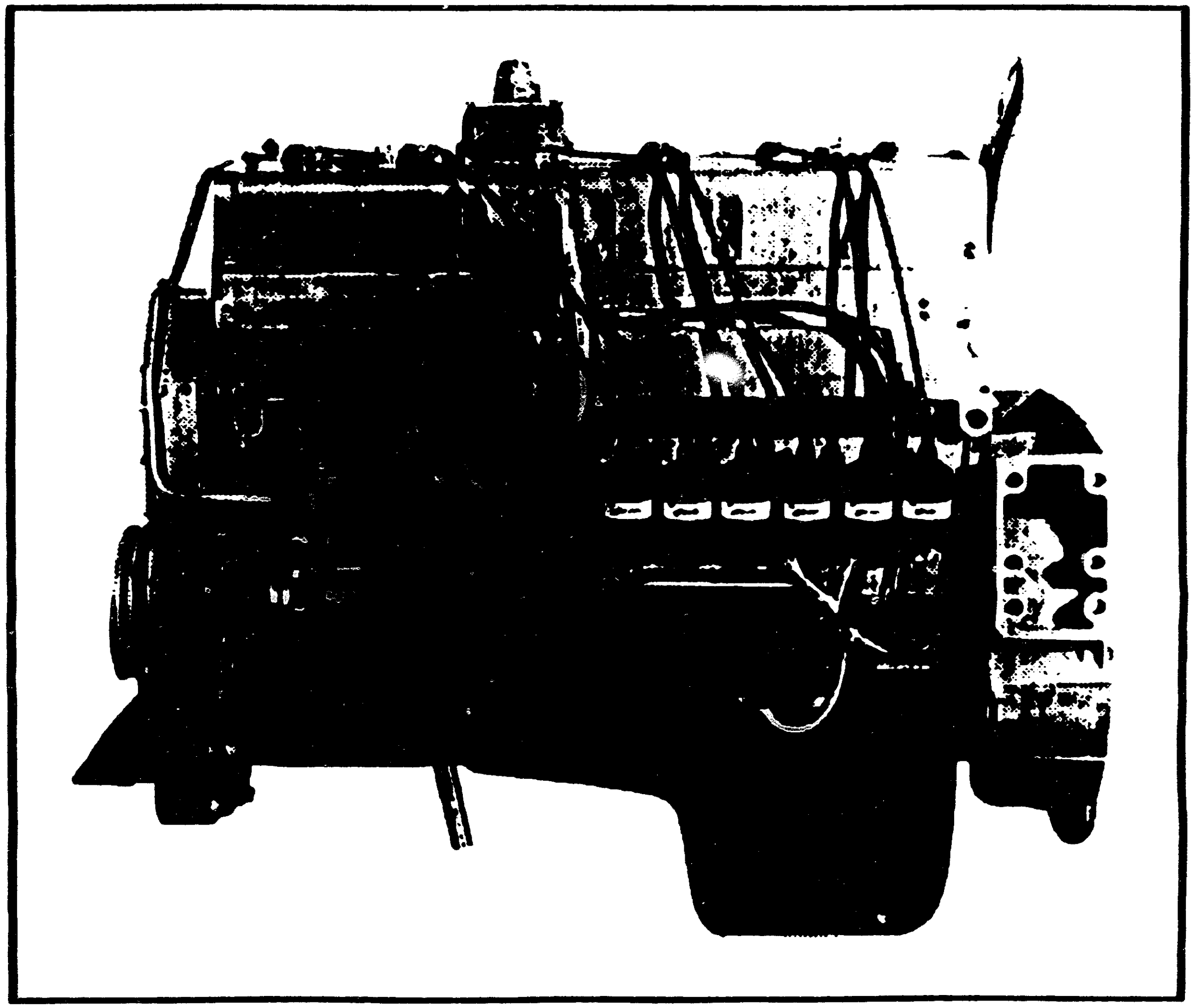
93283s06

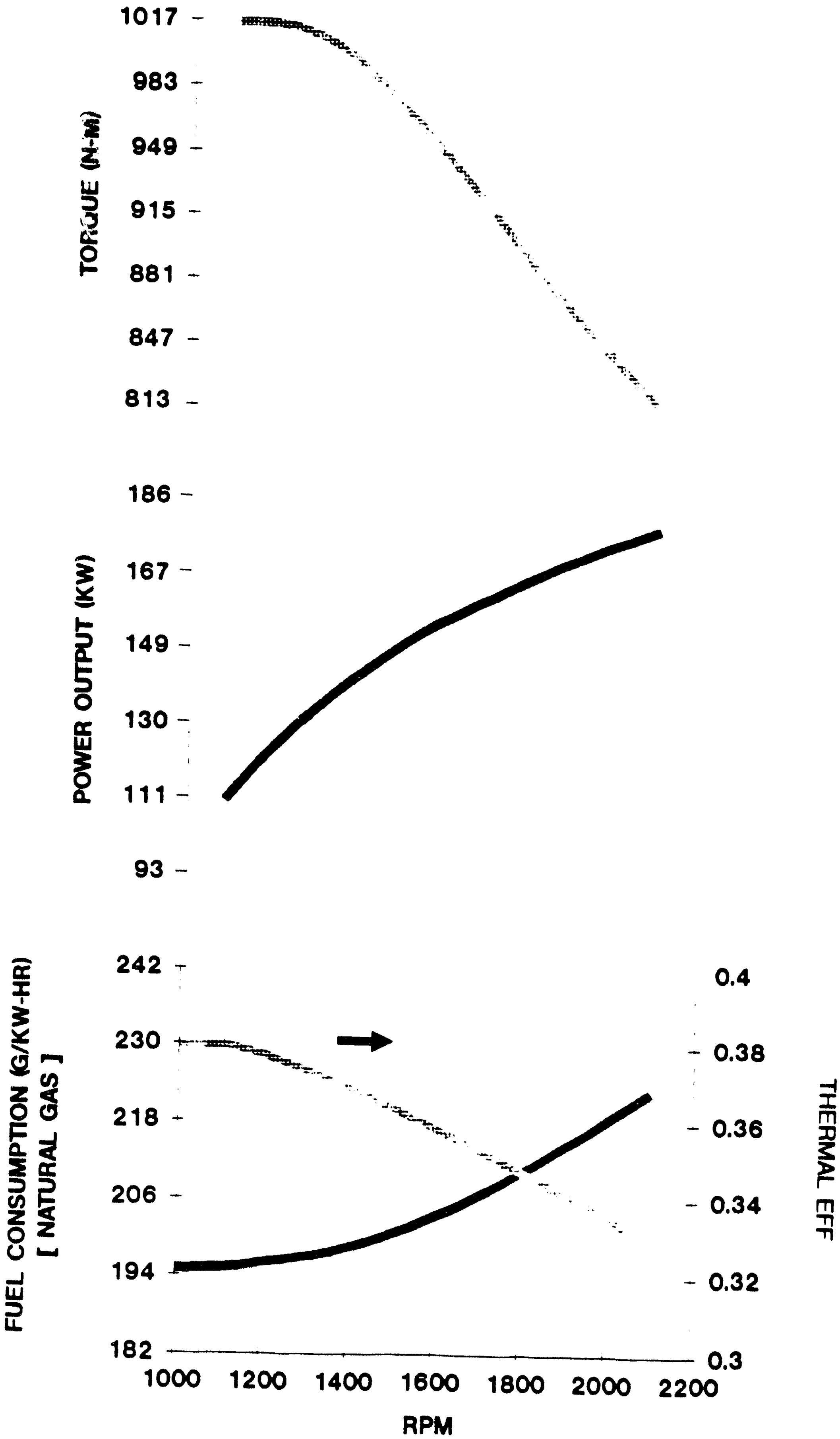
Current Engine Spec.

Power	**240 HP**
Torque	**850 FT-LBS**
Transmission	**Automatic**
Engine Cooling	**Water-cooled (city bus specific)**
F/A/Mixing	**Mechanical**
Engine Control	**Limited, non-integral**

93298s03

L10-240G

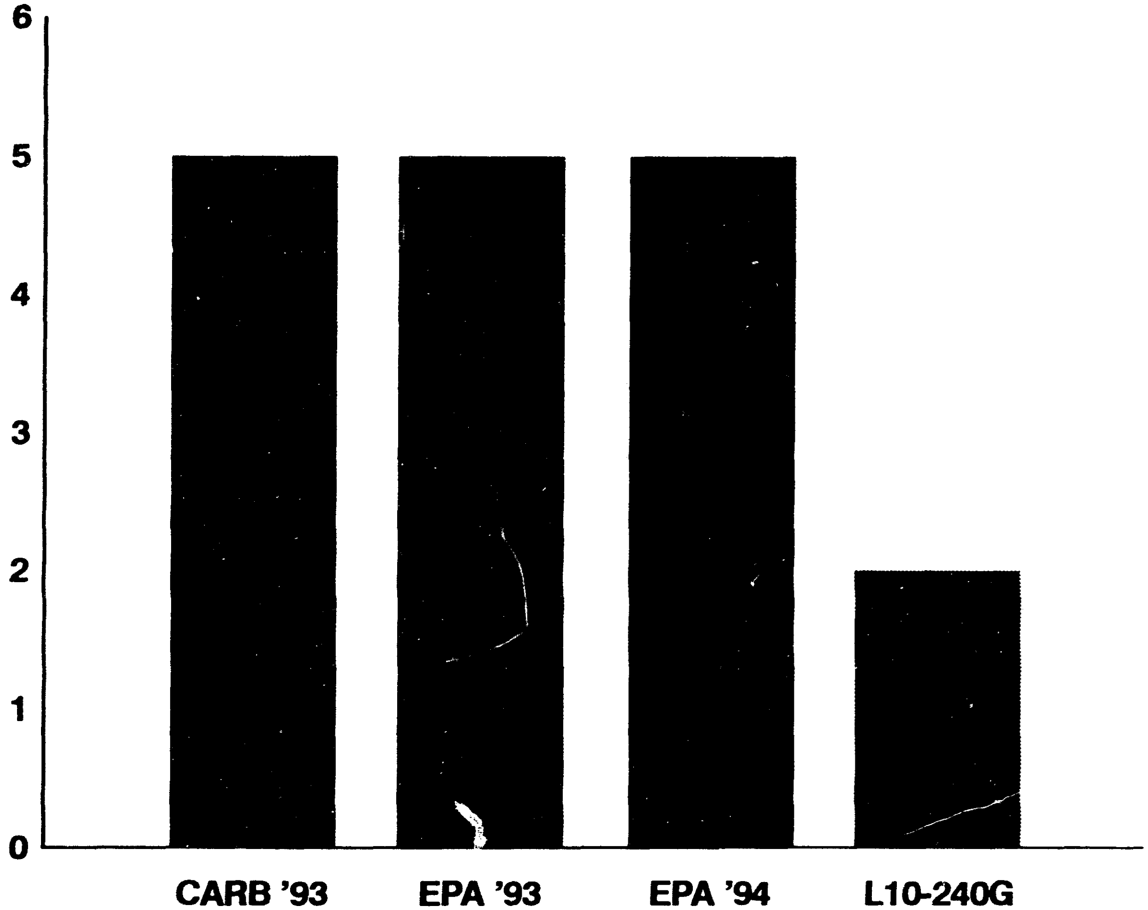




1017
983
949
915
881
847
813
TORQUE (N-M)
186
167
149
130
111
93
POWER OUTPUT (KW)
242
230
218
206
194
182
FUEL CONSUMPTION (G/KW-HR)
[NATURAL GAS]
0.4
0.38
0.36
0.34
0.32
0.3
THERMAL EFF
1000
1200
1400
1600
1800
2000
2200
RPM

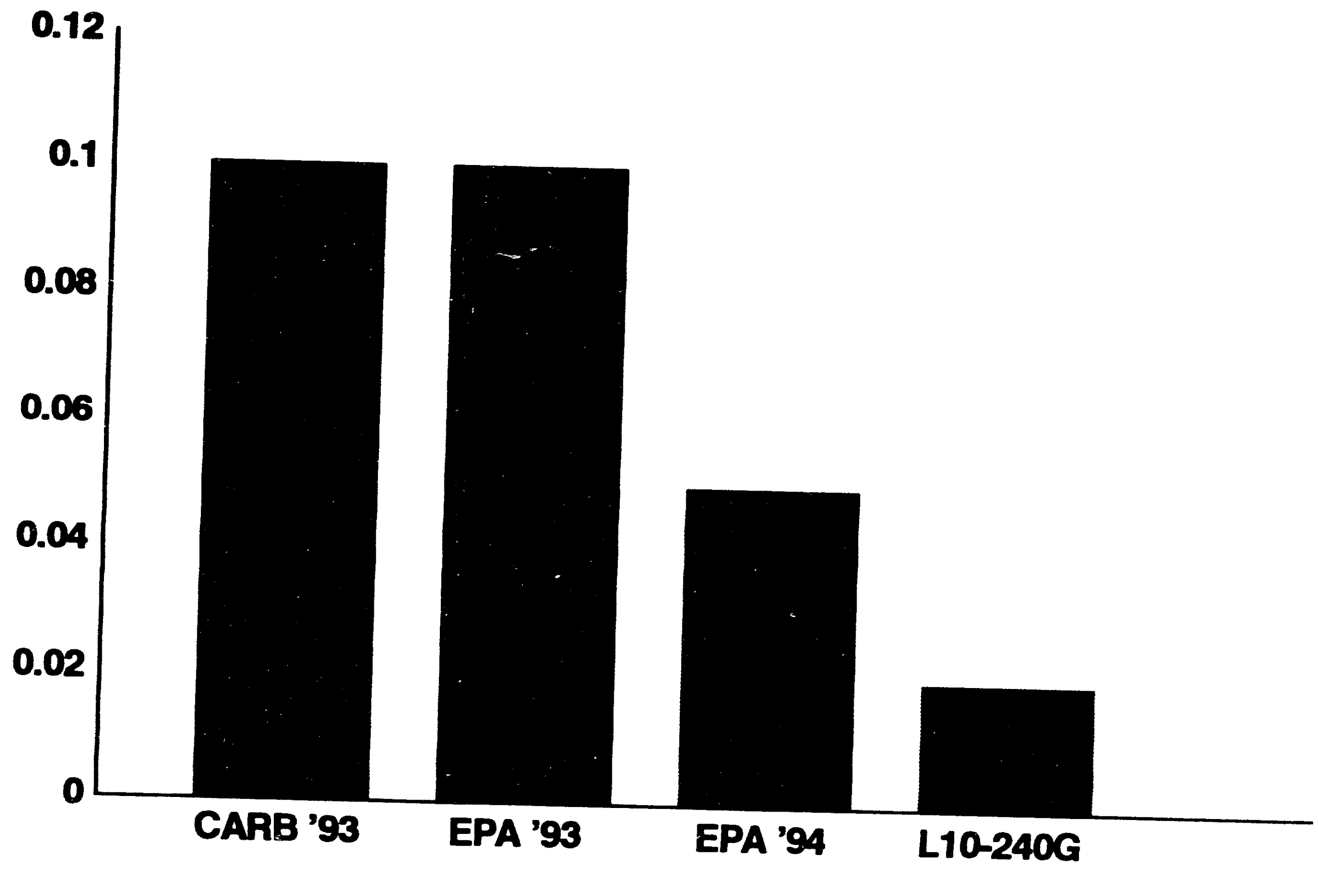
548d22

L10-240G NOx Emissions vs. CARB/EPA Standards



93283t20

L10-240G Particulate Emissions vs. CARB/EPA Standards



93283t21

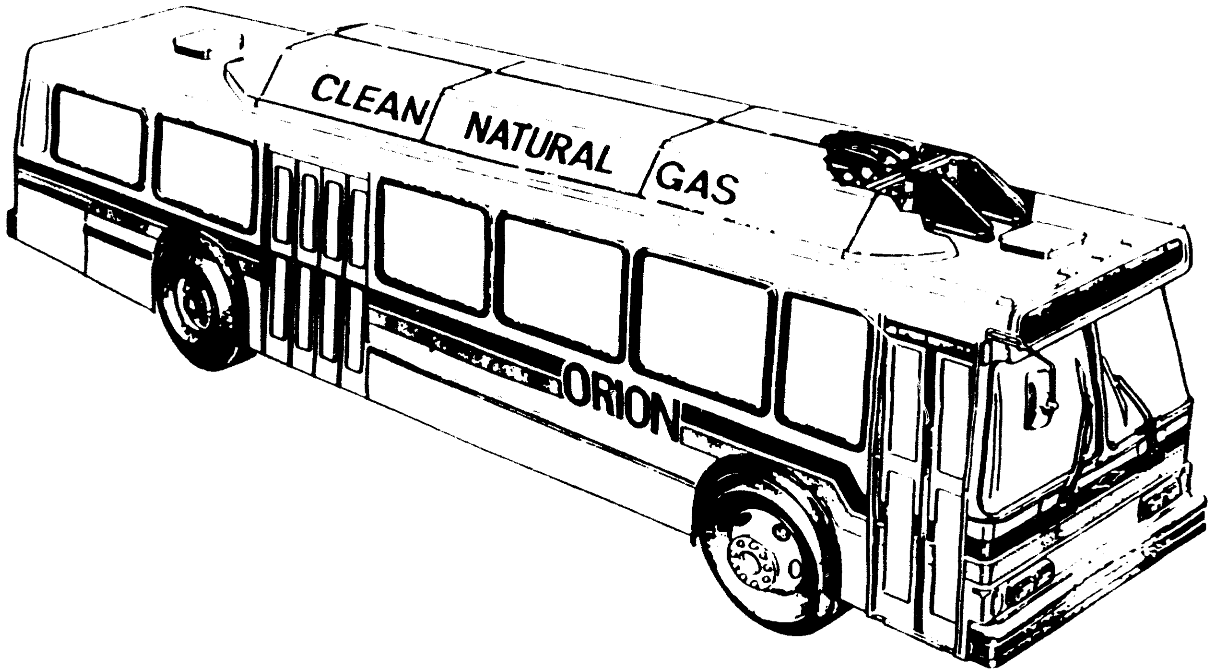
CNG L10 Engine Emissions Cert. Data

(g/bhp-hr)

	1993 CARB Diesel NG Standards	CNG L10 Design Goals	Sacramento Requirement	CARB Certification
NOx	5.0	4.5	2.5	2.0
PM	0.1	0.06	.06	0.02
HC	1.3	0.9	.9	-
NMHC	1.2	-	<1.2	0.6
CO	15.5	4.0		0.4

* Includes DF to 290,000 miles

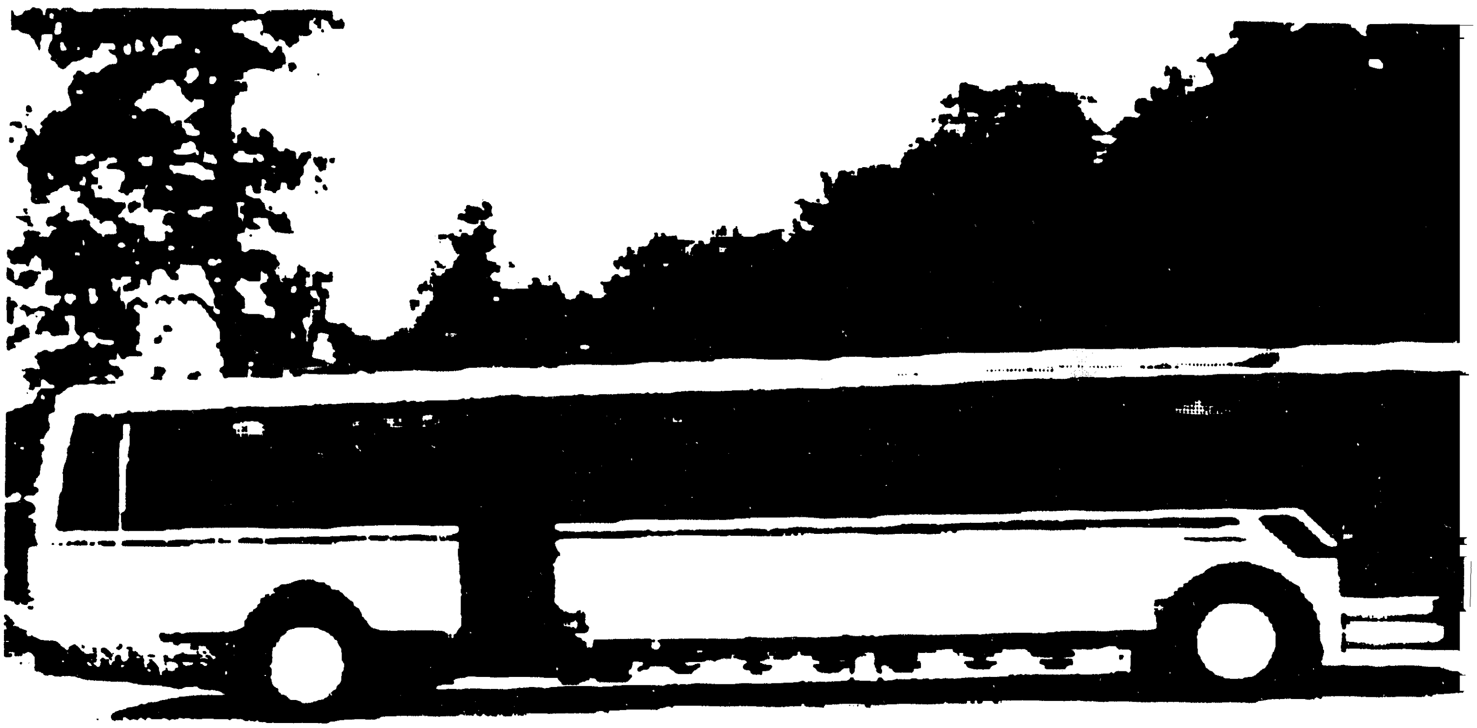
93283s07



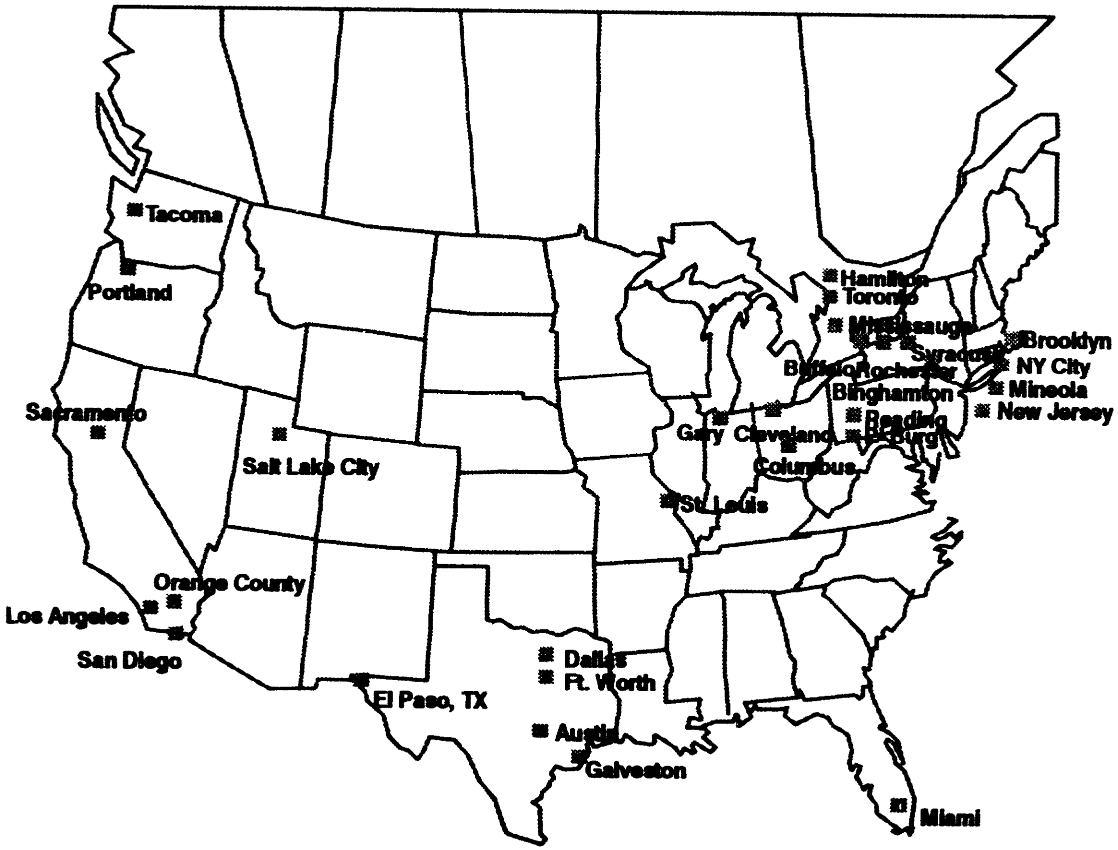
Alu Suisse Cylinders

Construction:	**Al liner hoop wound with fibre tape**
Size:	**20 ft x 13 in**
Water capacity:	**395 litres**
Weight:	**638 lbs**
Gas Volume:	**3450 SCF**
Gas Weight:	**150 lbs**
Range:	**400 miles (4 tanks)**

548d20a



Cummins L10 Natural Gas Engine Locations



Salt Lake City, UT
Toronto, Ont
Los Angeles, CA
Ft. Worth, TX
Dallas, TX
Cleveland, OH
Columbus, OH
Mississauga, Ont
New York City, NY
Pittsburgh, PA
San Diego, CA
Hamilton, Ont
Miami, FL
Newark, NJ
St. Louis, MO
Tacoma, WA
Orange County, CA
Galveston, TX
Reading, PA

Binghamton, NY
Buffalo, NY
Syracuse, NY
Rochester, NY
Mineola, NY
Brooklyn, NY
Portland, OR
Gary, IN
Sacramento, CA
Austin, TX
El Paso, TX

93283s09

Chassis Dyno Results - Sacramento CNGL10 Bus

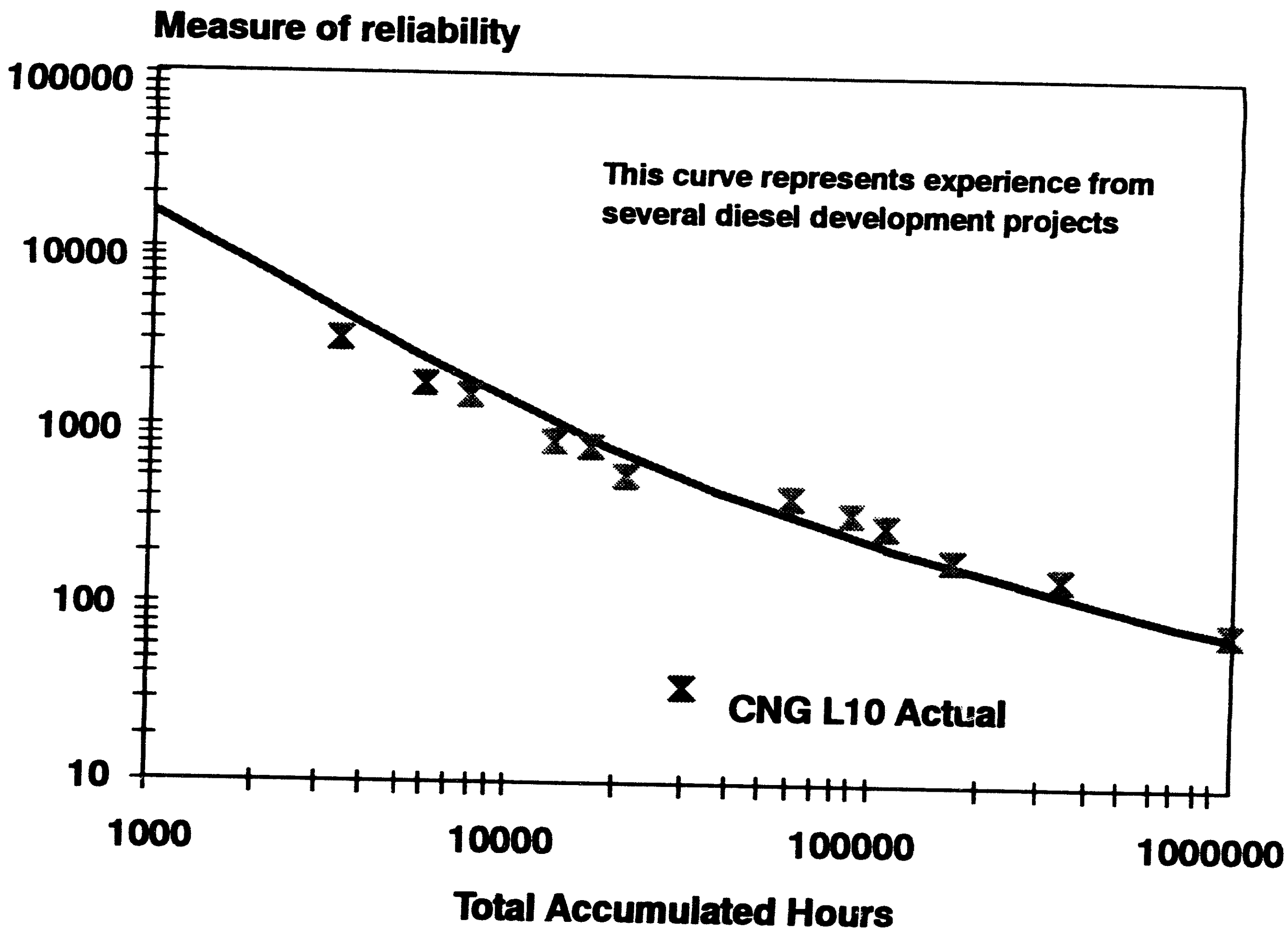
Hot CBD Test Cycle (g/mile)*

NOx	6.5
PART	.025
CO	.035
NMHC	**
CO_2	2430

* Tests at SCRTD

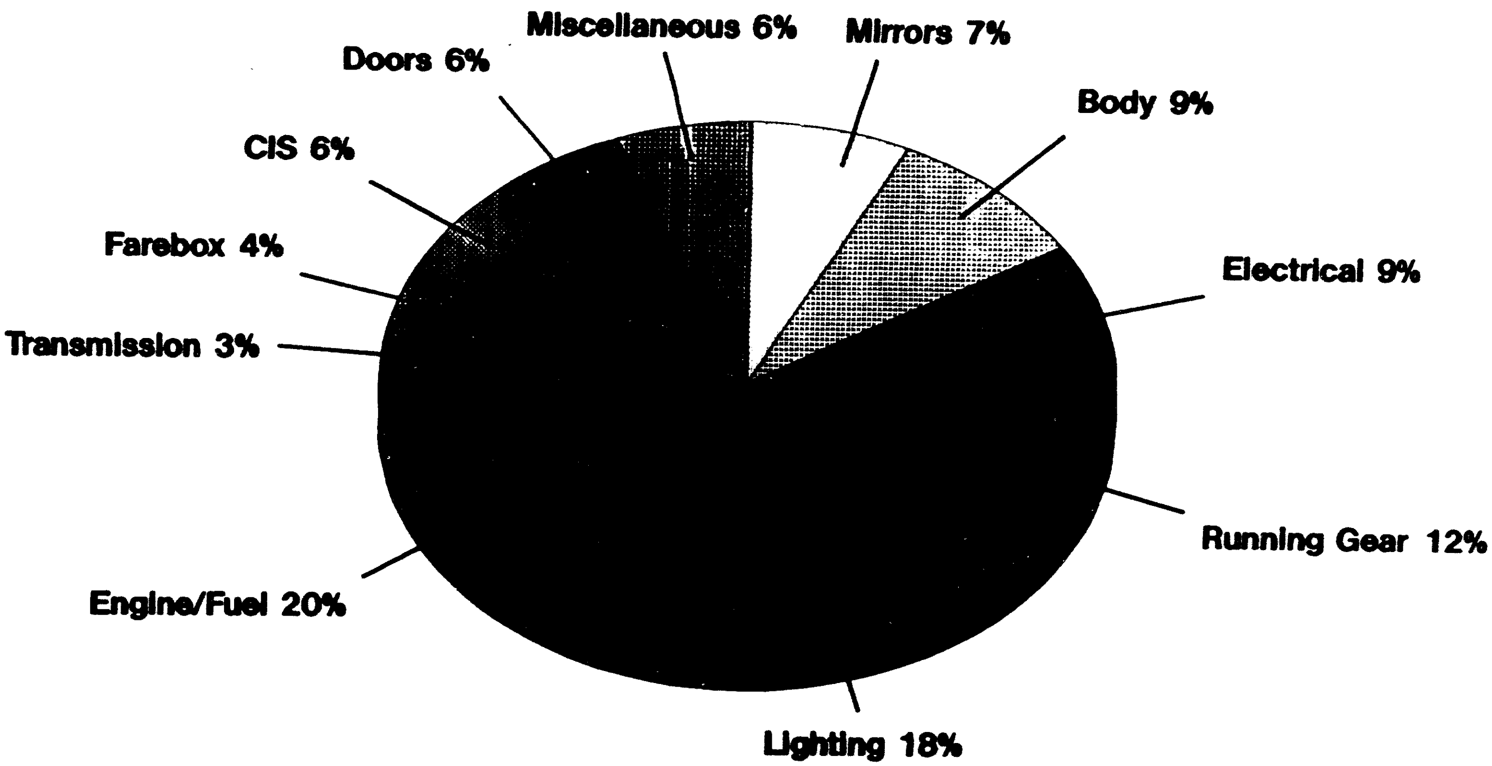
** Not measured

Cummins Reliability Experience



93283s12

All Repairs & Inspections*

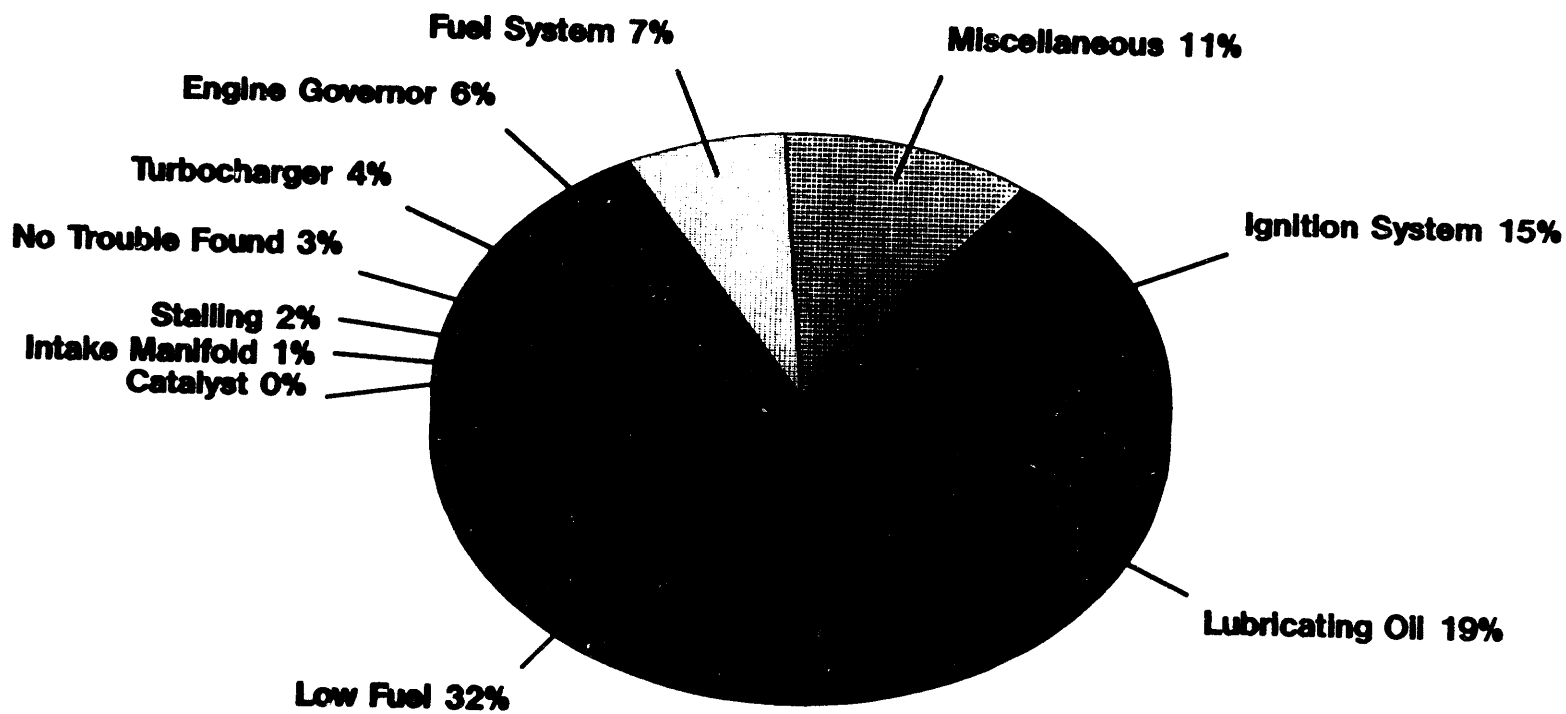


*TTC CNG Bus Operation - MTO Data

9253711

Fuel & Engine-Related Work*

(20% of all Repairs/Inspections)



*TTC CNG Bus Operation - MTO Data

9253710

L10G Urban Engine Field Experience

- **Field engines in urban bus refuse and urban truck**

- **A total 350 engines have been built including 100 CARB certified config.**
  - **Approximately 300 engines in revenue service**
  - **Over 10,000,000 revenue miles**
  - **Repeat orders**

L10G Urban Engine Field Experience (Cont.d)

- L10 G engine reliability approaching L10 diesel bus engine
- Durability goals B10 - 250K miles; B50-350K miles
- Fuel economy ~ 2.5 - 3.8 MPG equivalent diesel
- Oil consumption ~ 350-600 MPQ equal or better than diesel

LNG Application

- Opportunity for fuel quality control
- Fuel storage medium needs to be transparent to the engine operation
- Standardize components, test schedule, manufacturing costs
- Envision low pressure delivery system

93283s10

LNG Application (Cont'd.)

- A/F ratio and fuel rate must be managed to maintain engine operation within the design spec. Necessary for emissions, performance and durability

- Systems evaluation planned/on-going in laboratory and in field
  - Gillig buses in Portland, OR
  - Overnite truck in Roanoke, VA

- Develop general application specifications for the OEM's

Current Development Issues

- Sub-system issues
  - Ignition system performance including plug life
  - Fuel delivery system sensitivity
  - Governor control stability
  - Wastegate accumulator drain service requirement
  - Turbocharger wastegate control
  - Catalyst thermal fatigue
  - OEM/engine wiring interface

93283s19

Developments Perspective

- **Current Product Enhancements**
  - Digital governing
    - ▸ Electronic wastegate control
    - ▸ Engine protection
    - ▸ Direct electronic link to transmission
    - ▸ Fault code logging
  - Shorter plug wire length
  - 260 HP rating

- **Future Product**
  - Rated at 300 HP and 900 lb-ft peak torque
  - ULEV emissions
  - Full authority electronic control
  - LNG/CNG compatible
  - All automotive markets

93283s15

Summary

- Focused NG product development across engine product lines
- Implemented new technologies and concepts
- Current product L10 G CARB certified close to 1998 ULEV standards. Low NOx emissions on CBD cycle
- Next generation of products planned for mid 90's

Acknowledgements

We acknowledge the following organizations for their support and funding:

Gas Research Institute

Canadian Gas Association

Ontario Ministry of Transportation

Ontario Ministry of Energy

548d35

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

CUMMINS NATURAL GAS ENGINE PROGRAMS - L10 G ENGINE UPDATE
V.K. Duggal, Cummins Engine Co. Inc.

Q. Robert Alvey, Brooklyn Union Natural Gas: What type of governor is being used on the current L10 engines?

A. Most of the engines are using the analog version. There are about six digital governors operating in buses in Ontario to gain experience with this newer type.

Q. Morrie Kirshenblatt, Environment Canada: Can you elaborate on the catalyst thermal fatigue that was mentioned?

A. Using an oxidation catalyst, unburned natural gas in the exhaust occasionally causes excessive thermal load. This can occur when the vehicle is coasting downhill. We are working on ways to handle the problem.

Q. Anonymous: Question inaudible.

A. A typical bus engine averages 25 to 30 thousand miles per year, and average speed is 10 to 12 miles per hour.

Q. Anonymous: What was the NOx deterioration factor?

A. We found no deterioration in NOx emissions. Based on emissions tests at intervals of 250 hours operation up to 1000 hours, the NOx data actually showed a negative slope.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

DDC ALTERNATIVE FUEL PRODUCT EXPERIENCE AND FURTHER DEVELOPMENT

S.P. Miller
Detroit Diesel Corporation

DDC ALTERNATE FUEL ENGINES

IN SERVICE

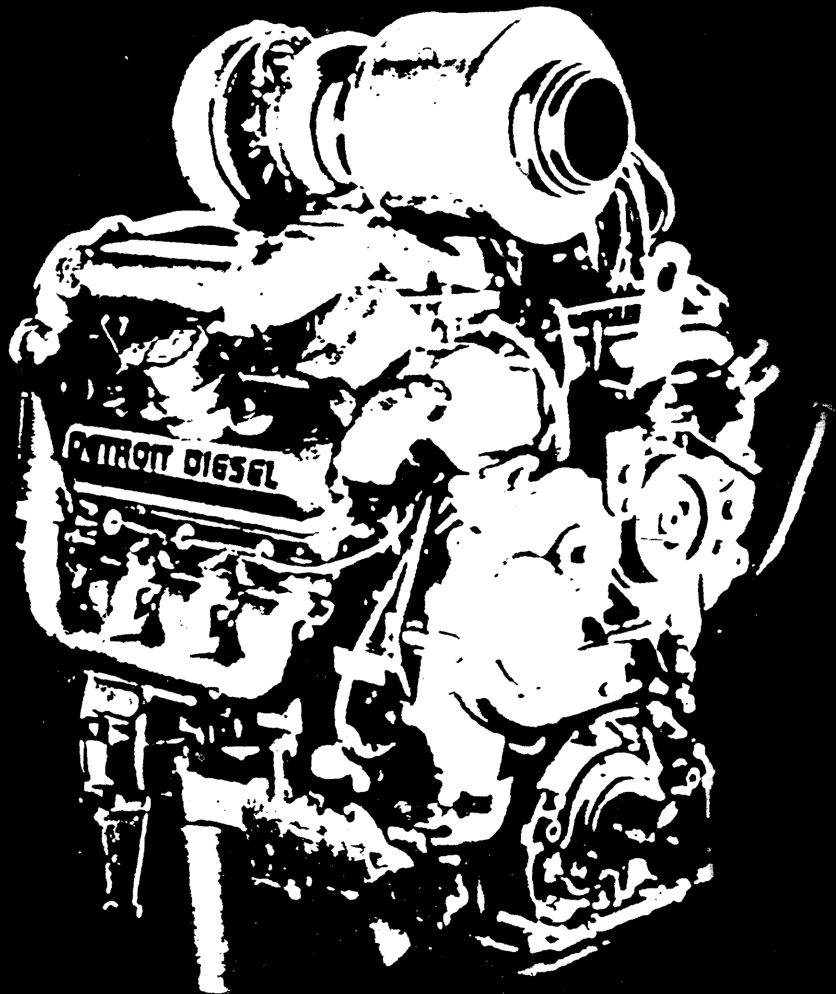
	METHANOL	ETHANOL	CNG	LNG
TRUCKS	7	5	2	0
BUSES	454	21	38	~~15~~ 80

DELIVERIES IN PROCESS

	METHANOL	ETHANOL	CNG	LNG
TRUCKS	0	4	2	0
BUSES	108	3	16	180

DDC

6V-92TA ALCOHOL FUELED ENGINE



METHANOL ENGINE EMISSIONS

	G/HP-HR			
	HC	CO	NOx	PM
1998 TRUCK STANDARDS	1.3	15.5	4.0	0.10
METHANOL ENGINE CERTIFICATION RESULTS	0.08	2.0	1.7	0.03

DDC

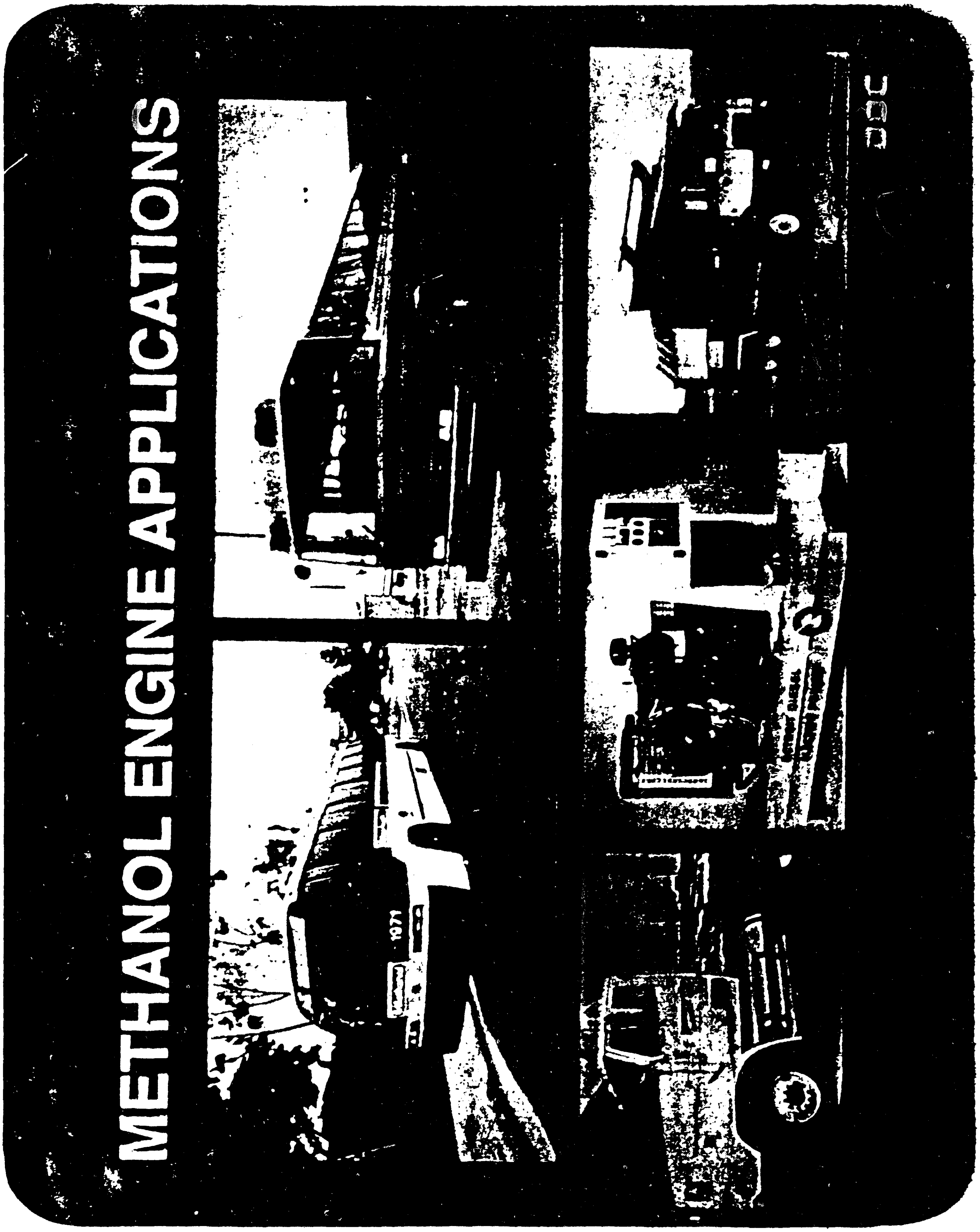
120

METHANOL ENGINE DATA

	BUSES	TRUCKS
NUMBER OF UNITS	454	7
TOTAL MILES	>10 MILLION	>250,000
ENERGY CONSUMPTION RATIO (METHANOL : DIESEL)	1.03 - 1.30	1.0 - 1.20

TANK VOLUME VS. DIESEL FOR EQUAL RANGE: 2.3 - 2.7 × GREATER

DDC


METHANOL ENGINE APPLICATIONS
DDC

ETHANOL ENGINE APPLICATIONS

ETHANOL ENGINE EMISSIONS

	G/HP-HR			
	HC	CO	NOx	PM
1998 TRUCK STD.	1.3	15.5	4.0	0.10
ETHANOL ENGINE CERTIFICATION RESULTS	0.7	1.7	4.2	0.04
ETHANOL ENGINE DEVELOPMENT RESULTS	0.3	1.7	3.7	0.04

DDC

ETHANOL ENGINE DATA

	BUSES	TRUCKS
NUMBER OF UNITS	21	5
TOTAL MILES	400,000	430,000
ENERGY CONSUMPTION RATIO (ETHANOL : DIESEL)	1.0 - 1.1	1.0 - 1.1

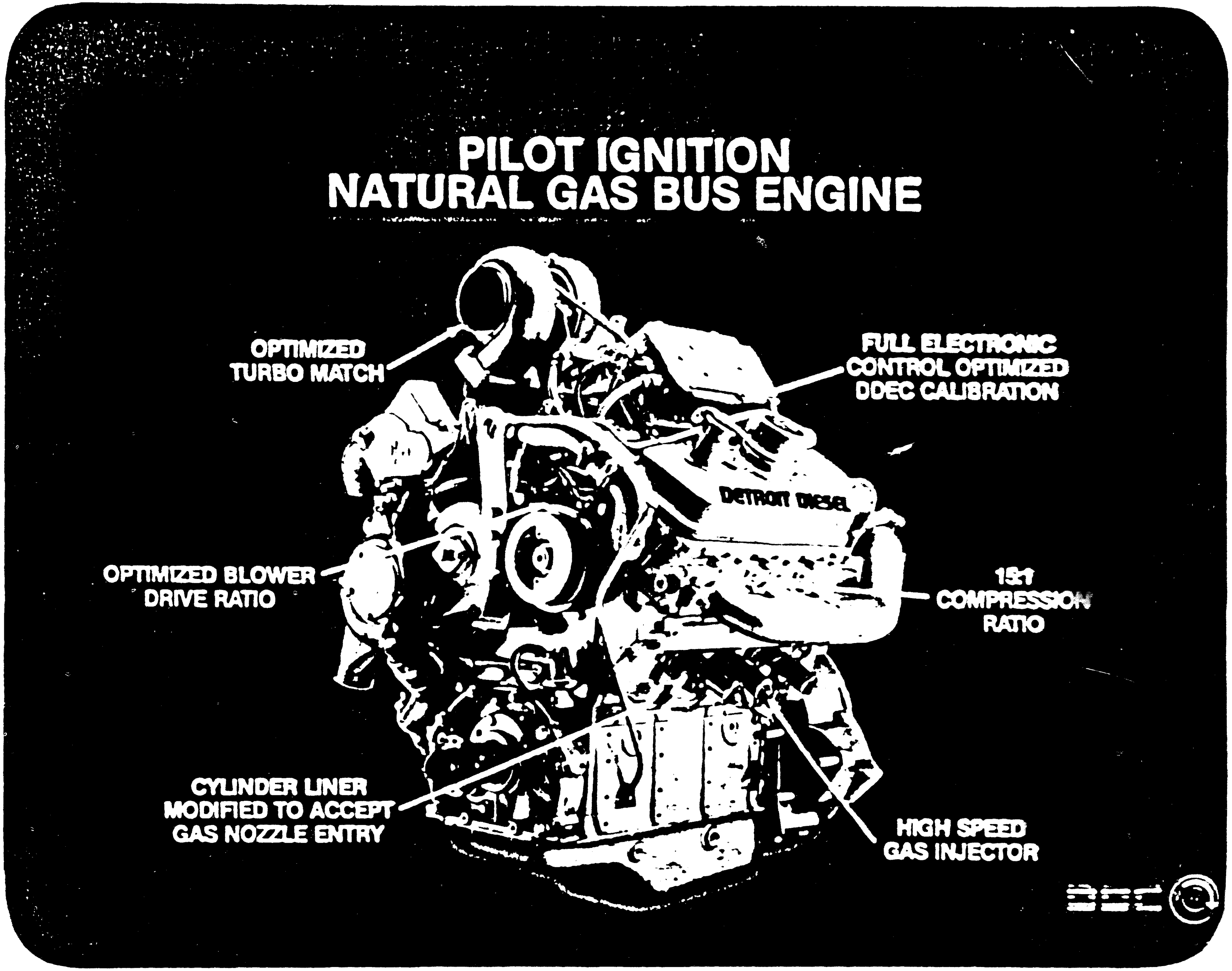
TANK VOLUME VS. DIESEL FOR EQUAL
RANGE: 1.7 - 1.9 × GREATER

DDC

DETROIT DIESEL CORPORATION NATURAL GAS ENGINE PROGRAM

- PILOT IGNITION 6V-92TA
- DIRECT INJECTION 6V-92TA
- SPARK IGNITION S-50
- SPARK IGNITION S-30

DDC


PILOT IGNITION
NATURAL GAS BUS ENGINE
OPTIMIZED TURBO MATCH
FULL ELECTRONIC CONTROL OPTIMIZED DDEC CALIBRATION
DETROIT DIESEL
OPTIMIZED BLOWER DRIVE RATIO
15:1 COMPRESSION RATIO
CYLINDER LINER MODIFIED TO ACCEPT GAS NOZZLE ENTRY
HIGH SPEED GAS INJECTOR

PILOT IGNITION NATURAL GAS ENGINE EMISSIONS

DEVELOPMENT RESULTS

	G/HP-HR			
	HC	CO	NOx	PM
1994 BUS STD.	1.3	15.5	5.0	.07
PI-NG ENGINE	0.9	0.3	4.8	0.07

DDC

PILOT IGNITION NATURAL GAS ENGINE

	BUSES	TRUCKS
NUMBER OF UNITS	108	2
TOTAL MILES	1.5 MILLION	60,000
ENERGY CONSUMPTION RATIO (NATURAL GAS : DIESEL)	1.05	1.05

TANK VOLUME VS. DIESEL FOR EQUAL RANGE:

CNG - 4.7 × GREATER

LNG - 1.7 × GREATER

DDC

ALTERNATE FUEL DURABILITY EXPERIENCE

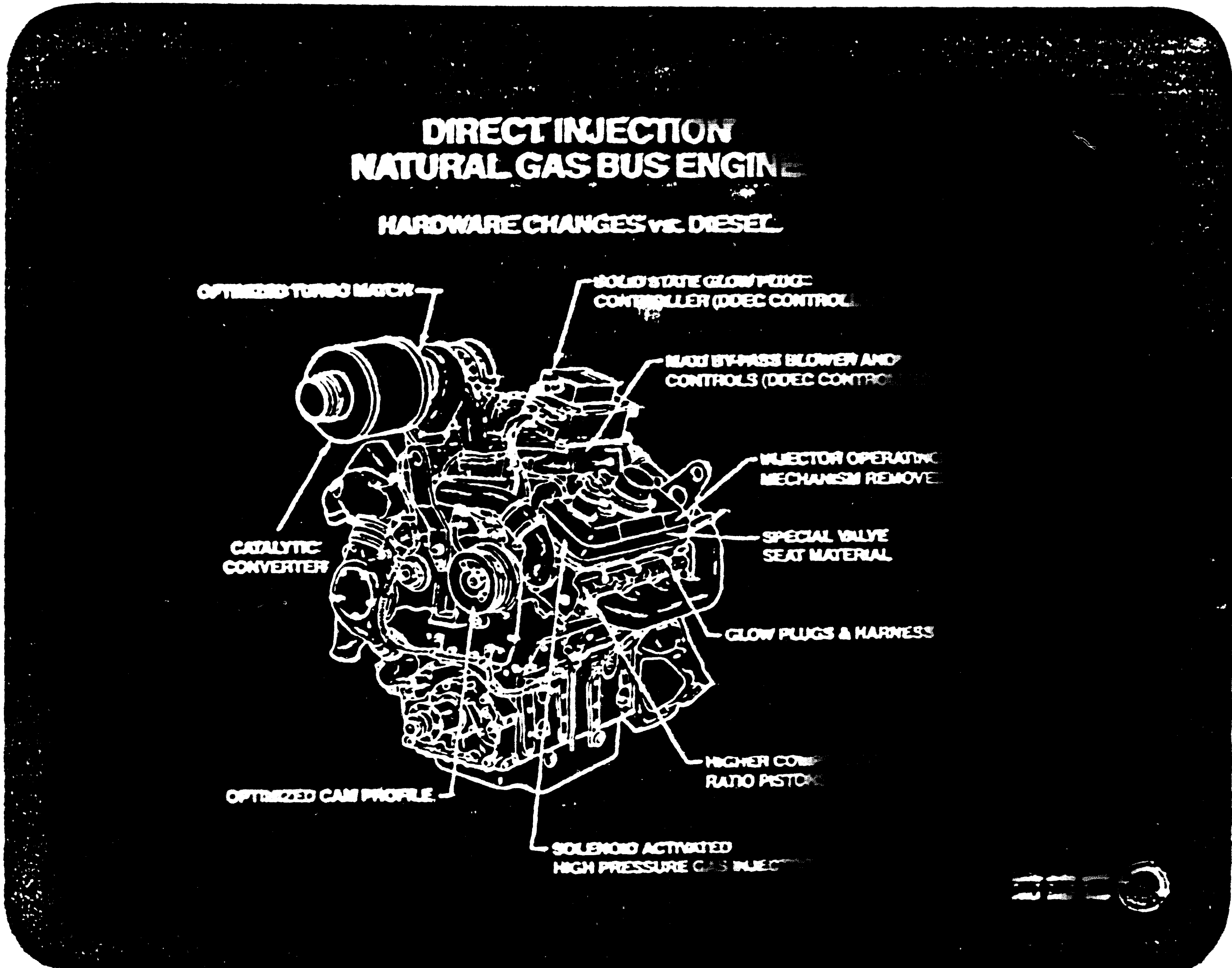
	METHANOL	ETHANOL	NATURAL GAS
MAXIMUM MILES ON ROAD	185,000	112,000	83,000
TEARDOWN INSPECTION @ 100,000 MILES	YES	-	-

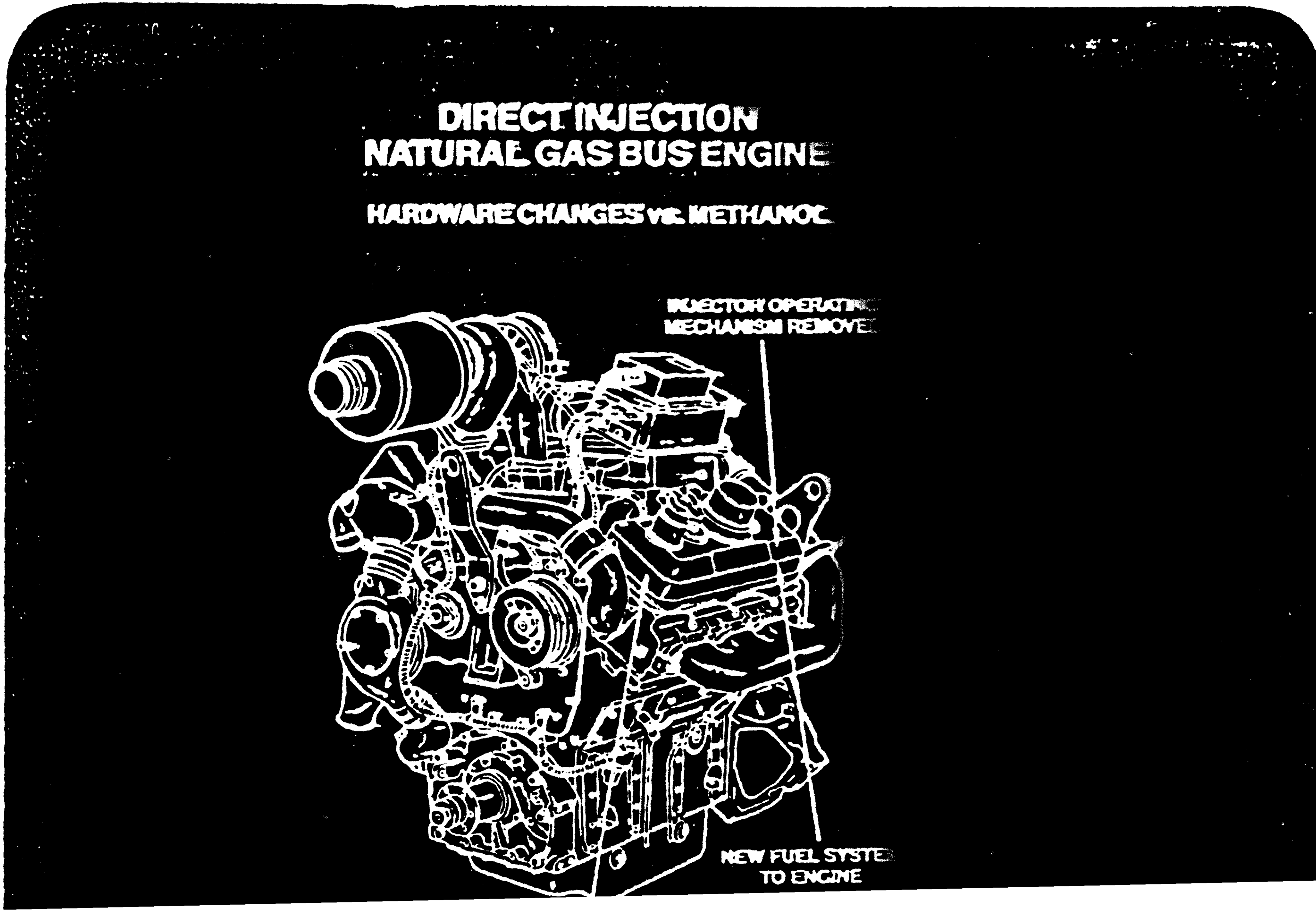
130

METHANOL TEARDOWN RESULTS

- RING & LINER WEAR EQUAL TO DIESEL
- BEARING WEAR SLIGHTLY HIGHER THAN DIESEL

DDC


DIRECT INJECTION
NATURAL GAS BUS ENGIN
HARDWARE CHANGES vs. DIESEL
OPTIMIZED TURBO MATCH
SOLID STATE GLOW PLUG
CONTROLLER (DDEC CONTROL
MAG BY-PASS BLOWER AND
CONTROLS (DDEC CONTRO
INJECTOR OPERATING
MECHANISM REMOVE
SPECIAL VALVE
SEAT MATERIAL
GLOW PLUGS & HARNESS
CATALYTIC
CONVERTER
HIGHER COM
RATIO PISTO
OPTIMIZED CAM PROFILE
SOLENOID ACTIVATED
HIGH PRESSURE GAS INJEC


DIRECT INJECTION
NATURAL GAS BUS ENGINE
HARDWARE CHANGES vs. METHANO
INJECTOR OPERATIN
MECHANISM REMOVE
NEW FUEL SYSTE
TO ENGINE

DIRECT INJECTION NATURAL GAS ENGINE EMISSIONS

	G/HP-HR			
	HC	CO	NOx	PM
1994 STANDARD	1.3	15.5	5.0	0.10
1998 STANDARD	1.3	15.5	4.0	0.10
DI-NG EMISSION TARGETS	0.6	2.0	2.5	0.05

DDC

FAMILY OF SI-NG ENGINES

MODEL	DISPLACEMENT (LITERS)	HP RANGE	EPA CLASS
S-30G (NAVISTAR V8)	7.3	200-250	LIGHT-HEAVY
S-40G (NAVISTAR I-6)	8.7	250-300	MEDIUM-HEAVY
S-50G	8.5	250-300	HEAVY-HEAVY
S-60G	12.7	300-400	HEAVY-HEAVY

DDC

GENERAL SI-NG ENGINE FEATURES

- LEAN BURN COMBUSTION TECHNOLOGY
- COMPRESSION RATIO 10:1
- AIR-TO-AIR CHARGE COOLING
- TURBOCHARGED WITH WASTEGATE CONTROL
- ELECTRONIC IGNITION, INJECTION AND THROTTLE CONTROLLED THROUGH DDEC
- FULL DDEC CAPABILITIES

DDC

DEVELOPMENT STATUS

S-50G

- LEAD DEVELOPMENT ENGINE IN FAMILY
- IMPRESSIVE EFFICIENCY, KNOCK-FREE PERFORMANCE AT HIGH POWER DENSITY DEMONSTRATED
- FIRST ENGINE DELIVERED FOR CUSTOMER DEMO APRIL 9, 1993
- TARGETED START OF FULL PRODUCTION APRIL 1, 1994

S-30G

- AGREEMENT SIGNED WITH NAVISTAR FOR DEVELOPMENT, PRODUCTION & MARKETING OF THIS ENGINE
- BASELINE DEVELOPMENT DONE AT RICARDO
- TEST SCHOOL BUS INSTALLATION COMPLETED IN JUNE, 1992
- TARGETED START OF FULL PRODUCTION JANUARY 1, 1995

DDC

4-71T METHANOL ENGINE

- PROGRAM FUNDED BY THE SCAQMD
- USES METHANOL + AVOCET IGNITION IMPROVER
- BASED ON LAC-MTA 6V-92 M + A EXPERIENCE
- COMPONENT CHANGES TO MINIMIZE THE AMOUNT OF AVOCET REQUIRED
    - 23:1 COMPRESSION RATIO
    - LOWER DISPLACEMENT BLOWER
- HIGH OUTPUT MUI INJECTORS DELIVER 160 HP
- APPLICATIONS TO DATE
    - GENERATOR SET
    - AIRPORT SHUTTLE BUS
- FOLLOW ON PROGRAM UNDERWAY TO DEVELOP DDEC VERSION @ 200 HP FOR PORT OF LONG BEACH YARD TRACTORS

DDC

8V-92TA ETHANOL TRUCK ENGINE

- DEVELOPMENT-ONLY PROGRAM FUNDED BY THE GREAT LAKES GOVERNORS COUNCIL
- BASED ON THE 6V-92TA ETHANOL ENGINE (USES THE SAME PISTONS, INJECTORS, GLOW PLUG CONTROLLERS, ETC.)
- USES CYLINDER HEADS & BYPASS BLOWER FROM HIGH OUTPUT MILITARY DIESEL ENGINE
- STATUS - CONTRACT AWARDED IN MAY, ACTIVITY JUST BEGINNING

DDC

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

DDC ALTERNATIVE FUEL PRODUCT EXPERIENCE AND FURTHER DEVELOPMENT
S.P. Miller, Detroit Diesel Corporation

Q. Robert Last, FEV of America: Could you comment on maximum thermal efficiency observed? Also, how does thermal efficiency change at part load operation compared to a conventional diesel engine?

A. The peak thermal efficiency was about 30 to 40 percent which is slightly less than the diesel at full load. However, as load decreases, the thermal efficiency of the gas engine is slightly better than the diesel engine.

Q. Ron Bright, Ford Motor Co. Canada: Is your work with liquefied natural gas related to the availability of fuel in Texas?

A. The main factor is that Houston Metro has selected LNG as a test fuel with potential for being used for their entire fleet. They have arranged for a fuel supply near Houston. Our work is being done to respond to a customer request.

Q. Joseph Wagner, NYSERDA: What is the commercial potential for the direct injection engine?

A. We need to demonstrate reliability of the engine. We would expect this technology to be used in off-highway applications of the larger engines.

Q. What about transit bus applications?

A. We will have competing technologies for awhile and the outcome depends on a lot of things such as engine cost and fuel efficiency.

Q. Anonymous: Are you testing vegetable oils or bio-diesel fuels?

A. Yes, we are working with esterified vegetable oil as possible blending agents. They add oxygen to the diesel fuel to reduce particulates in the exhaust. They may also increase the NOx emissions although injection timing adjustment can compensate for that effect. We have also tested bio-diesel as pilot fuel for ignition of natural gas.

Q. Mostafa Kamel, Cummins Engine Co.: Could you comment on pressure levels for LNG injection?

A. There are a couple of candidate fuel systems being developed, tentatively with 50 to 70 psi pressure range.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

DEDICATED NATURAL GAS ENGINES FOR ON-HIGHWAY APPLICATIONS "THE NATURAL CHOICE"

K. Boyer
Hercules Engine Company

NOVEMBER 25, 1992

HERCULES ENGINES, INC.

TO

HERCULES ENGINE COMPANY

HERCULES ENGINE COMPANY

- Located in Canton, Ohio
- Founded in 1915
- Manufacturers of Diesel, Gasoline, LPG and Natural Gas engines
- After sale support provided by a Distributor - Dealer network in the United States and Canada
- Hercules' engines can be found in a number of Industrial and On-highway applications

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE MODEL GTA 5.6

- Dedicated natural gas engine
- 5.6 liter (339 cubic inch) displacement
- 6 cylinder, in-line configuration
- Turbocharged and aftercooled (air to air)
- 190 horsepower at 2800 rpm
- 460 lbs./ft. of torque at 1500 rpm

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

- **STARTED IN 1989 WITH G.R.I. CO-FUNDING**
- **PROJECT OBJECTIVES**
  - Similar power rating to current diesel rating
  - Low emissions
  - Engine component commonality

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

	EPA 1991 Diesel	Hercules Natural Gas
NOx	5.0	1.68
THC	1.8	13.7
NMHC	N/A	1.3
CO	15.5	3.6
PM	0.25	0.1

– Success stimulated further development

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

- **MECHANICAL REFINEMENTS**
  - Iron plated piston crown
  - Revised piston skirt profile
  - Reduced oil consumption ring set
  - Modified valve stem oil seals
  - Electronic fuel-ignition control

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

- **KEY TO LOWEST EMISSIONS**
  - Cyl. to Cyl. air/fuel ratio consistency
- **FUEL SYSTEM**
  - Electronic air/fuel ratio control
- **IGNITION SYSTEM**
  - 12 volt, capacitive discharge

HERCULES ENGINE COMPANY

"THE NATURAL CHOICE"

ENGINE DEVELOPMENT

BACKGROUND - GTA 5.6

- **DEVELOPMENT SUB-CONTRACTORS**
  - ORTECH International
  - Southwest Research Institute
- **FINAL CONFIGURATION**
  - Primarily diesel components
  - Open loop electronic fuel and ignition control
  - 10:1 Compression ratio pistons
  - Lean burn combustion

TRANSIENT EMISSION TESTING

ENGINE OUT EMISSIONS

Grams/Hp/Hr.

	GTA 5.6	1994 CARB
NOx	1.56	5.0
THC	3.97	1.3
NMHC	0.76	1.2
CO	2.09	15.5
PM	0.06	0.1

HERCULES ENGINE COMPANY

MODEL GTA 5.6

STATE OF CALIFORNIA

AIR RESOURCES BOARD

EXECUTIVE ORDER

A-289-3

Issued on March 30, 1993

HERCULES ENGINE COMPANY

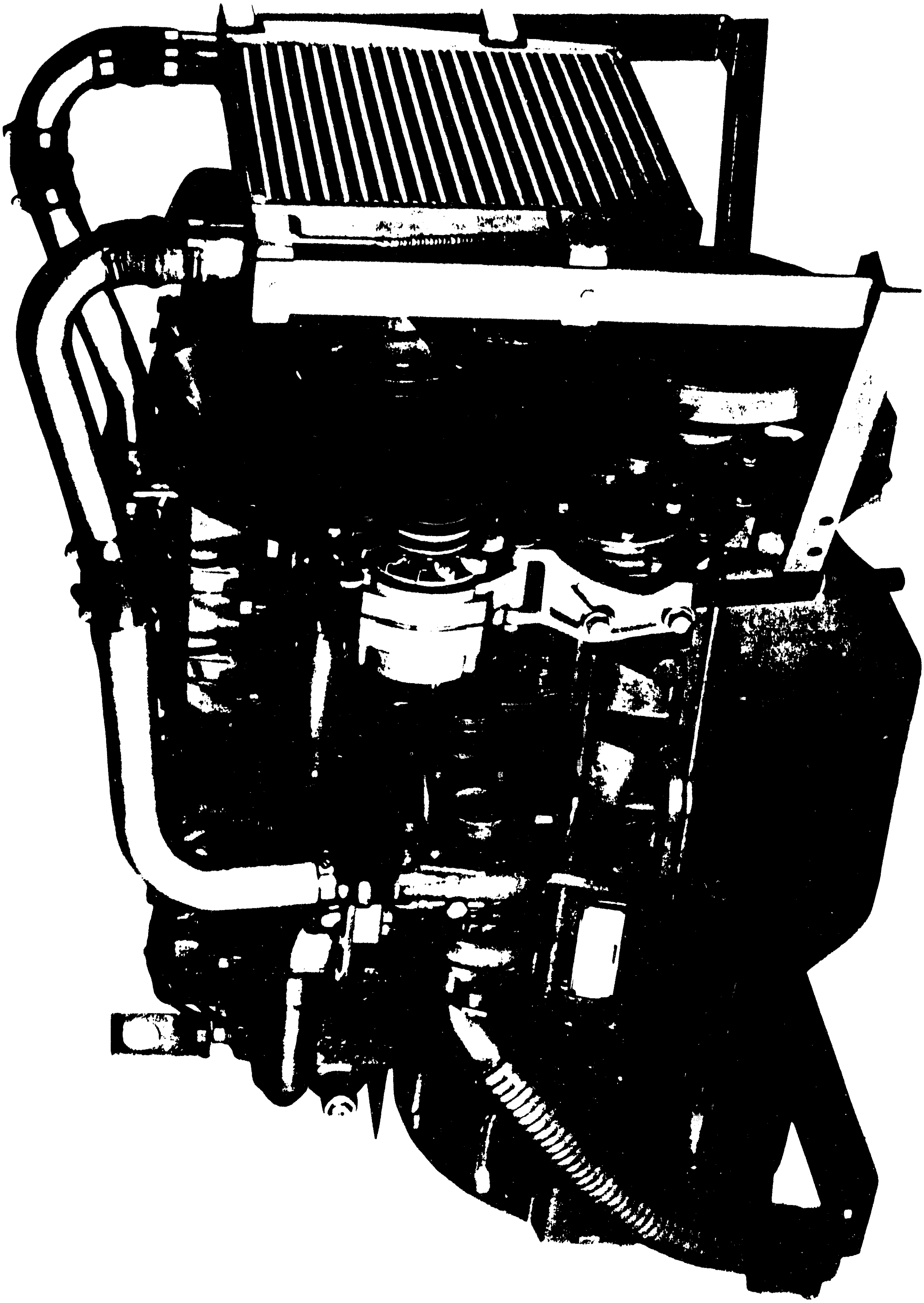
MODEL GTA 5.6

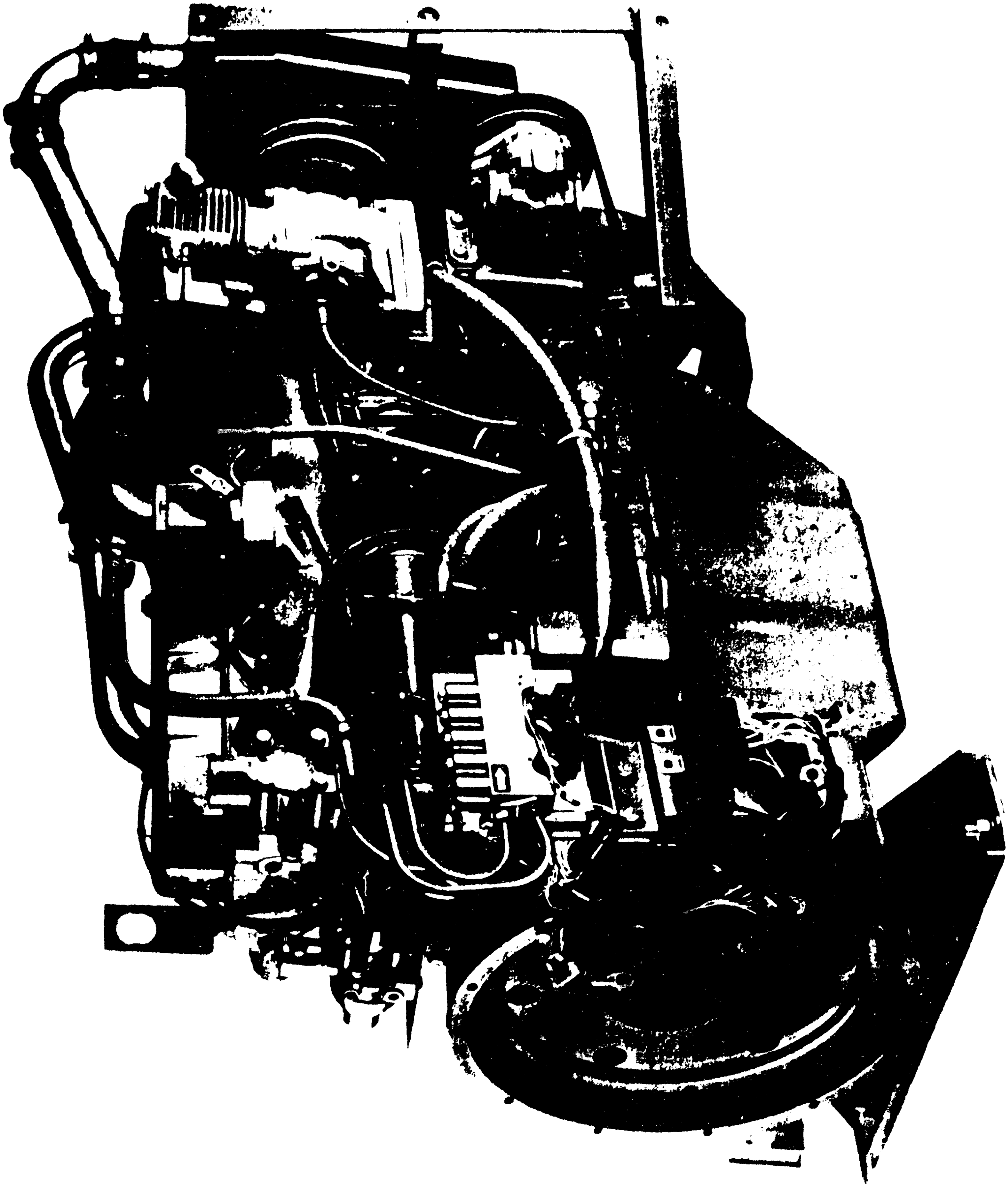
PRODUCTION AVAILABLE

HERCULES ENGINE COMPANY

GTA 5.6
WARRANTY

- TWO YEARS
- UNLIMITED MILAGE
- 100% PARTS & LABOR





Counselor: The Student Body by Carpenter that goes the distance in efficiency.

Extra-large, aluminum split sash Hehr* passenger windows open fully to provide ample escape exits in case of an emergency.

A panoramic windshield, combined with forward placement of the driver's seat and a flat faced front end, maximizes the driver's field of vision.

Electric powered windshield wipers keep the windshield clear in rain or snow.

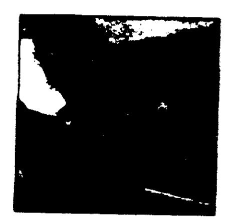
Deep side skirts accommodate large underfloor storage compartments which make Counselor well suited for transporting students to out-of-town school activities.

A wraparound, 12-inch bumper provides added protection in the event of a front-end collision.

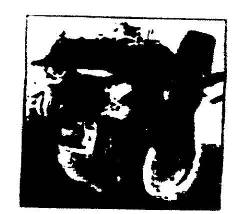
The front grill and dual-maintenance panels can be removed without tools for easy access to electrical components, heaters, windshield washers and other front-end maintenance components.

A wide, low-angled, three-step stairwell facilitates entry and exit and the low-profile engine cover expands the driver's view of on- and off-loading passengers.

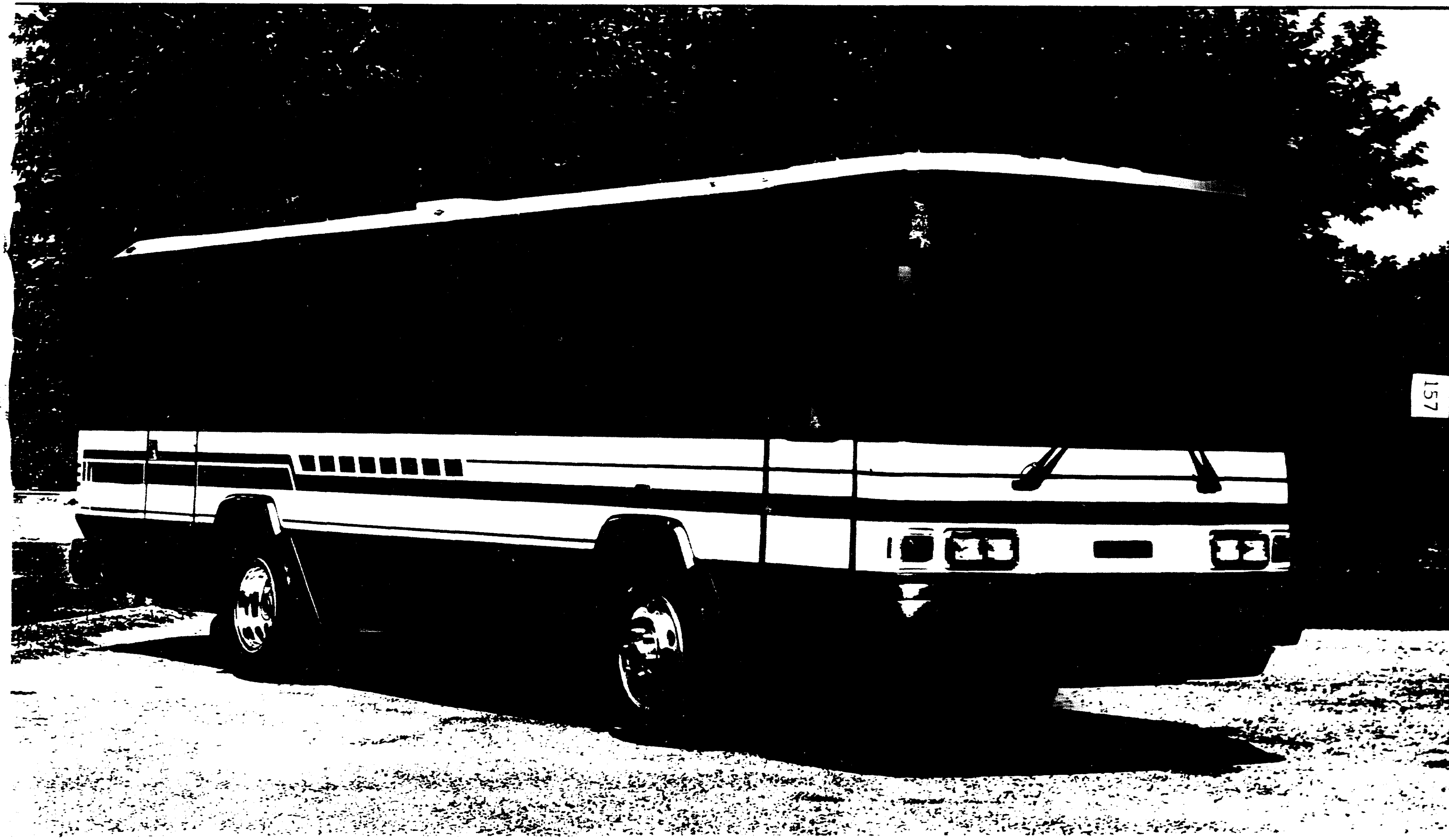
No tools are needed for the removal of the front grill and dual-maintenance access panels.



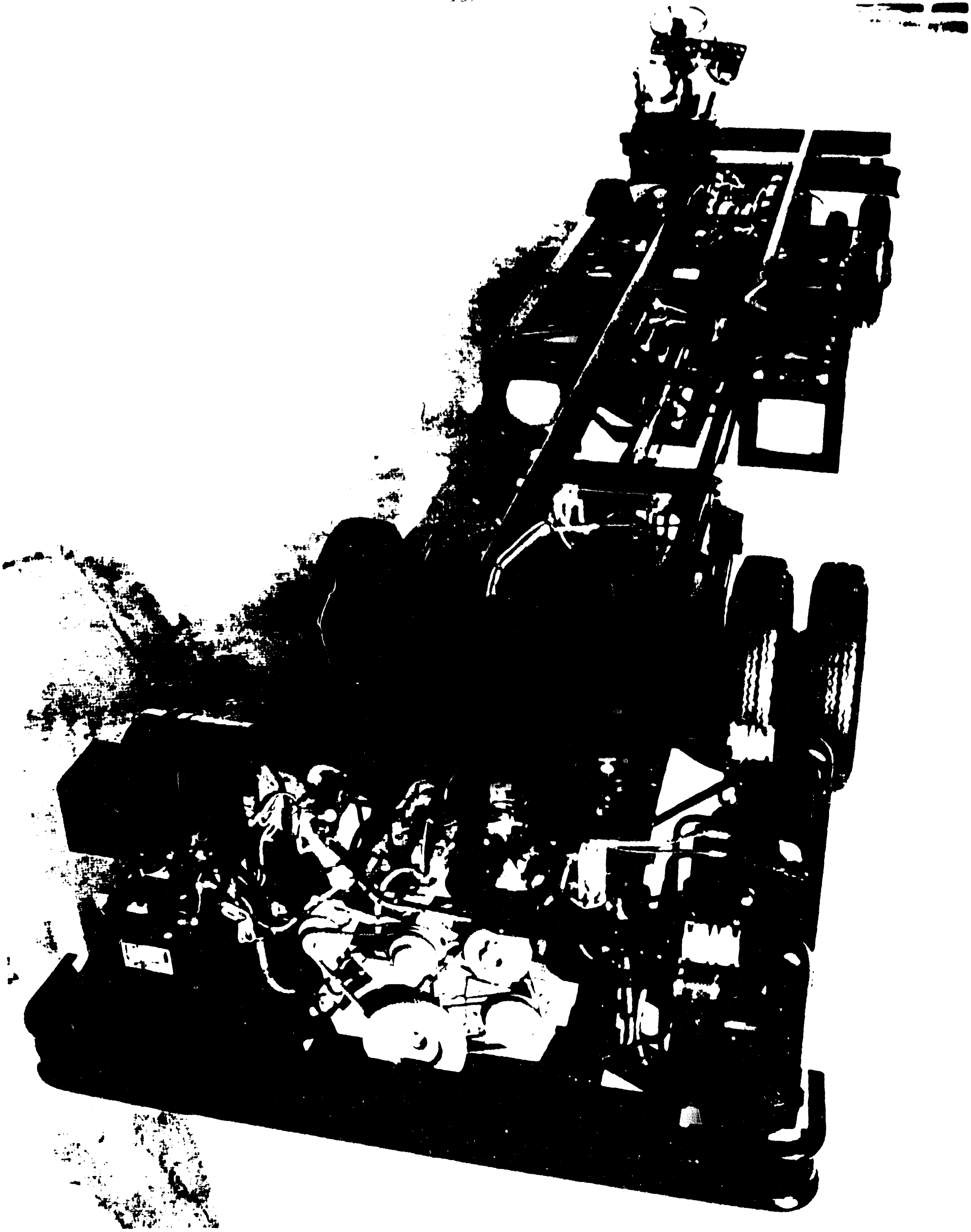
There's ample room for luggage, band instruments or athletic equipment in Counselor's optional deep side-skirt luggage compartment.

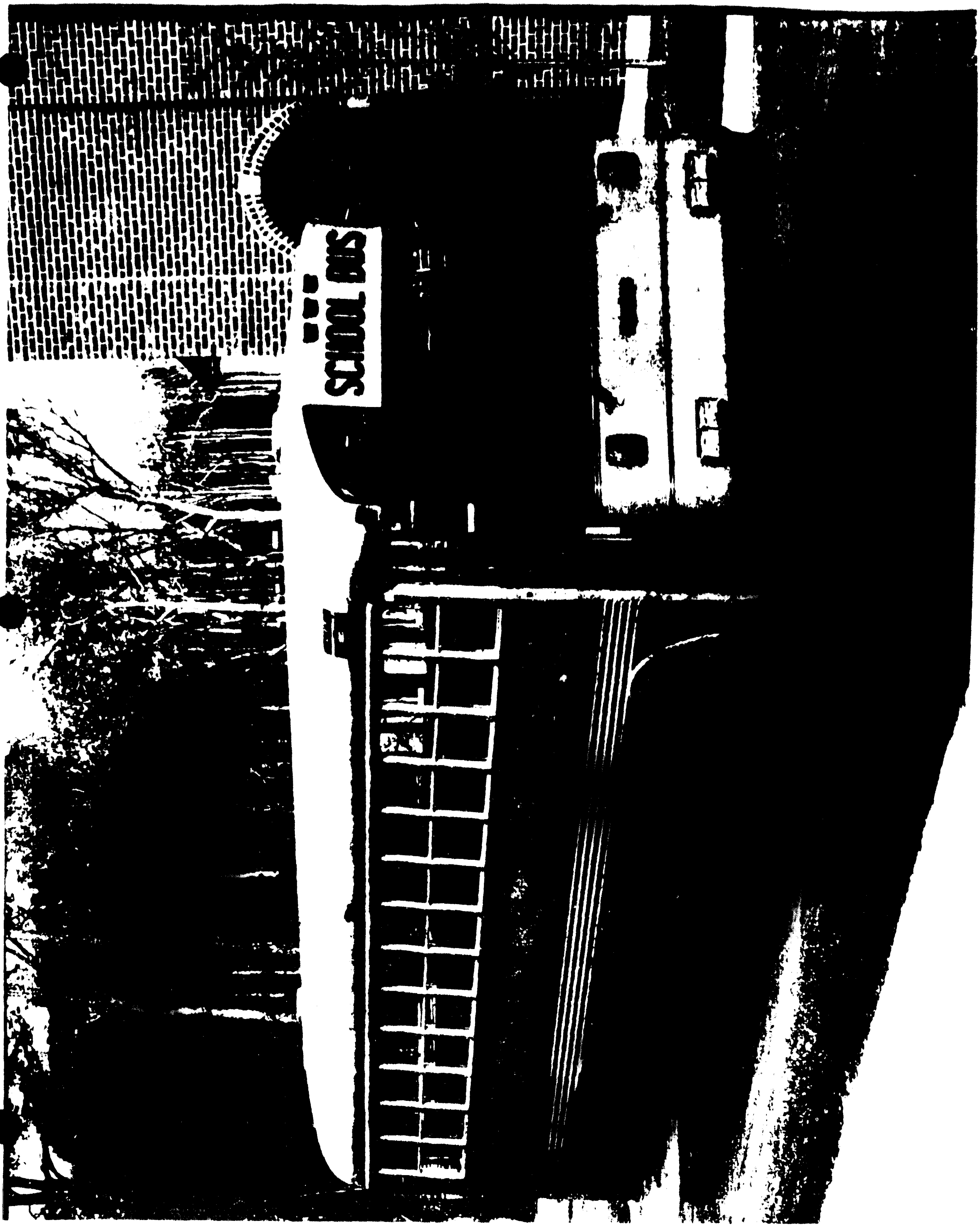


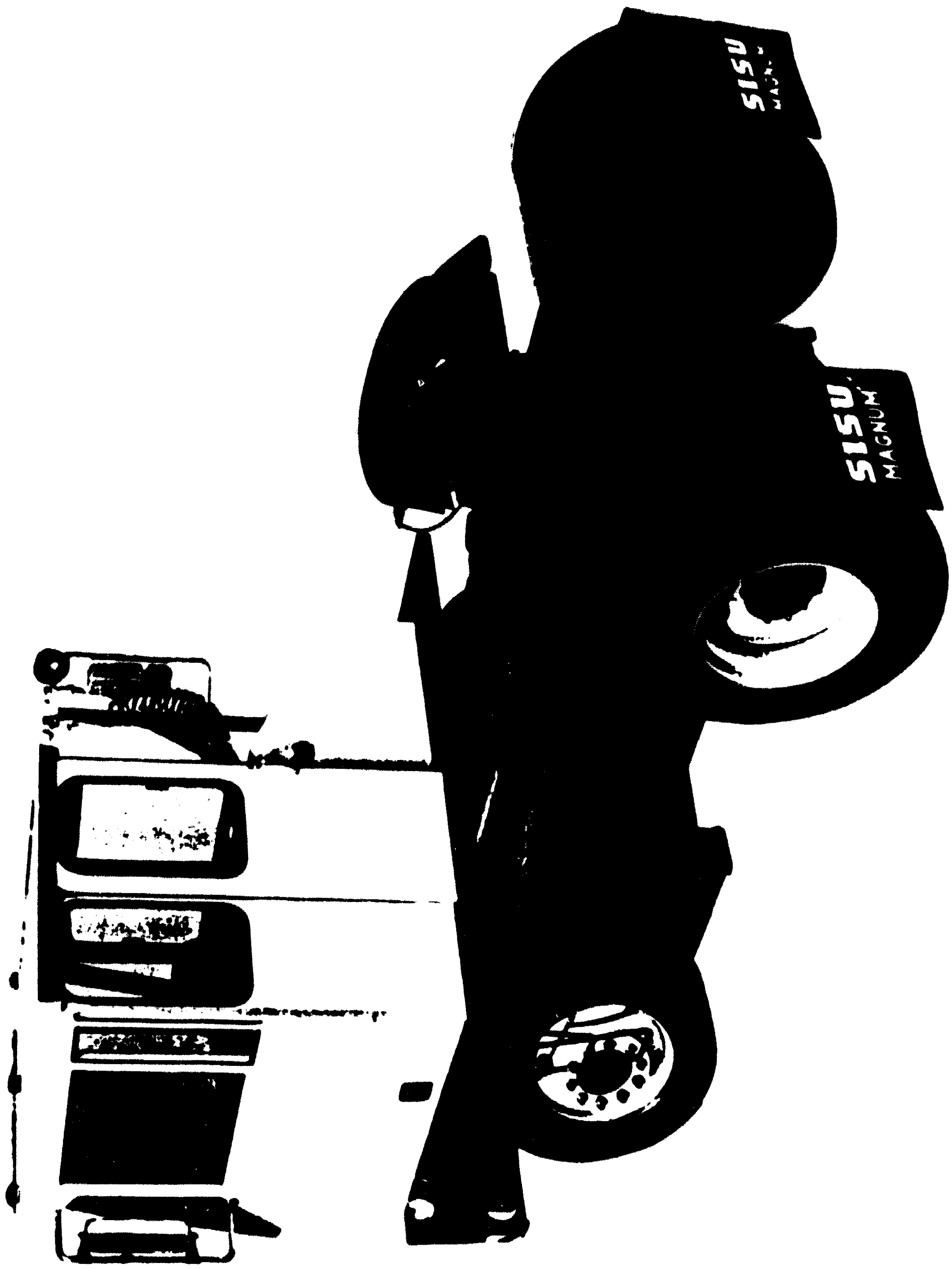
Counselor is available with an efficient Hercules dedicated Compressed Natural Gas (CNG) engine that's kinder to both your fuel budget and the environment.



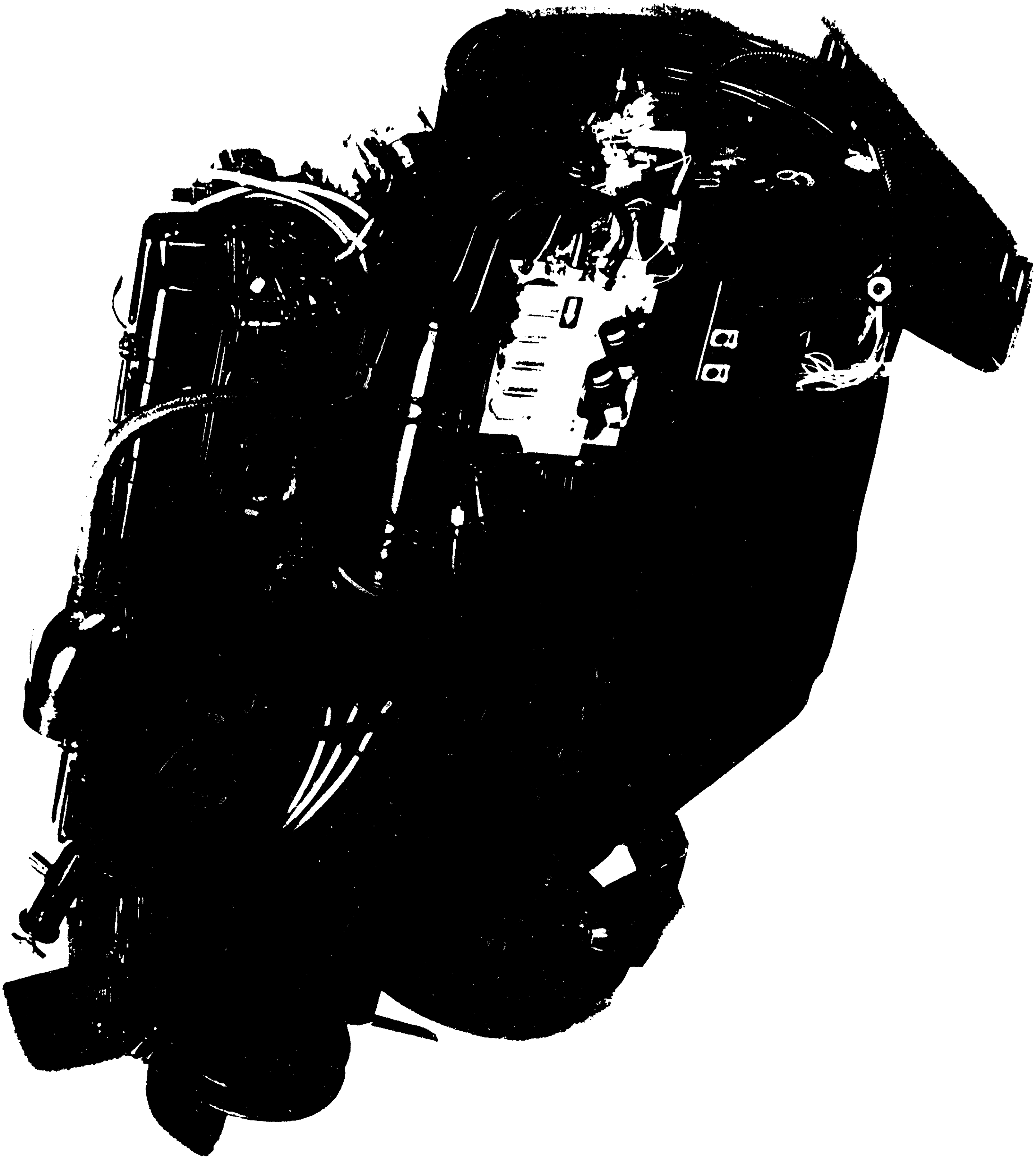

LADOT
DASH




SCHOOL BUS


SISU
SISU
MAGNUM


HERCULES
ENGINES INC



SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

DEDICATED NATURAL GAS ENGINES FOR ON-HIGHWAY APPLICATIONS - THE NATURAL CHOICE
K. Boyer, Hercules Engine Company

Q. Mostafa Kamal, Cummins Engine Co: Could you comment on gas supply pressure to the engine?

A. Yes, the system requires 100 psi at the intake side of the regulator.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

NATURAL GAS ENGINE AND VEHICLE DEVELOPMENT AT NAVISTAR PROGRAM STATUS

R.A. Baranescu
Navistar International

- Introduction - Market Forces Toward Natural Gas Fuel
- Natural Gas Engine Concept Development At Navistar
- Field Demonstration Of CNG Vehicles
- Natural Gas Engine Production Development
- Summary And Conclusions

NAVISTAR CNG ENGINE PROGRAM
MARKET FORCE INFLUENCE ON NAVISTAR

- 50% Share On School Bus Market
- 35% Share On Medium Truck Market
- 25% Share Of Heavy Truck Market
- Largest Volume Diesel Engine Producer
- Navistar Holds A Leadership Position And Responsibility

NAVISTAR CNG ENGINE PROGRAM
NAVISTAR'S MARKET STUDY

- A Sizable CNG Engine Market Exists Both Due To Mandates And Customer Benefit Reasons
- Initial Application To Centrally Fueled Fleets, Buses, Delivery Trucks, Etc.
- Must Meet EPA And California Emission Standards
- Customers Require Low Cost Of Ownership
- No Loss Of Power, Performance, Range, Driveability, Etc. Is Acceptable
- Use Commercially Available Fuel

RB7_593

NAVISTAR CNG ENGINE PROGRAM
DESIGN FEATURES

Power and Speed	210 HP @ 2800 RPM
Torque	450 Ft. Lb. @ 1800 RPM
Compression Ratio	10 to 11.3
Combustion	Lean Burn
Fuel Efficiency	30% Better Than Gasoline 15% Worse Than Diesel
Emission Goal	Meet EPA & California Standards
Intercooling	Only Later
Catalyst	Not Planned; Possibly Later
Fuel System	Mechanical Mixer For Veh. Demo Electronic Gas Valve For Prod. Dev.
Ignition	High Energy CD For Veh. Demo Automotive Induction System For Prod. Dev.

RB6B_593

NAVISTAR CNG ENGINE PROGRAM
DESIGN MODIFICATIONS - CYLINDER HEAD

- Plug Position
- Sleeve Design
- Metal Sections
- Rocker Cover Modification
- Seat Inserts
- Use Of Current Casting

RB2_593

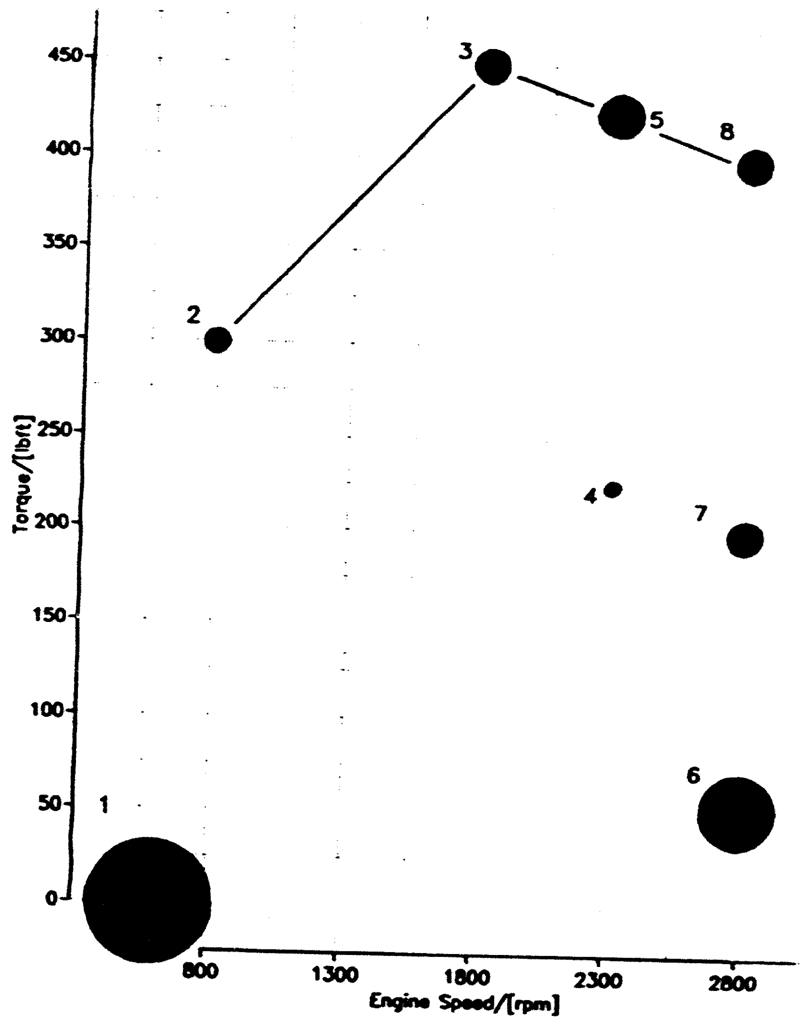
NAVISTAR CNG ENGINE PROGRAM
DESIGN MODIFICATION - PISTON

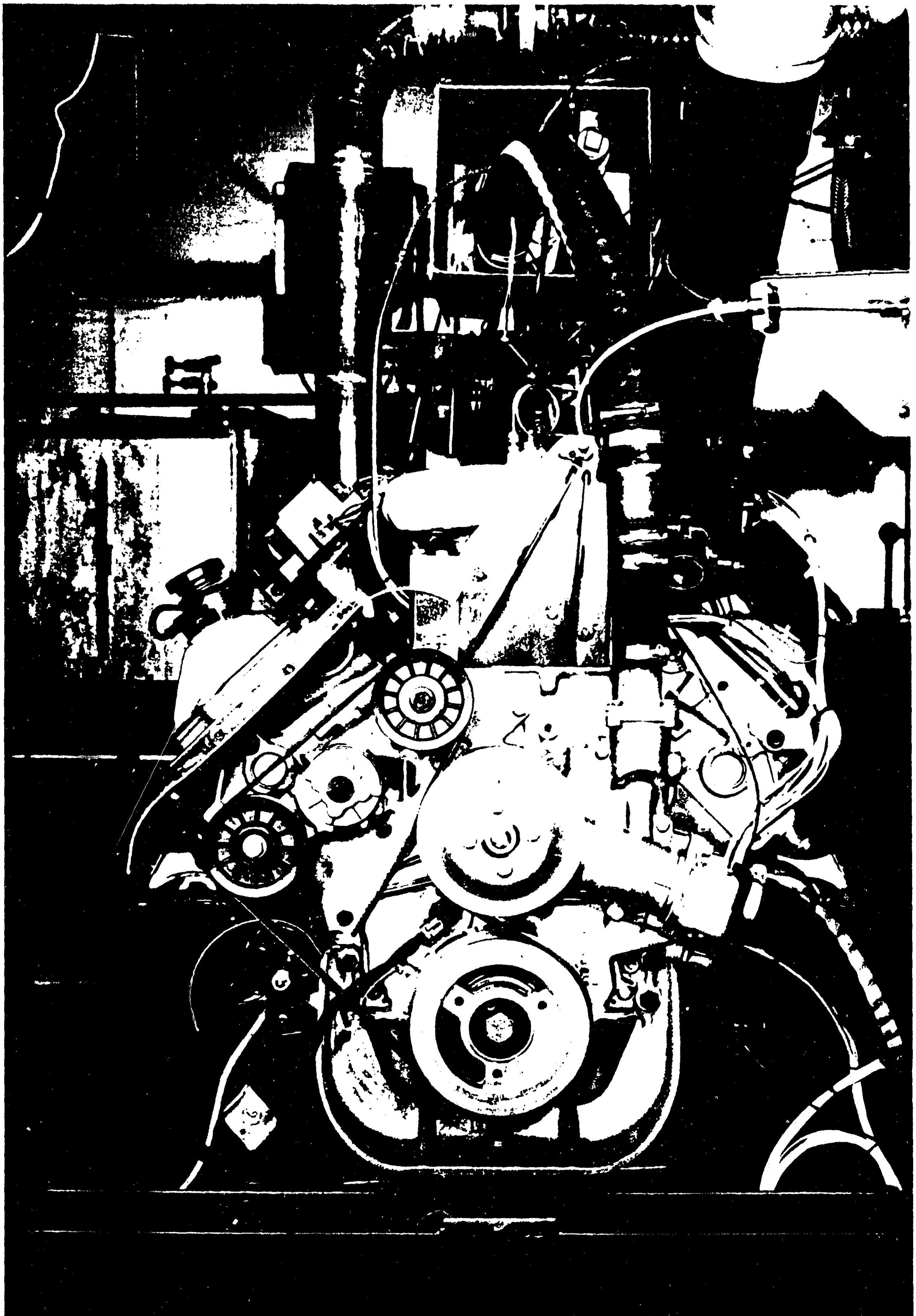
- Compression Ratio Selection
- Lost Volumes - Valve Recess
- Undercrown Thickness
- Ring Height
- Thickness Behind Ring
- Chamber Orientation/Plug Position

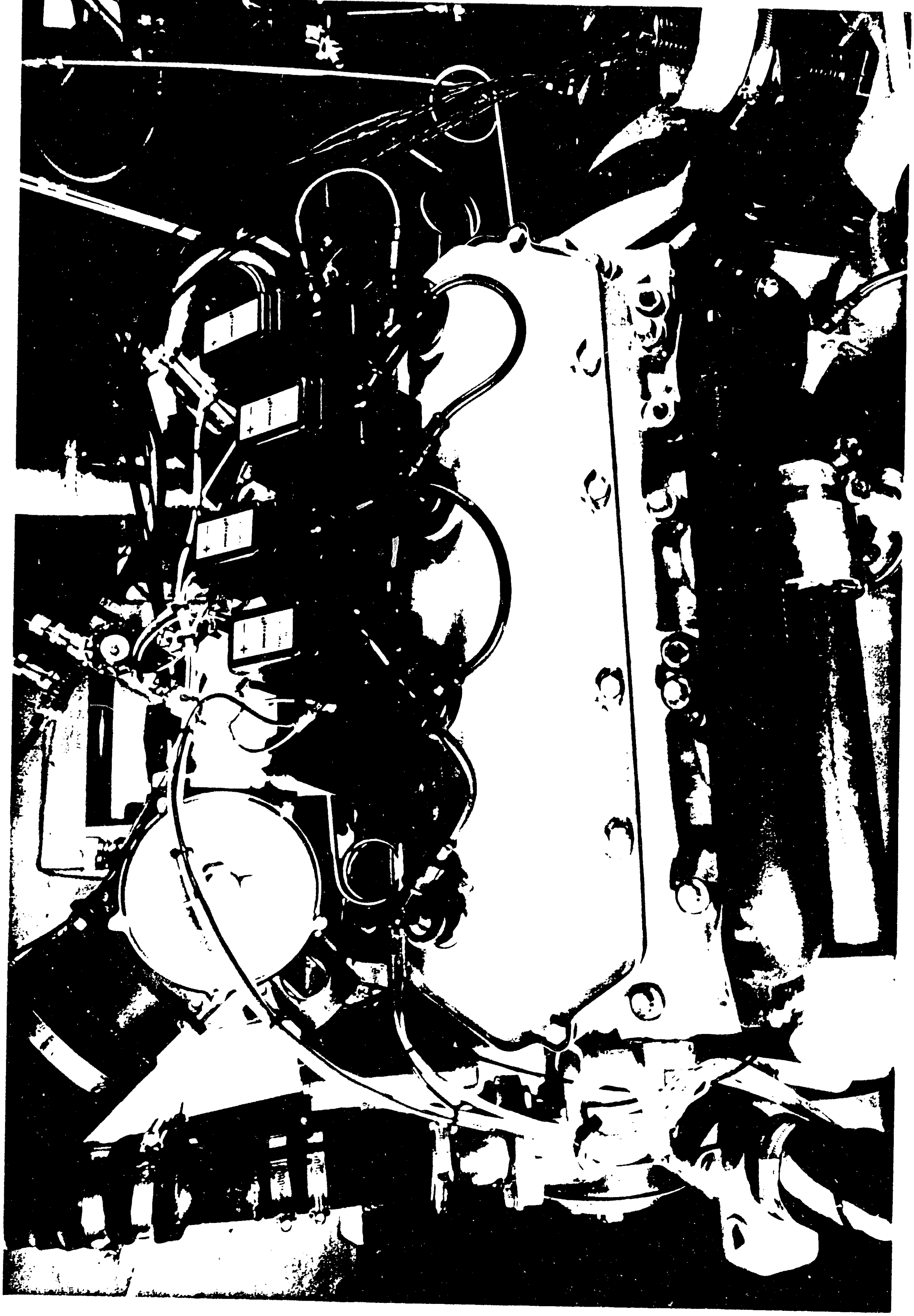
NAVISTAR CNG ENGINE PROGRAM
DESIGN MODIFICATIONS - INDUCTION SYSTEM

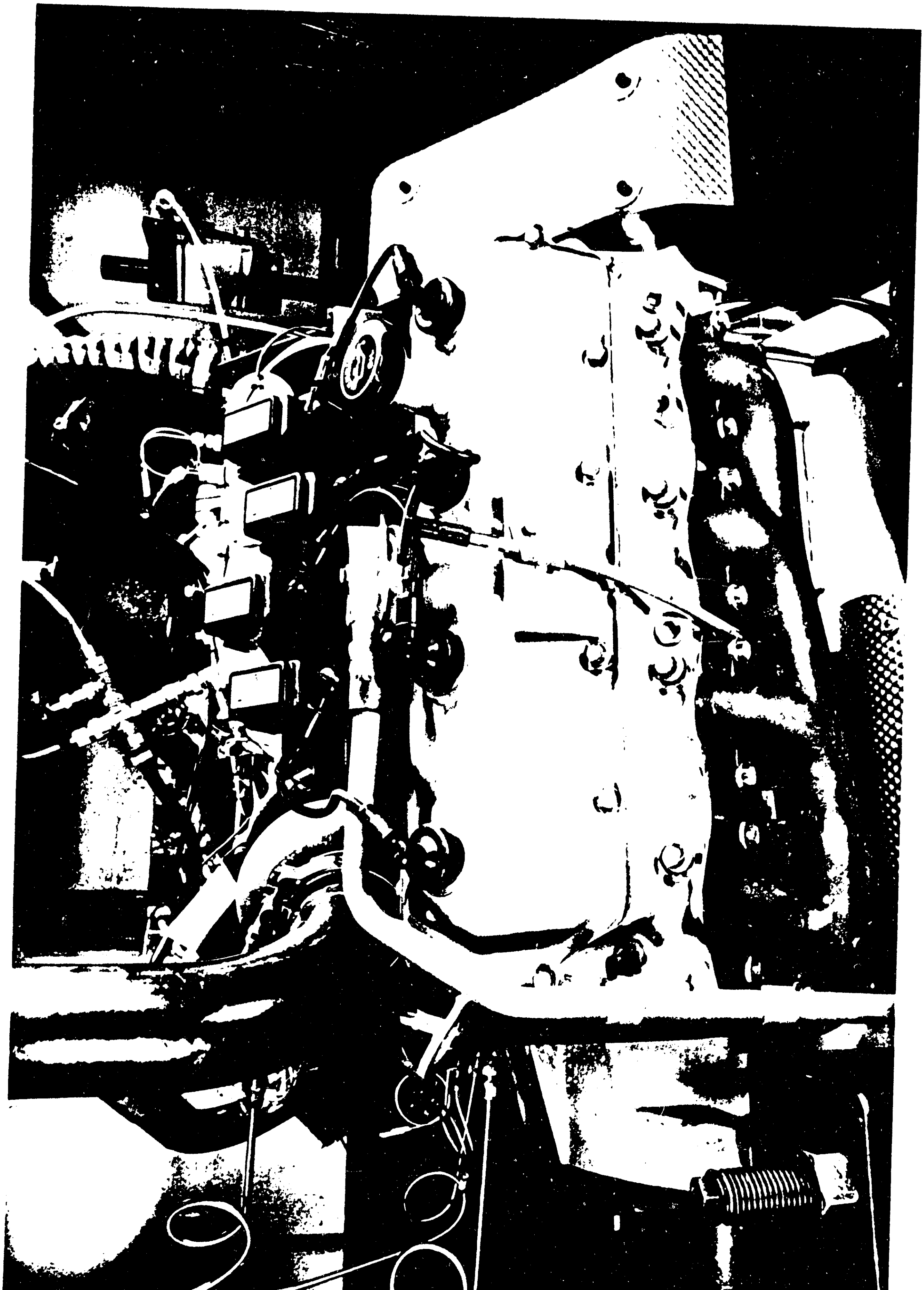
- Turbocharger Selection
- Mixer Selection
- Mixer / Throttle Relationship
- Upstream / Downstream
- Installation Constraints

8 MODE TEST POINTS





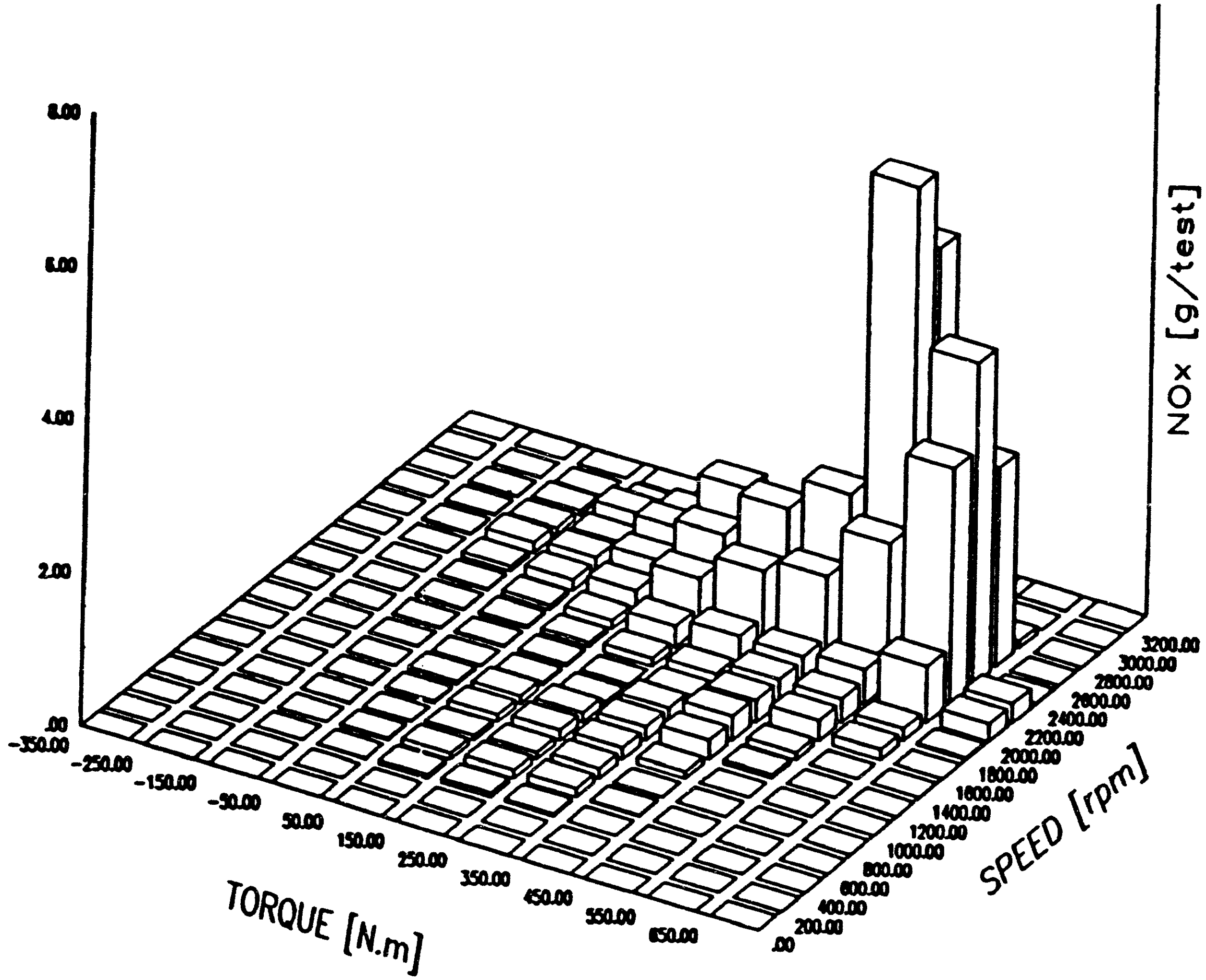




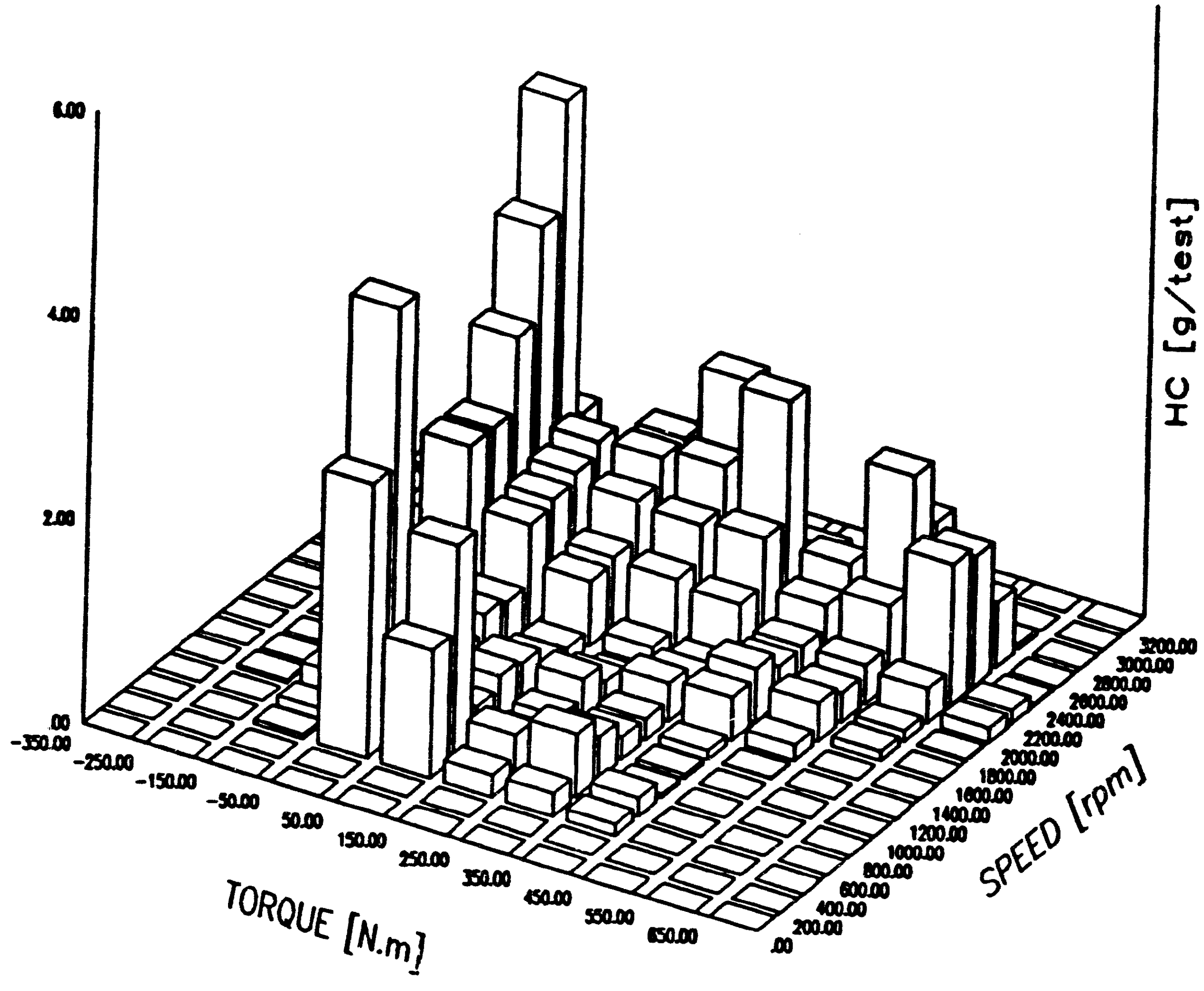
NAVISTAR CNG ENGINE PROGRAM ACHIEVEMENT

Torque Curve	Target	Achievement
Rated Power (2800 RPM)	210 BHP	210 BHP
Peak Torque (1800 RPM)	450 LB FT	450 LB FT
Low Speed (800 RPM)	240 LB FT	285 LB FT
Emissions (G/BHP-Hr) Over FTP Transient Cycle):		
NOx	4.5	2.0
CO	12.5	2.84
NMHC	1.0	0.56
PM	0.08	-
Efficiency		
Brake Thermal Efficiency (Hot Cycle)	23.0%	28.1%

RB5_593



MAP OF INTEGRATED EMISSIONS HOT START NOx



MAP OF INTEGRATED EMISSIONS HOT START HC

KEY DESIGN ISSUES OF NATURAL GAS ENGINE

- CYLINDER HEAD DESIGN
  - Cast-In Spark Plug Access
  - Cast Valve Cover (Accessibility Simplicity Of Sealing)
  - Water Jacket Optimization

- VALVE AND SEAT WEAR (ESP. EXHAUST VALVE)
  - Exhaust Seat Angle
  - Valve Face And Seat Materials

- OIL CONTROL (POWER CYLINDER ROBUST AGAINST EFFECT OF VACUUM IN INDUCTION SYSTEM)
  - Side Clearance On All Rings
  - Piston Land Diameter
  - Oil Drain Back

- COMBUSTION BOWL GEOMETRY (EFFECT OF TURBULENCE)

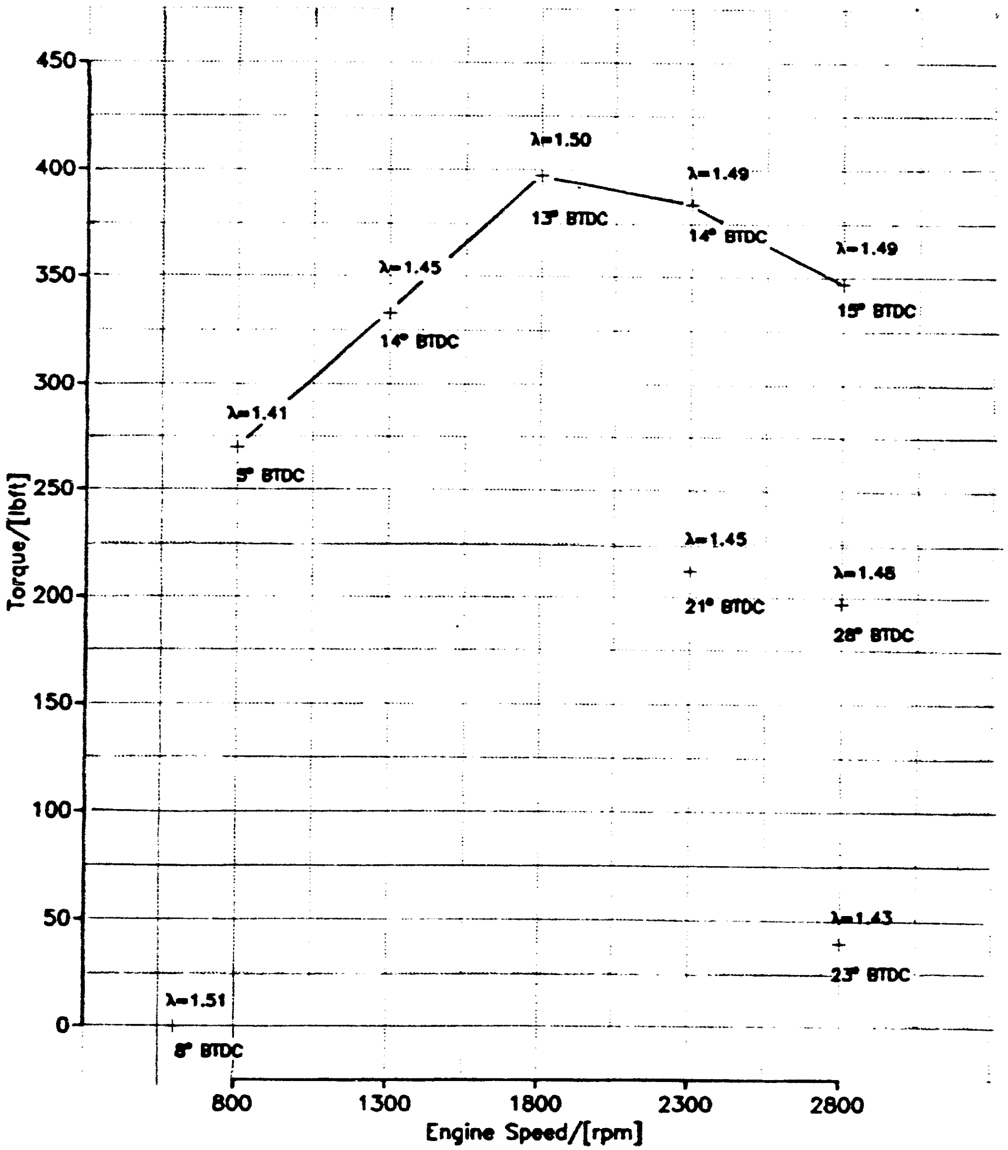
RB13_593

CALIBRATION OF VEHICLE DEMONSTRATION ENGINE

- Best Overall Solution To Satisfy:
  - Torque Shape Requirements
  - Low Emissions - NOx And HC
  - Acceptable Thermal Efficiency
  - Robustness To Ambient Temperature Effects

- Within Limits Of:
  - Mixer's Lack Of A/F Ratio Control
  - Mixer's Lack Of Temperature Compensation
  - Wastegate Actuator Hardware

RB19_593



CNG ENGINE FOR VEHICLE DEMONSTRATION IGNITION AND LAMBDA MAPS

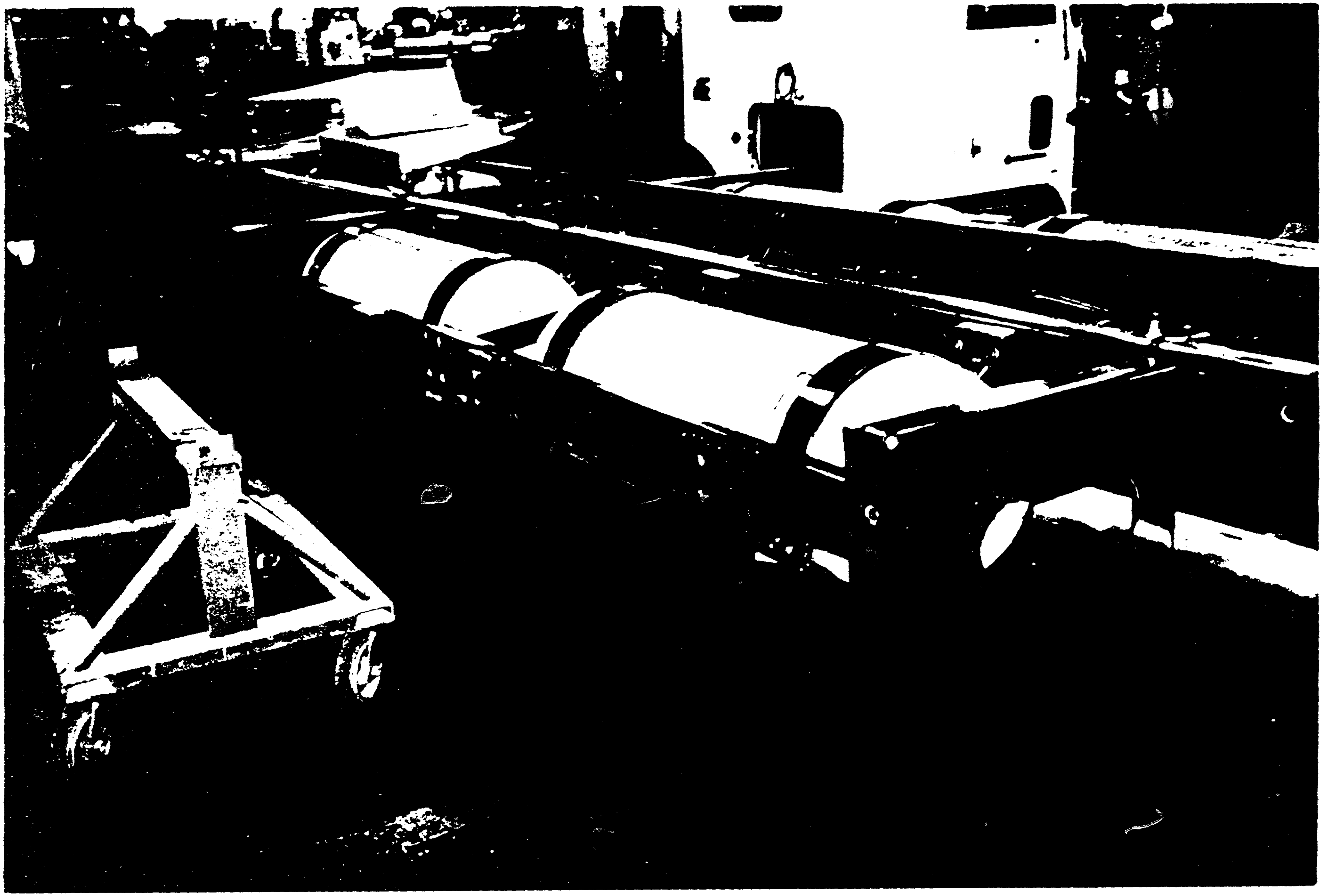
FIELD TESTS AND VEHICLE DEMONSTRATIONS

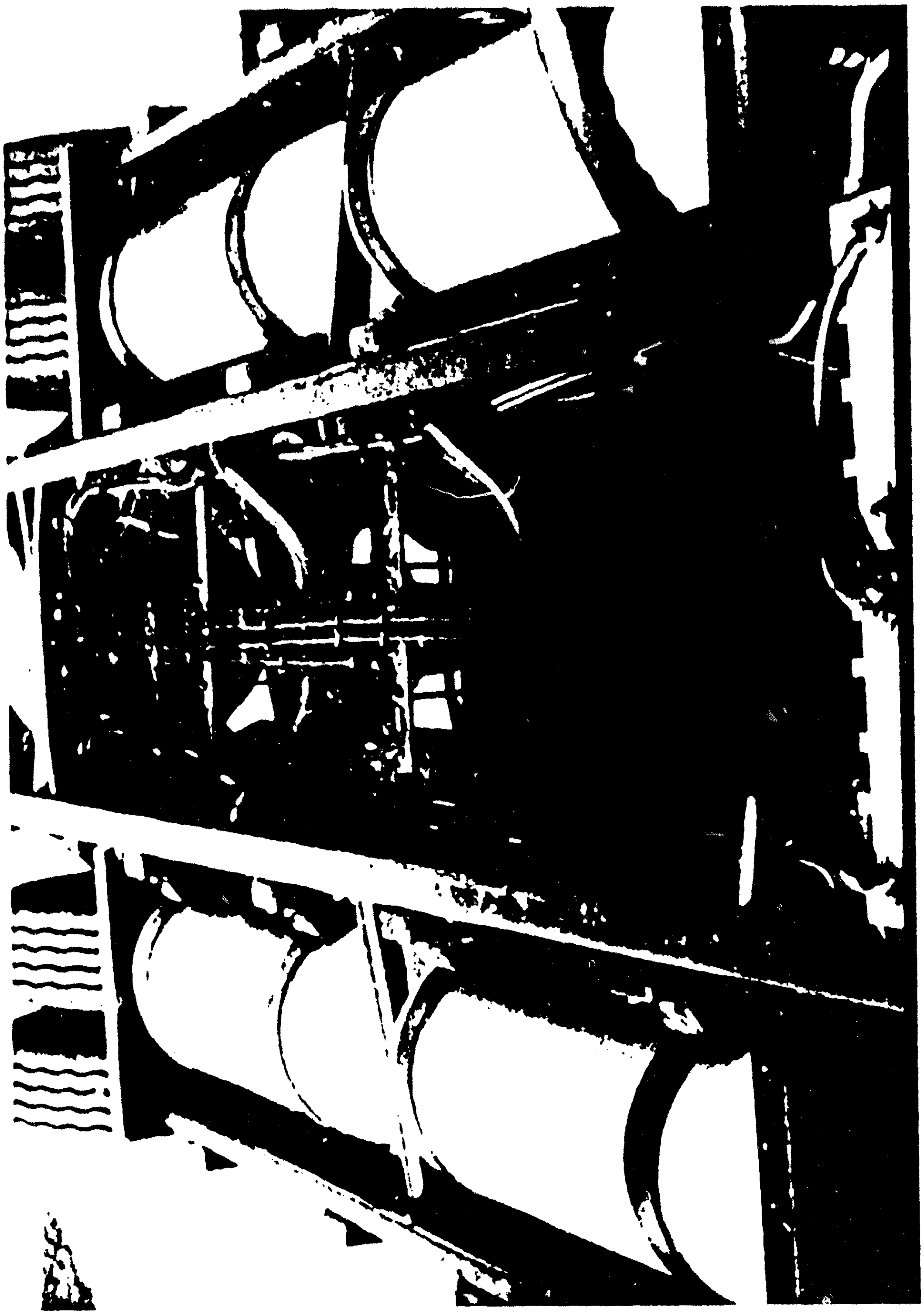
- Objectives
  - Evaluate Engine And Fuel System In Vehicle Operation
  - Provide Workhorse For New Designs
  - Demonstrate Proof-Of-Concept To Potential Users
- One "Mule" School Bus (At Navistar)
- Five Demonstration Vehicles At Customers
  - Four Buses
  - One UPS Vehicle

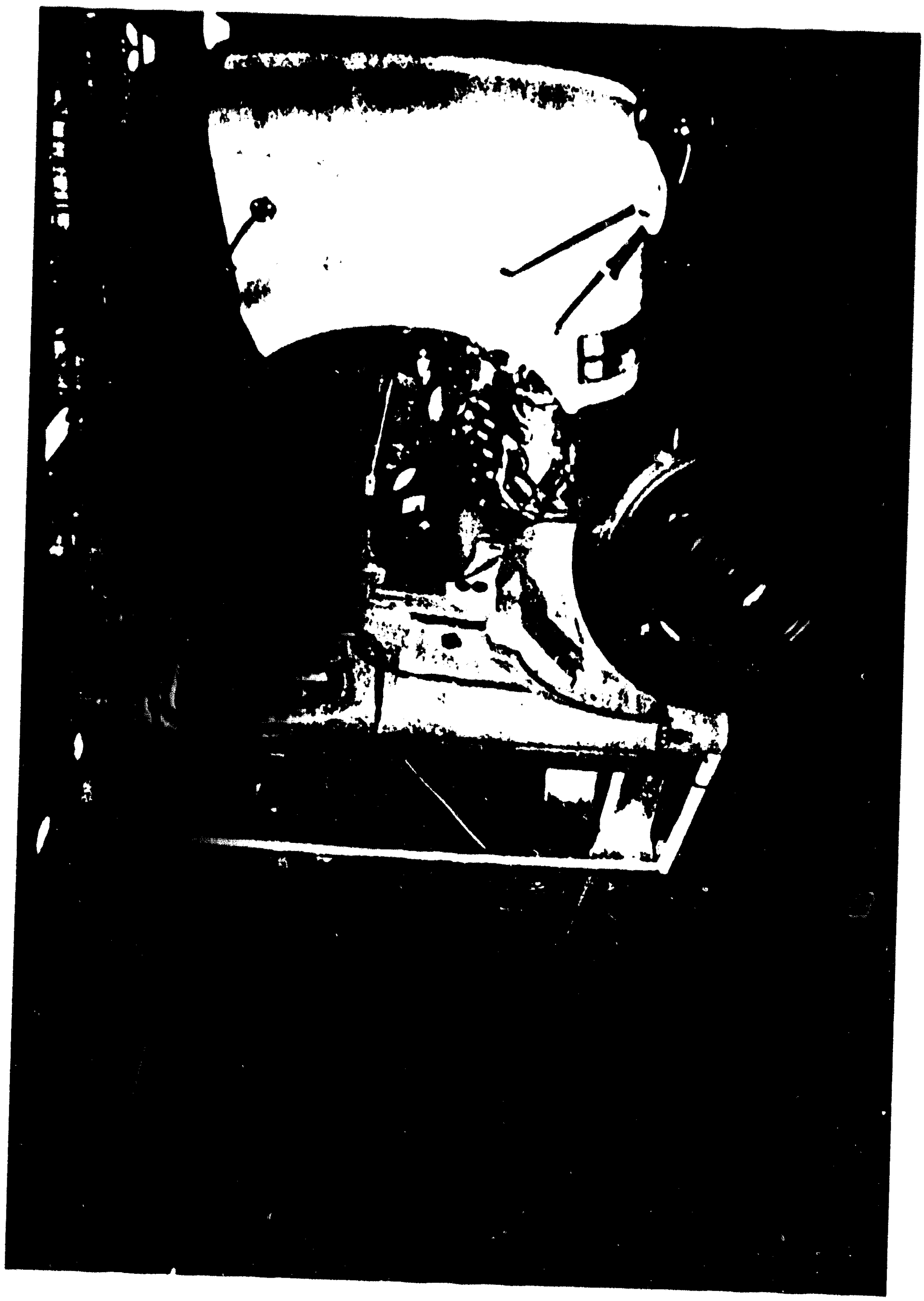
RB18_593

MULE VEHICLE PROGRAM

- VEHICLE SPEC
  - 3700 Chassis School Bus
  - Exhaust System Compatible W/CNG
  - Accelerator Cable To CNG Throttle
- FUEL SYSTEM
  - Four Fuel Tanks (15 X 54")
  - 5000 Ft 3@ 3000 PSI Capacity
  - 200 Mi Operating Range
  - Two Stage Pressure Regulators
- ENGINE
  - 7.3 CNG Proof-Of-Concept Engine
  - Impco 200 Carburetor
  - Altronic Ignition System W/ECM







MULE VEHICLE PROGRAM (Cont'd)

- **ACTIVITIES**

- Fuel Economy, Operating Range - Driveability Performance - Engine Cooling, Heater Performance

- Cylinders Supplier Cert. Tests - Cylinder Mounting - School Bus Barrier Tests

- Ignition System Tests - Radiated Emissions - RF Susceptibility - Interference On Radio Systems Immunity To Water

Engine Validation

PRODUCTION DEVELOPMENT

Joint Venture Between Navistar & DDC

Time Frame: August 1993 - December 1994

Focus:

- Electronic Fuel System (Gas Valve)
- Ignition System (Automotive Inductive)
- Integrated Engine Controls (DDEC)
- Durability / Reliability Validation

Twenty Nine Engines In Laboratory And Field Tests

RB14_593

SUMMARY AND CONCLUSIONS

- A 7.3 Liter Lean Burn Natural Gas Engine Concept Was Demonstrated - For School Bus And Truck Applications - That Achieves The Same Power Output And Torque As The 7.3 Liter Diesel Engine
- The Proof-Of-Concept Has Demonstrated Emission Levels Lower Than Initial Targets On All Major Pollutants, And Compliance With Emission Standards of 1994 - 1995 (US & California)
- Energy Efficiency Of The Concept Engine Has Exceeded Initial Targets; It Is Only About 12% Inferior To Diesel Efficiency

RB15_593

SUMMARY AND CONCLUSIONS (Cont'd)

- Upcoming Vehicle Demonstrations Will Validate The Proof-Of-Concept And The Key Design Features Such As:
  - Cylinder Head
  - Valve Train Design And Durability
  - Power Cylinder Design For Oil Control
  - Air Management, Induction System
  - Vehicle Fuel System

- Production Development Of The 7.3L Engine Will Focus On:
  - Fuel System Development
  - Ignition System Development
  - Integrated Engine Controls

  To Utilize The Latest Technology Achievements In Gaseous Fuel Systems And Electronic Controls

RB16_593

SUMMARY AND CONCLUSIONS
(Cont'd)

- Market Introduction Of The New Engine Is 1995
- The 7.3 Liter Natural Gas Engine Is A Viable Alternative For Advanced Mobile Applications Where Gaseous Fuels Are The Preferred Choice (Non Attainment Areas, Urban Fleets, School Buses, Etc...)
- Future Developments May Be Applied To This Engine To Reduce Emissions Even More, In Compliance With Evolving Standards

RB17_593

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

NATURAL GAS IN VEHICULAR APPLICATIONS - STATUS OF DEVELOPMENT AT NAVISTAR

R.A. Baranescu, Navistar International Corporation

Q. Eric Milkins, NGV-Australia: We have had similar experience with lean burn engines with a range of 1.5 to 2.0 for lambda values. Would you comment on air/fuel ratios used in your work?

A. We started at a lambda value of 1.5, but have gone as high as 1.7 which was the maximum value limited by hydrocarbon emissions. With an oxidation catalyst we could go to higher values of lambda.

Q. Mostafa Kamel, Cummins Engine Co.: Can you tell us why the capacitive discharge ignition system was selected?

A. This engine was developed for the lowest possible cost, and the ignition system selected was the obvious choice for that objective.

Q. Mehboob Sumar, ORTECH International: Was there any pre-ignition or deterioration at high speed?

A. So far, no problems have been experienced.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

UPDATE ON LIGHT DUTY ENGINES
PANEL DISCUSSION

Panel Moderator: Ron Bright

GENERAL MOTORS ALTERNATIVE FUEL PRODUCTS

J. Christie
General Motors of Canada

(Other presentations made during this Panel Discussion are unavailable)

GENERAL MOTORS ALTERNATIVE FUEL PRODUCTS

by

JOHN M. CHRISTIE

at

1993 WINDSOR WORKSHOP, TORONTO, ONTARIO

JUNE 14, 1993

JMCLOGO1

GM ALTERNATIVE FUEL VEHICLES

200

HISTORY OF GM ALTERNATIVE FUEL VEHICLE PRODUCTION

FUEL	TIME PERIOD	PRODUCTS	VOLUME
PROPANE/LPG	1984/85	PICKUPS & VANS (CANADA ONLY)	<300
METHANOL/ETHANOL	1991/93	CHEVROLET LUMINA VFV	2100
ETHANOL E20+	THRU 1993	GM DO BRASIL CARS & TRUCKS	250,000
NATURAL GAS	1992/93	GMC/CHEVROLET 3/4 TON PICKUPS	2300
ELECTRICITY	---	GM OF EUROPE BEDFORD VANS	70
ELECTRICITY	1991	GM/VEHMA G-VAN	

JMC#3:B:193-46:08JUNE93

GM ALTERNATIVE FUEL VEHICLES

JMCLOGO1

WE HAVE LEARNED A LOT ABOUT:

ALCOHOL VFV'S:

- *FUEL SENSORS & INJECTORS*
- *EVAPORATIVE EMISSION CONTROLS*
- *HOT RE-START*
- *COLD START*
- *MATERIAL COMPATIBILITY*
- *FUEL PUMP*
- *CONVENTIONAL TAILPIPE EMISSIONS*

GASEOUS FUEL VEHICLES:

- *COMPRESSION RATIO & POWER*
- *CNG FUEL STORAGE*
- *AIR/FUEL DISTRIBUTION*
- *COLD START*
- *FUEL PRESSURE REGULATOR*
- *TAILPIPE EMISSIONS*

JMC#3:B:193-46:08JUNE93

JMCLOGO1

GM ALTERNATIVE FUEL VEHICLES

THERE IS MORE TO LEARN ABOUT:

ALCOHOL FUEL VFV'S

- ALDEHYDE CONTROL
- ULTRA - LOW EMISSIONS
- SPECIFIC CATALYSTS
- ENHANCED EVAPORATIVE EMISSION STANDARDS
- OBDII - DIAGNOSTICS
- HIGH MILEAGE COMPONENT DURABILITY
- HANDLING LOW QUALITY FUEL
- LOWER COST SYSTEMS

GASEOUS FUEL VEHICLES

- OBDII - DIAGNOSTICS
- HIGH MILEAGE COMPONENT DURABILITY
- THC CONTROL
- FUEL STORAGE
- LOWER COST SYSTEMS

JMC#3:B:193-46:08JUNE93

GM ALTERNATIVE FUEL VEHICLES

JMCLOGO1

WHERE THE DEMAND WILL BE, 2000 A.D.:

EPACT

- FEDERAL & STATE FLEETS
- FUEL PROVIDERS
- PRIVATE FLEETS

PLUS

FREE MARKET

- STATE/MUNICIPAL FLEETS
- PRIVATE FLEETS
- INDIVIDUALS

JMC#3:B:93-46:08JUNE93

JMCLOGO1

GM ALTERNATIVE FUEL VEHICLES

WHY THEY WILL BUY:

ALCOHOL FUEL VEHICLES

- MANDATED & LOW FUEL USERS
- MANDATED & LOW BID
- ADVOCATES/FUEL PROVIDERS

GASEOUS FUEL VEHICLES

- MANDATED & HIGH FUEL USERS
- MANDATED NGV PURCHASES
- FREE MARKET HIGH FUEL USERS
- ADVOCATES/FUEL PROVIDERS

ELECTRIC VEHICLES

- OE MANDATED SALES (2 % CALIFORNIA)

JMC#3:B:193-46:08JUNE93

JMCLOGO1

GM ALTERNATIVE FUEL VEHICLES

ROLL-OUT = PRODUCTS + TIMING+ VOLUMES + WHERE

	ALCOHOL FUEL VEHICLES	GASEOUS FUEL VEHICLES	ELECTRIC VEHICLES
PRODUCTS	COMPACT CARS/TRUCKS	FULL SIZE CARS/TRUCKS CURRENT CONVERSION PRODUCTS	COMMUTER CAR AND/OR MINIVAN
TIMING	1998 - 2000 AD	NOW	1998
VOLUMES	N/A	N/A	2% OF OE CALIFORNIA SALES
WHERE	US WIDE	US WIDE & REGIONAL	CALIFORNIA

JMC#3:B:\93-46:08JUNE93

JMCLOGO1

GM ALTERNATIVE FUEL VEHICLES

BUSINESS CASE = CONSERVATIVE ESTIMATE + OTHER SUPPORT

"OTHER SUPPORT" HAS SIGNIFICANT UPSIDE POTENTIAL:

- **CAFE** CREDIT
- PUBLIC RELATIONS
- "HALO" SALES
- IMPROVE GASOLINE
- **EPACT** FUEL USE OBJECTIVE
- COMPETITIVE STRATEGIES
- MARKETS OUTSIDE USA
- FUEL PROVIDER MARKETING

JMC#3:B:93-46:08JUNE93

ALTERNATIVE FUEL VEHICLES

JMCLOGO1

WHAT COULD/WILL HAPPEN:

1. OE'S COULD ABANDON METHANOL/ETHANOL PROGRAMS

- FUEL COST NOT ATTRACTIVE
- FRAGMENTED MARKET
- GOVERNMENT POLICY DRIVEN; NO CUSTOMER DRIVERS
- FUEL INFRASTRUCTURE INADEQUATE
- FUEL QUALITY NOT ADDRESSED
- EXPENSIVE O.E. DEVELOPMENT PROGRAMS
- CHALLENGING EMISSION STANDARDS: **OBDII & EVAP**

BIG FACTORS: GOVERNMENT POLICY, FUEL COST, FUEL QUALITY, FUEL AVAILABILITY

JMC#3:B:193-46:08JUNE93

GM ALTERNATIVE FUEL VEHICLES

JMCLOGO1

WHAT COULD/WILL HAPPEN (Cont'd):

2. OE'S WILL BE IN THE GASEOUS FUEL MARKET WILLINGLY OR UNWILLINGLY

- TWO WAYS
  - AFTERMARKET CONVERSIONS
  - O.E. MONO-FUEL/BI-FUEL PROGRAMS
- FREEMARKET CUSTOMER DRIVEN - LOW FUEL COST & ENVIRONMENTAL BENEFITS
- STEADY REGIONAL GROWTH
- HOME REFUELLING APPLIANCE
- PRO-ACTIVE GOVERNMENT SUPPORT - FEDERAL/STATE

BIG FACTORS: PRODUCT COSTS; FUEL QUALITY; FUEL AVAILABILITY

JMC#3:B:193-46:08JUNE93

GM ALTERNATIVE FUEL VEHICLES

JMCLOGO1

<u>**_WHAT NEEDS TO BE DONE:_**</u>

1. **_MOVE ALTERNATIVE FUEL VEHICLES OFF THE ENVIRONMENTAL AGENDA_**
   - _SMALL VOLUME; SMALL BENEFIT_
   - _OTHER MORE EFFECTIVE STRATEGIES_

2. **_IMPLEMENT AN EFFECTIVE COMMERCIALIZATION STRATEGY_**
   - _DRIVEN BY ENERGY SELF SUFFICIENCY & ECONOMICS_
   - _UTILIZE CUSTOMER INFLUENCES_
     - _WHAT MAKES SENSE TO CUSTOMER, MAKES SENSE UPSTREAM_
     - _CUSTOMERS NEED TO UNDERSTAND AND BELIEVE_

210

JMC#3:B:193-46:08JUNE93

JMCLOGO1

GM ALTERNATIVE FUEL VEHICLES

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

UPDATE DATE ON LIGHT DUTY ENGINES - PANEL PRESENTATIONS
GENERAL MOTORS ALTERNATIVE FUEL PRODUCTS
J. Christie, General Motors of Canada

Q. Anonymous: Is there a reduction in purchases of alternative fuel vehicles after their introduction?

A. Yes, the initial purchase rates are the highest right after the production run. It is a matter of developing the best product for customer acceptance.

Q. Anonymous: What has been the experience on warranty costs for propane and natural gas conversions?

A. We analyzed data on 10,000 vehicles over the last 10 years in Canada. The significant finding was that complaints were related more to the installation rather than to the hardware.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

HIGHLIGHTS OF CHRYSLER'S ALTERNATIVE FUEL PROGRAMS
J.W. Lanigan, Chrysler Canada Ltd.

(Presentation unavailable at time of printing)

Q. Alex Lawson, Alex Lawson Associates: I didn't hear hybrid electric vehicles mentioned in your talk.

A. We are not ignoring that possibility. The program will be emphasized when appropriate for the consumer.

Comment: Ron Bright, Ford Motor Co. - Canada: The University of Alberta was first in competition with 30 universities and did an outstanding job of vehicle modification.

Q. Bernie James, Energy, Mines & Resources Canada: What percentage of power do you expect from regenerative braking systems?

A. It depends on the duty cycle, but in current tests we get on the order of 5 to 10 percent.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

STRATEGIES TOWARD EXPANDING NGV PRODUCTION
T.W. Rogers, Cardinal Automotive Inc.

(Presentation unavailable at time of printing)

Q. Chandra Prakash, Environment Canada: How many vehicles have you converted to natural gas?

A. We do more conversions to fuels other than natural gas. The demand for natural gas conversions has been relatively low, and we have done groups of 1 to 4 vehicles at a time.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

AFTERMARKET NG CONVERSIONS OR OEM PRODUCTS - STRATEGIC OPTIONS AND I IMPACTS
B. Wilson, Colorado State University

(Presentation unavailable at time of printing)

Q. Anonymous: Various conversions are now available with closed loop controls integrated with hardware. Would you comment on these?

A. There are five types of systems being used: Fully mechanical, mechanical with closed loop oxygen feedback, fully electronic add-ons, translators which work with OEM computers, and OEM electronic systems. The second of those, if properly installed, gives good air/fuel ratio control at steady state but does not handle transients well.

SESSION 2: EMERGING TECHNOLOGIES

Chair: Bernie James, Energy, Mines & Resources Canada

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

EXPERIENCE WITH LNG AND LNG - CNG

V. Jayaraman
Consolidated Natural Gas Company

<u>ISSUES TO BE COVERED</u>

- What is LNG?
- Why should we consider using LNG as a transportation fuel?
- What is LNG's availability/price?
- Is LNG safe?
- Who are all experimenting with LNG at this time?
- What has been their experience to date?
- What are the technical/commercial/regulatory obstacles?
- Is there a role for LNG in fueling CNG vehicles?

LNG (LIQUID METHANE) PROPERTIES

■ Temperature @ Atmos. Press	-259°F
■ Density	3.54 lb/gal
■ 1 Gallon LNG	83.6 cu ft of gas

■ LHV of Methane (CH_4)	911 Btu/cu ft
■ LHV of LNG (CH_4)	76,160 Btu/gal
■ LHV of Gasoline (C_4-C_{10})	114,132 Btu/gal
■ LHV of Diesel (C_{12} - C_{20})	129,400 Btu/gal

- 1 gal Gasoline $= \frac{114{,}132}{76{,}160} =$ 1.5 gal LNG
- 1 gal Diesel $= \frac{129{,}400}{76{,}160} =$ 1.7 gal LNG

VJ/1130

WHY LNG?

- @ 3000 PSI, 250 cu ft Natural Gas in 1 cu ft of space

  @ LNG, 625 cu ft Natural Gas in 1 cu ft of space

  ∴ With LNG, we can pack 2 1/2 times as much fuel in a given space.

- LNG offers the possibility of being able to control the fuel composition within close limits.

- LNG offers the possibility of being able to serve areas not covered by pipeline gas.

- LNG fuel tanks could cost only about half that of compressed gas tanks.

- LNG fueling stations could cost only about a third of compressed gas fueling stations.

- Delivered cost of LNG on vehicles could be less than that of compressed gas.

VJ/1130

LNG SAFETY

- Cryogenic liquid; possibility of severe burns on contact.
- Vapor heavier than air below - 170°F, thereafter lighter than air.
- More difficult to ignite and sustain ignition than gasoline/diesel.
- In accident situations, probably safer than gasoline/diesel if no ignition; if ignited, probably less intense fire than gasoline/diesel.
- No odorant; need to depend on methane sensors.

GENERAL INFORMATION ON CRYOGENIC LIQUIDS

LIQUID	TEMP. AT ATMOS. PRESS.	LB/GAL
Helium	-452°F	1.04
Hydrogen	-423°F	0.59
Nitrogen	-320°F	6.75
Argon	-303°F	11.63
Oxygen	-297°F	9.52
Methane	-259°F	3.54

VJ/1130

PRESENT & FUTURE LNG PROJECTS IN THE U.S.

Present	Roadway Express	-	3 trucks running; 4 more planned
	Houston Metro	-	80 buses running; hundreds more planned
	Greater Austin Transp.	-	26 vehicles running
	Burlington Northern Railroad	-	2 locomotives running
	Others		
Future	Chambers Development	-	7 refuse haulers
	Dallas Area Rapid Transit	-	30 buses
	Los Angeles Airport	-	12 coaches
	Union Pacific Railroad	-	6 locomotives
	Others		

TECHNICAL OBSTACLES

■ Vapor Generation	-	Recovery, Disposal
	-	Effect on Economics
■ Ease of Fueling	-	Intermittent Operations
	-	Priming, Cool-down, Cavitation
	-	Heat Pickup
■ Metering	-	Liquid/Vapor
■ Sensors	-	Cool-down
	-	Vehicle Filling
■ Weathering	-	Pure Methane
	-	Pipeline LNG
■ Odorant		

LNG HARDWARE PRICES

■ 100-gallon fuel tank	$ 4,000
■ 10,000-gallon storage tank	100,000
■ Submerged transfer pump	20,000
■ LNG dispenser	75,000
■ LNG fueling connector	5,000

VJ/1158

REGULATORY STATUS

- NFPA 57 under preparation
- Local authorities have cooperated
- Tunnels
- Roof-mounted tanks

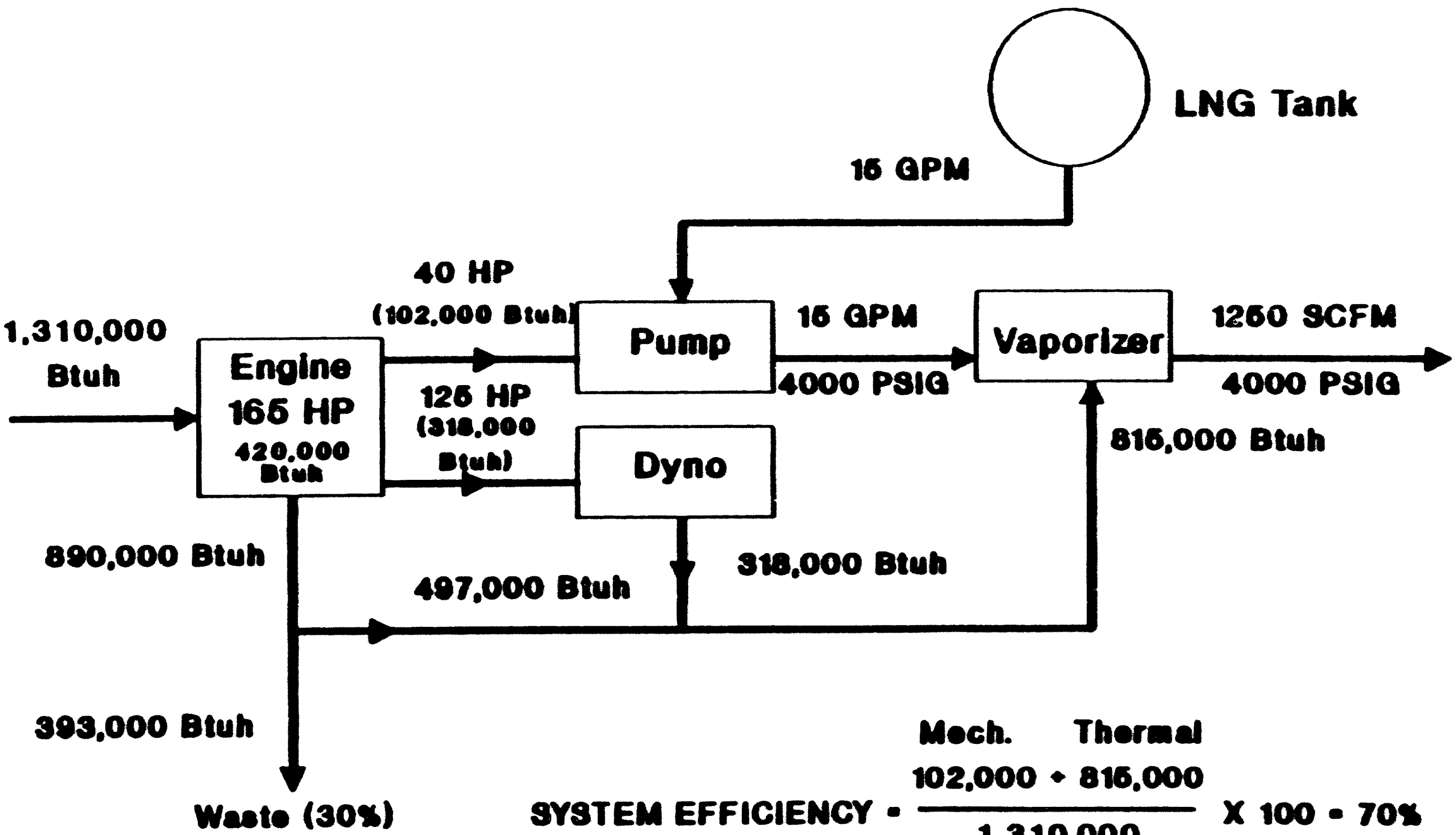
COST OF COMPRESSED GAS SYSTEMS

	1	2	3
Capacity, SCFM	50	240	700
Inlet Pressure, PSIG	15	100	50
Outlet Pressure, PSIG	3600	3600	3800
HP	30	100	300
Storage, SCF	44,000	?	22,000
Costs - Compressor	40,000		364,000
- Storage	55,000		39,000
- Dryer	25,000	380,000	69,000
- Dispenser	32,000		28,000
- Site Prep, Install, Misc.	98,000	90,000	150,000
- Total	$ 250,000	470,000	650,000
Cost $/SCFM	5,000	2,000	1,000

Variables: Inlet Pressure
Storage
Site Prep

VJ/1134

LNG Fast Fill System



$$\text{SYSTEM EFFICIENCY} = \frac{\overset{\text{Mech.}}{102{,}000} + \overset{\text{Thermal}}{815{,}000}}{1{,}310{,}000} \times 100 = 70\%$$

COST OF LNG - CNG SYSTEM

*LNG Tank (10,000 gallons)	100,000
LNG Pumping/Vaporizing System (15 GPM or 1250 SCFM, @ 4000 PSIG)	150,000
Site Prep, Install, Misc.	50,000
Storage	35,000
Dispenser	40,000
Total	**$ 375,000**
Cost $/SCFM	300

**Can serve 100 vehicles/day at the rate of 100 gallons/vehicle.*

VJ/1134

LNG - CNG SYSTEM

ADVANTAGES

- Much lower cost than compressed gas systems.
- No moisture in gas.
- Can control gas temperature to compensate for temperature rise during fast fill.
- Mobile fueling stations possible.

DISADVANTAGES

- Need supply of LNG.
- Cost of LNG could vary from competitive to non-competitive, depending on hauling distance.

VJ/1134

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

EMERGING TECHNOLOGIES FROM SwRI

J. Cole, D. Meyers, K. Guglielmo
Southwest Research Institute

Emerging Technologies From SwRI

Abstract

SwRI has been working to reduce emissions from powerplants burning many types of fuels. A hybrid rich-burn/lean-burn engine concept has been developed to take advantage of the high hydrogen-to-carbon ratio of natural gas. Rich-burn operation using natural gas produces high amounts of hydrogen and carbon monoxide in the exhaust. This exhaust can then be routed through a watershift catalyst where additional hydrogen is produced. The hydrogenated exhaust from rich-burn cylinders can then be supplemented to remaining lean-burn cylinders to extend the lean limit and further reduce NOx emissions.

In addition to the unique low emissions engine concept discussed above, SwRI has been developing advanced engine control technology for alternative fueled engines. A custom PC-based universal engine controller has been developed to enable researchers to fully optimize engines for performance and emissions. SwRI has also aided in the development of an advanced lean-burn control system for heavy-duty natural gas engines and a natural gas conversion system for light-duty vehicles. The details of these control systems including recent test data will be presented.

OUTLINE

- Hybrid Rich-Burn/Lean-Burn Engine Concept

- Advanced Engine Control Technology

HYBRID RICH-BURN/LEAN-BURN ENGINE CONCEPT

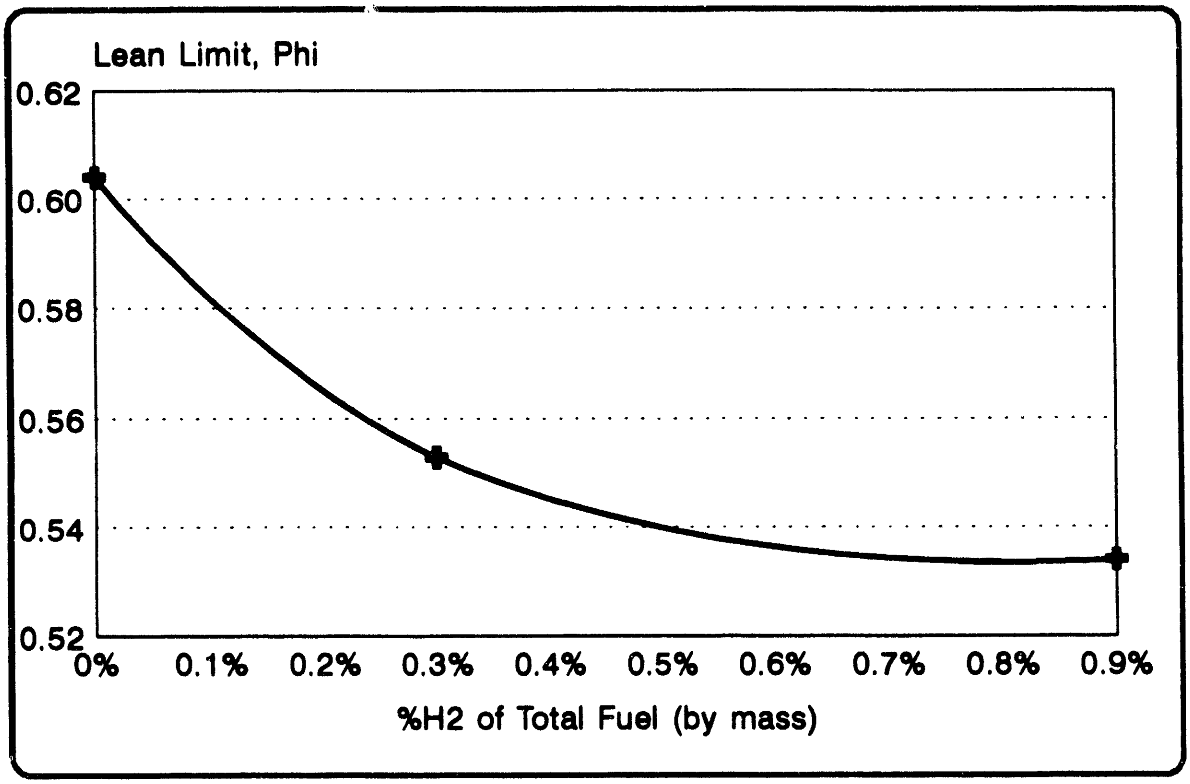
OBJECTIVE

- Demonstrate New Engine Concept
- 5 ppm NOx @ 15% Oxygen Stationary Engine
- Retain Thermal Efficiency of Base Engine

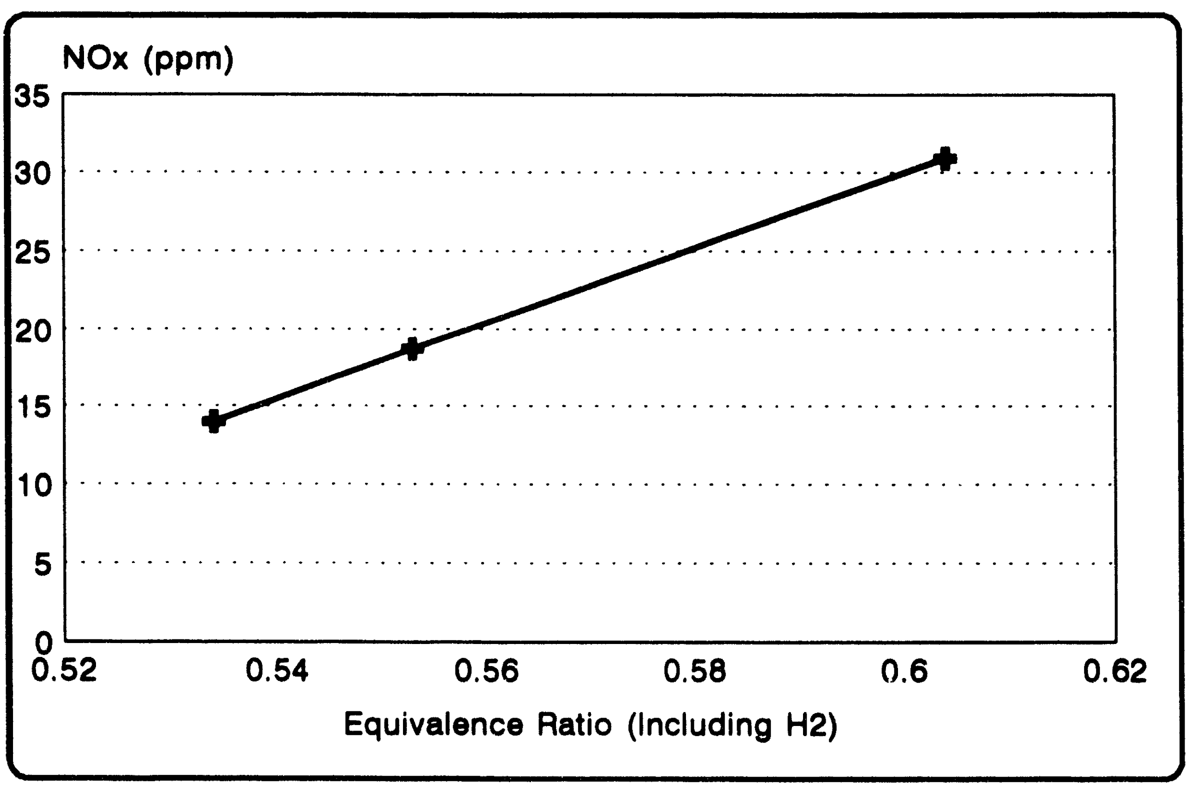
LEAN-BURN COMBUSTION

- NOx Decreases Phi$<$0.9
- NOx Level Limited by Misfire Limit
- Hydrogen Extends Misfire Limit of NG

HYDROGEN EFFECT ON LEAN LIMIT



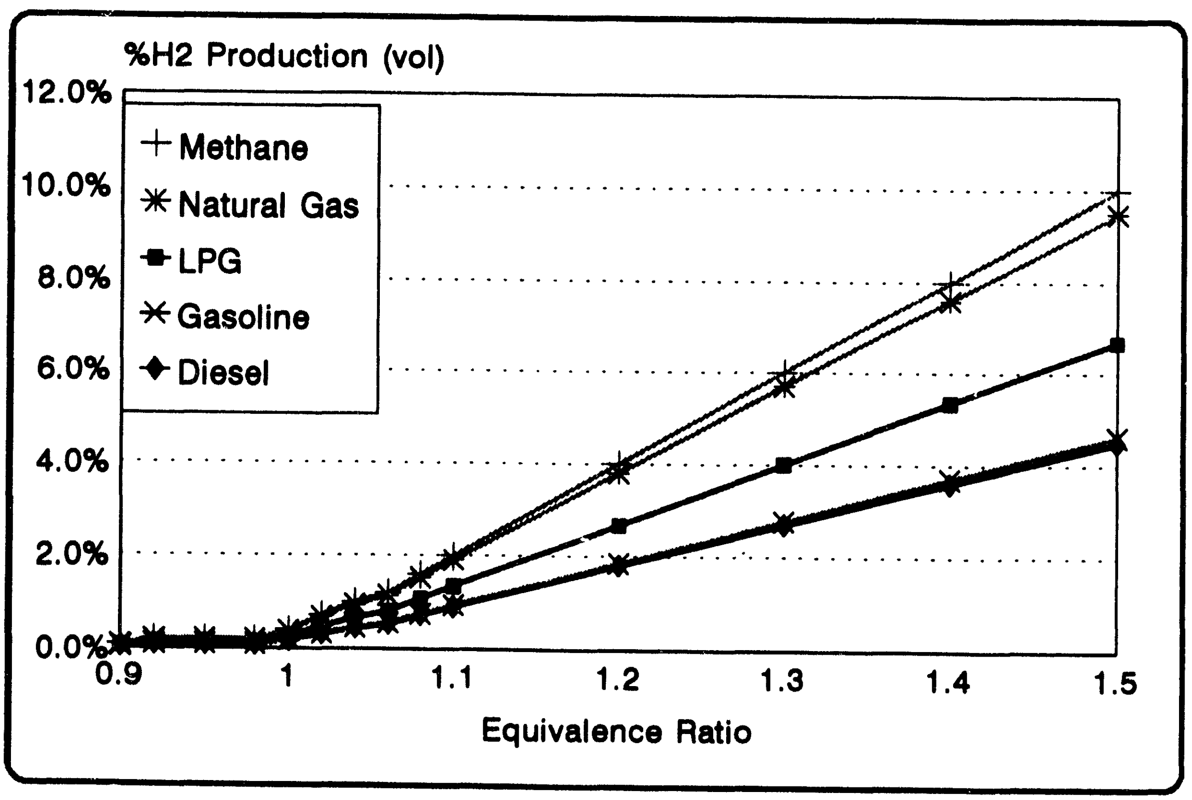
EQUIVALENCE RATIO EFFECT ON NOx



RICH-BURN COMBUSTION

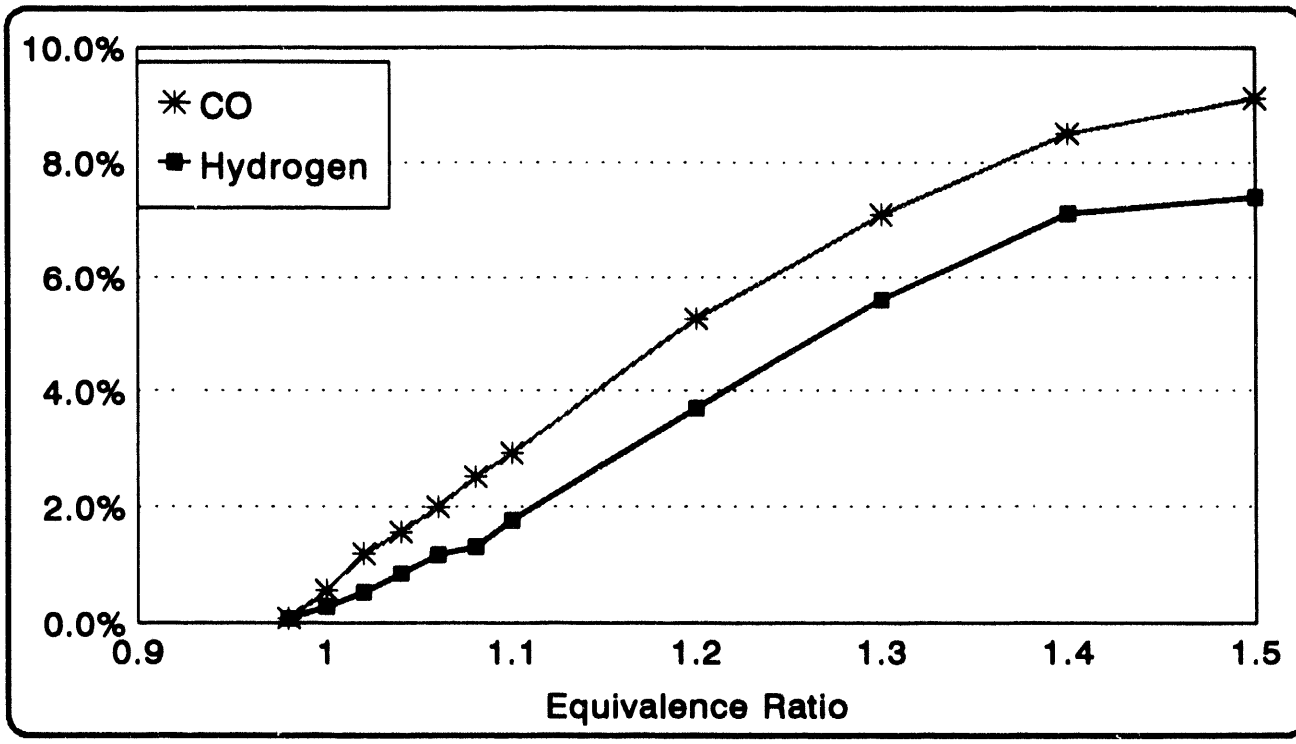
- NOx Decreases Phi>1.0
- NOx Level Limited by High CO and HC
- Excessive Hydrogen and CO Produced
- Hydrogen Production= f(H/C,Phi)

H/C EFFECTS ON HYDROGEN PRODUCTION



H2 & CO EMISSIONS

Labeco CLR Test Engine



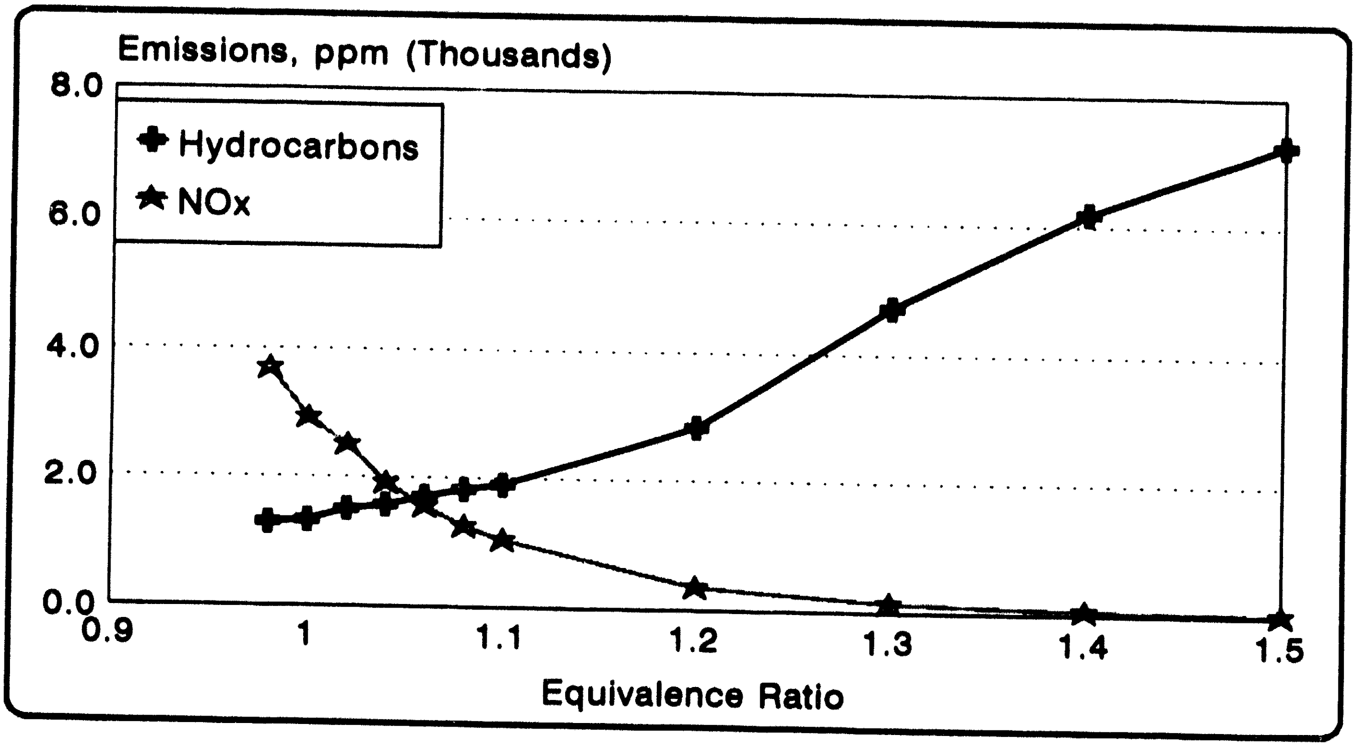
WATER-SHIFT CATALYST

- Converts CO and Water from Rich-Burn Exhaust into Hydrogen and CO2

$$CO + H20 \rightarrow CO2 + H2$$

HC & NOx EMISSIONS

Labeco CLR Test Engine



HYBRID RICH-BURN/LEAN-BURN ENGINE CONCEPT

- Operate 1 Cylinder Phi>1.4
- Rich Exhaust Through Watershift Catalyst
- Supplement Remaining Lean Cylinders w/ Hydrogen and EGR

PROJECT TASKS

1. Modeling
2. Rich-Burn Experiments
3. Combined Rich/Lean Experiments (Two Single Cylinder Engines)
4. Full-Size Engine Demonstration
5. Retrofit Package For Field Demonstration

ACCOMPLISHMENTS TO DATE

- Minimal Modeling Completed
- Rich-Burn Completed- 10:1 Diesel Piston (Burn Rate Too Slow at Phi=1.45)
- High-Turbulence Piston Design Completed
- Twin Engine Set-Up Completed

BENEFITS

- Extremely Low Emissions w/o Exhaust Aftertreatment
- Lean-Limit Extension Increases Efficiency-Reduced Throttling
- Ultra Rich/Lean Burn Allows Increased Compression Ratio

ADVANCED ENGINE CONTROL TECNOLOGY

ADVANCED CONTROL TECHNOLOGY OUTLINE

- Custom Engine Control System
- PRO-LEAN Engine Control System
- TRANSLATOR Conversion System

FEATURES CUSTOM CONTROL SYSTEM

- Fuel Neutral
- TBI/SMPI
- Adaptive Spark Control
- Advanced Adaptive Fuel Control
- Mass Air Flow or Speed-Density Open-Loop Fuel Metering
- Advanced Transient Compensation

FUEL DELIVERY
CUSTOM CONTROL SYSTEM

- Interface Circuitry for Driving:
  - Gasoline PWM Injectors
  - NG PWM Injectors
  - CNG Proportional Metering Valves
  - Diesel Electrically Actuated Injectors

FUEL DELIVERY
CUSTOM CONTROL SYSTEM

- Additional Interface Circuitry for Driving:
  - EGR Valves
  - Idle Bypass Valves
  - Wastegate Actuators
  - Drive-by-wire Throttle

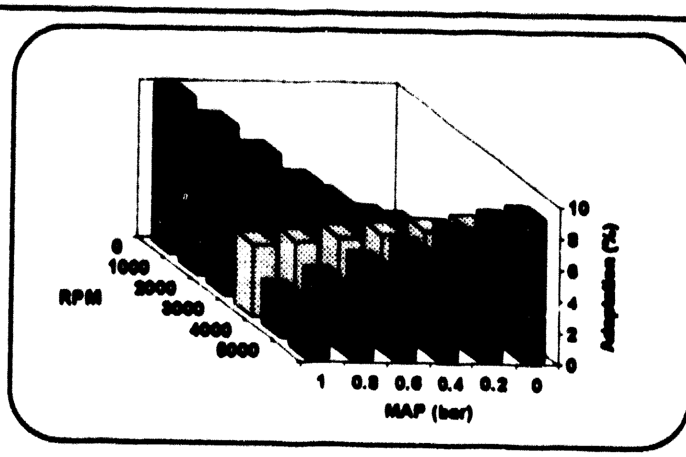
ADAPTIVE SPARK CONTROL CUSTOM CONTROL SYSTEM

- Possible Spark Adjustment Inputs:
  - Cylinder Pressure
  - Force Sensors
  - Ionization Probes
- Adaptive Learn of Optimum Spark Map
- Misfire Detection and Diagnostics

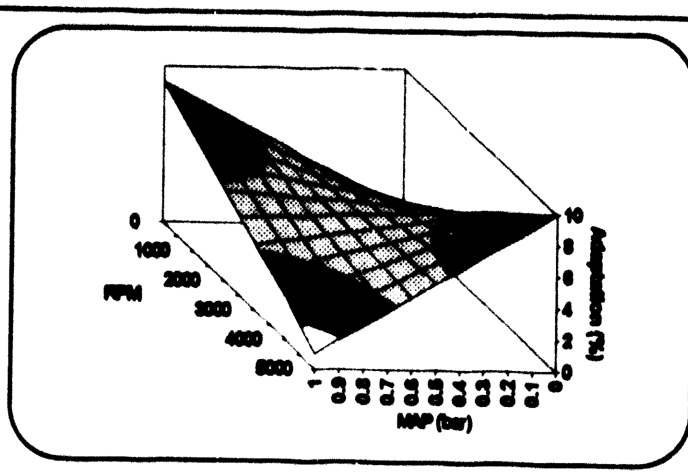
ADAPTIVE FUEL CONTROL CUSTOM CONTROL SYSTEM

- Non-Discontinuous Multi-Dimensional Adaptive Learn Scheme:
  - Injector Miscalibration/Aging
  - Volumetric Efficiency Changes
  - Drift in Sensors Used for Open Loop
  - Faster Fuel Metering Adaptation
- Computationally Efficient
- Small Memory Requirements

DISCONTINUOUS ADAPTATION



CONTINUOUS ADAPTATION SURFACE



OPEN-LOOP METERING CUSTOM CONTROL SYSTEM

- Mass Air Flow Sensor Measurement
- Speed-Density Based Calculation
- Advanced Manifold Filling/Emptying Model for Throttle Transients

EQUIVALENCE RATIO CONTROL CUSTOM CONTROL SYSTEM

- Ability to Use Feedback From:
  - Stoichiometric EGO
  - Wide-Range EGO Sensors
  - Multiple EGO Sensors
- Custom Circuitry for UEGO Sensor

PRO-LEAN NATURAL GAS FOR FUEL CONTROL SYSTEM

- Heavy-Duty Diesel and Gasoline Conversions
- Based on Ford EEC-IV Hardware
- Applied to Hercules GTA3.7L and Mack E7
- Teaming Partners:
  GRI
  DAI Technologies
  Southbend Controls

FEATURES PRO-LEAN CONTROL SYSTEM

- Mass Air Flow Measurement
- Closed Loop Control w/UEGO Sensor
- Direct-Fire Spark Coil Control
- Electronic Wastegate Control
- Engine Speed Governing
- Diagnostic Link

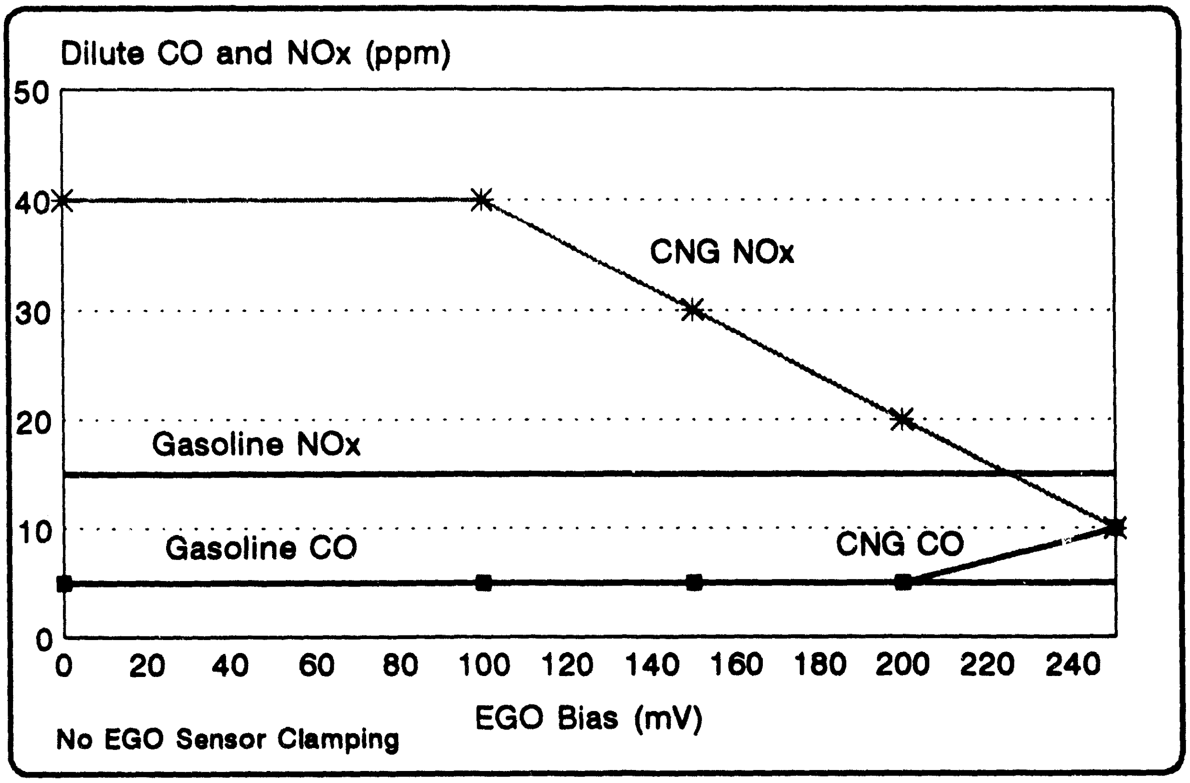
TRANSLATOR CONVERSION SYSTEM

- Simple Bi-fuel Conversion System
- EFI Closed-Loop Gasoline Vehicles
- Teaming Partners:
  GRI
  DAI Technologies

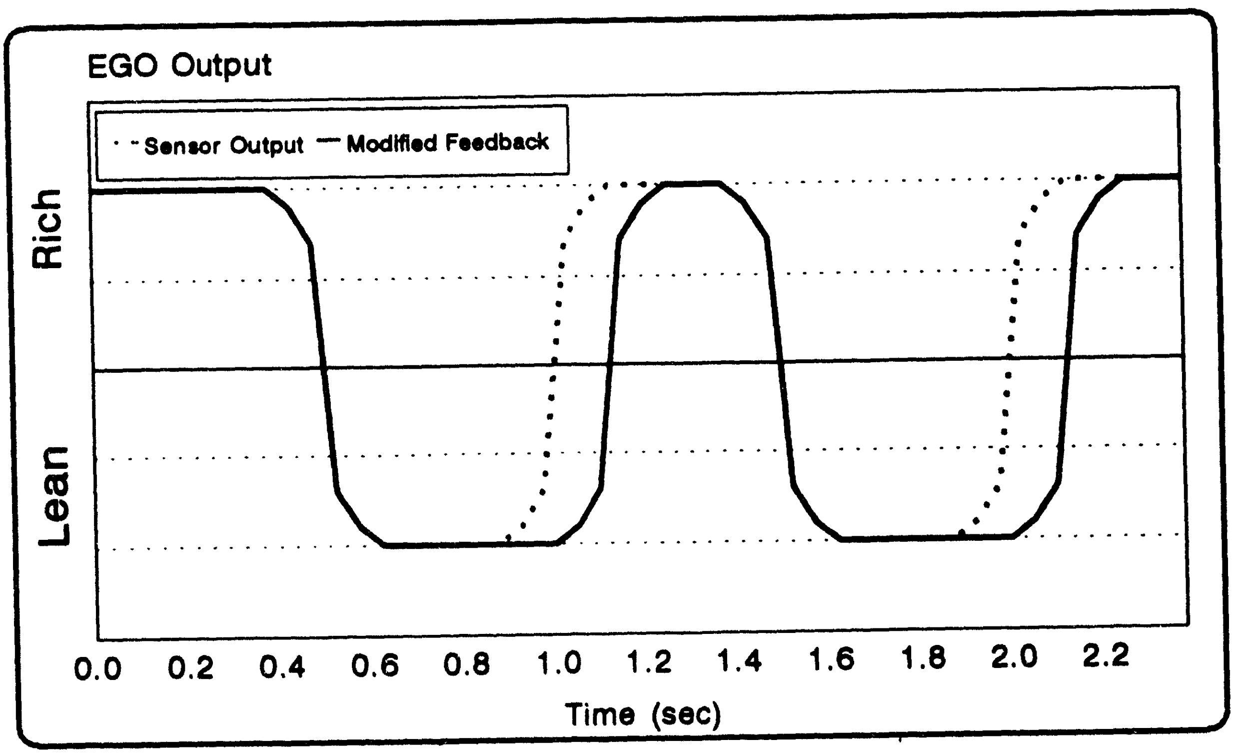
FEATURES
TRANSLATOR CONVERSION SYSTEM

- OEM Diagnostics
- OEM Adaptive Learn
- Elimination of Cold Enrichment
- Spark Advance
- Rich Bias for Low Emissions

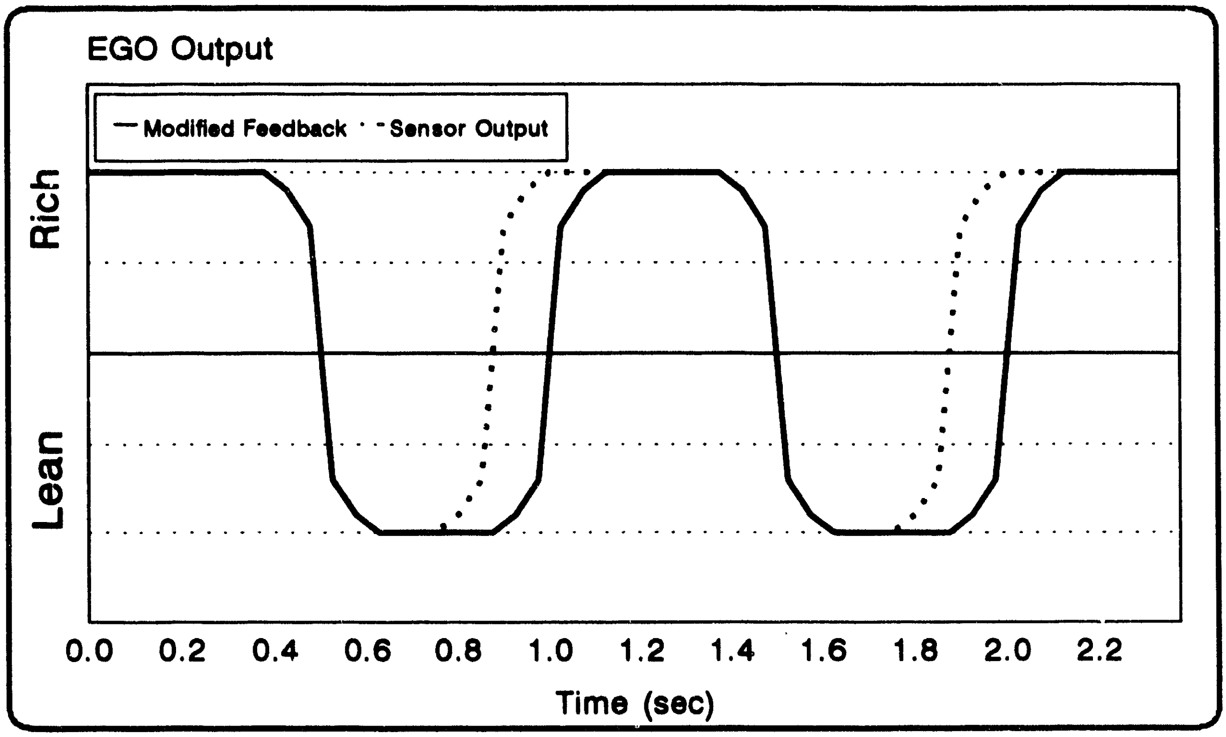
STEADY STATE NOx/CO TRADEOFF



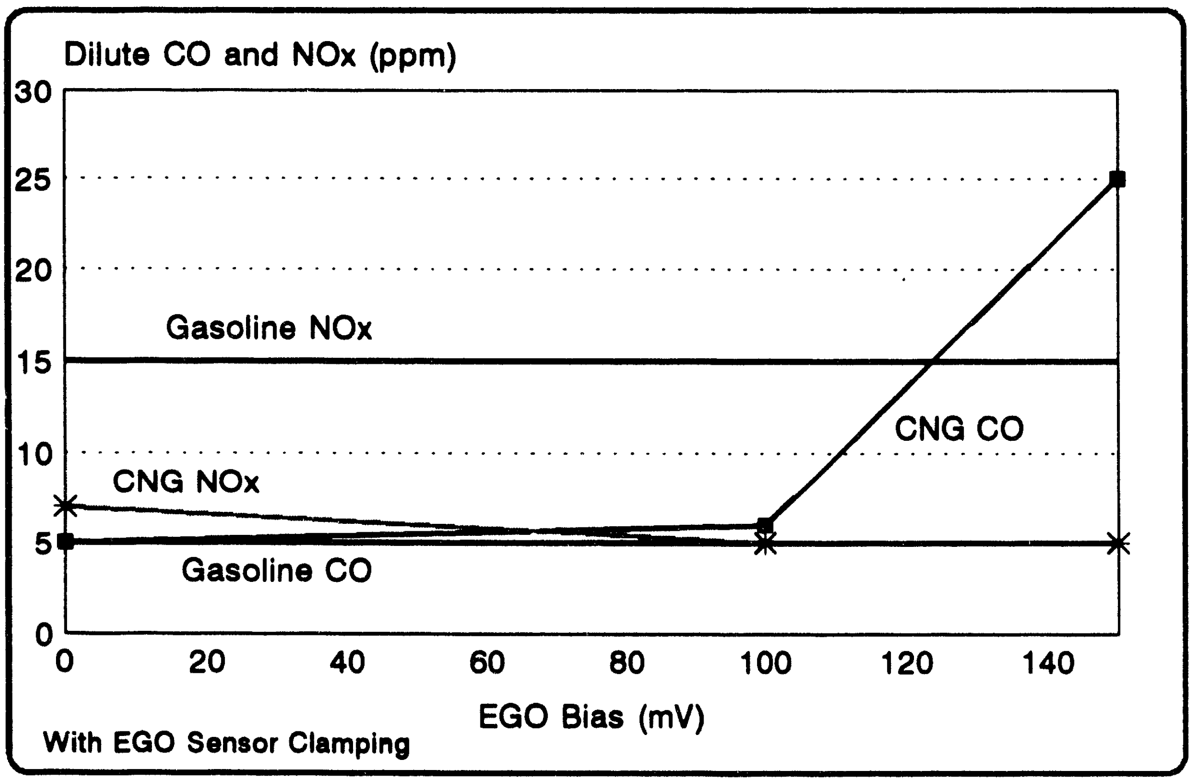
INITIAL LEAN CLAMPING RESPONSE



STABILIZED LEAN CLAMPING RESPONSE

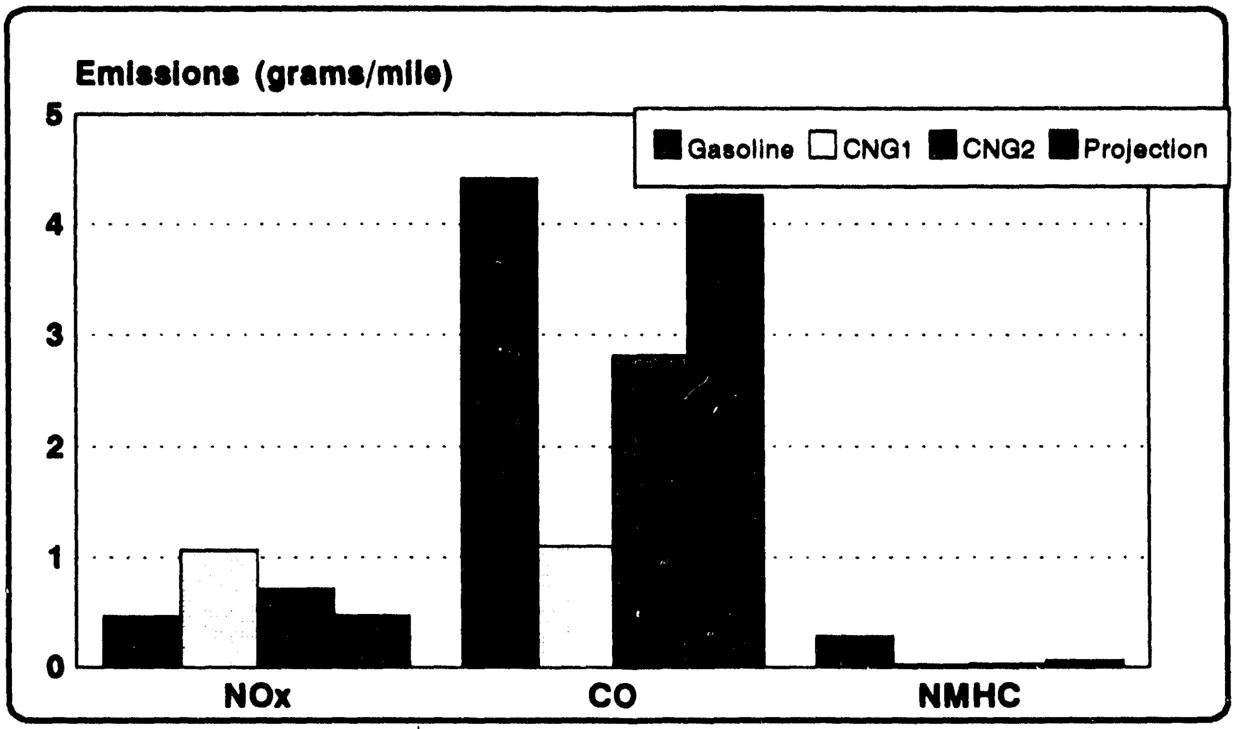


STEADY STATE NOx/CO TRADEOFF



3-BAG FTP EMISSIONS

5.2L TRANSLATOR-EQUIPPED DODGE



ACKNOWLEDGEMENTS

- South Coast Air Quality Management District
- Southern California Gas Company
- Gas Research Institute

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

EMERGING TECHNOLOGIES FROM SwRI
J. Cole, Southwest Research Institute

Q. Vinod Duggal, Cummins Engine Co.: As a suggestion, could you mix hydrogen with natural gas for the lean-burn operation?

A. That would be a good idea for laboratory tests, but hydrogen is not generally available for blending with natural gas. Also, the plan is to return the unburned and unconverted hydrocarbons from the rich cylinder to the engine so that these materials contribute to the overall efficiency.

Q. Anonymous: In the adaptive loop control system, what happens if the fuel is changed from gasoline to natural gas and back to gasoline?

A. If the loop is on calibration, not much change occurs, and the control loop adjusts to fit the new fuel.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

CUMMINS B6G: AN ADVANCED TECHNOLOGY NATURAL GAS ENGINE

M.M. Kamel
Cummins Engine Co. Inc.

CUMMINS B6G N.G. ENGINE
OUTLINE

* OBJECTIVE

* TECHNICAL PROFILE

* TECHNOLOGY CONCEPTS
  - DESIGN FEATURES
  - ELECTRONIC CONTROLS

* DEVELOPMENT SCHEDULE

* DEVELOPMENT STATUS
  - PERFORMANCE
  - EMISSIONS
  - MECHANICAL
  - FIELD TEST

* SUMMARY

(MMK,6/1/93,TO-2)

B6G OVERVIEW
OBJECTIVE

* OBJECTIVE

DEVELOP THE B6 ENGINE FOR OPERATION WITH NATURAL GAS FOR URBAN AUTOMOTIVE APPLICATION

* ENVIRONMENT

= LEGISLATIONS FOR LOWER EMISSIONS
= POLITICAL PRESSURES FOR CLEAN AIR
= ENERGY SECURITY
= ECONOMICS

(MMK,6/10/93,TO-5)

B6G TECHNICAL PROFILE

PERFORMANCE:
* 195 HP @2800 RPM
* 420 FT.LB. PEAK TORQUE @1600 RPM
* 285 FT.LB. CLUTCH ENGAGEMENT TORQUE @FULL THROTTLE
* UPTO 8500 FT ALTITUDE CAPABILITY

EMISSIONS:
* 1998 CARB ULEV LEVELS

    2.5 (NOx + NMHC) & 0.05 PART

NOISE:
* US AND EEC DRIVE-BY LEGISLATED LIMITS

([illegible], TO-1)

B6G TECHNICAL PROFILE (Con't.d)

HEAT REJECTION:
* LESS THAN OR EQUAL TO 94B-230 DIESEL

RELIABILITY:
* APPROACHES DIESEL RELIABILITY AT MATURITY

DURABILITY:
* EQUIVALENT TO DIESEL

ELECTRONICS:
* ENGINE MOUNTED

(MMK,6/1/93,TO-1)

TECHNOLOGY CONCEPTS
DESIGN FEATURES

* LEAN BURN / SPARK IGNITED
  = DIESEL LIKE THERMAL LOADING
  = HIGH BMEP CAPABILITY (IMPROVE EFFICIENCY)
  = LOW ENGINE OUT NOX EMISSION

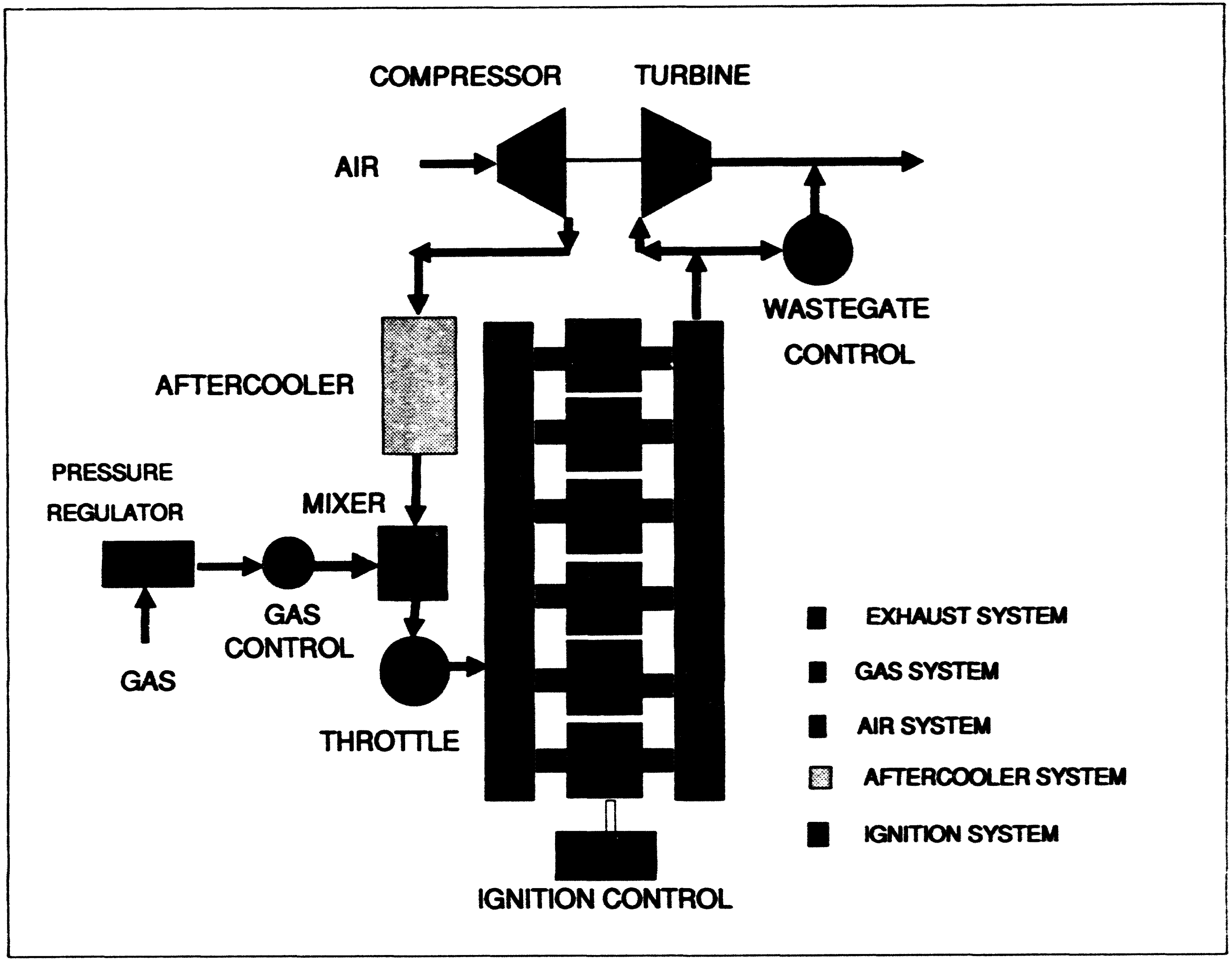
* WASTEGATED TURBOCHARGER
  = TORQUE CURVE SHAPING
  = ENGINE OUTPUT LIMITING
  = DROOP CURVE LIMITING
  = ALTITUDE COMPENSATION

* AIR-TO-AIR AFTERCOOLING
  = MATCHES '94 DIESEL CONFIGURATION (COMMONALITY)

* OXIDATION CATALYST
  = NMHC CONTROL

* ENHANCED DURABILITY
  = NEW CYLINDER HEAD WITH INSERTS
  = WATERCOOLED BEARING HOUSING TURBOCHARGER

(MMK,6/10/,TO-8)


COMPRESSOR
TURBINE
AIR
WASTEGATE
CONTROL
AFTERCOOLER
PRESSURE
REGULATOR
MIXER
GAS
CONTROL
GAS
THROTTLE
IGNITION CONTROL
EXHAUST SYSTEM
GAS SYSTEM
AIR SYSTEM
AFTERCOOLER SYSTEM
IGNITION SYSTEM

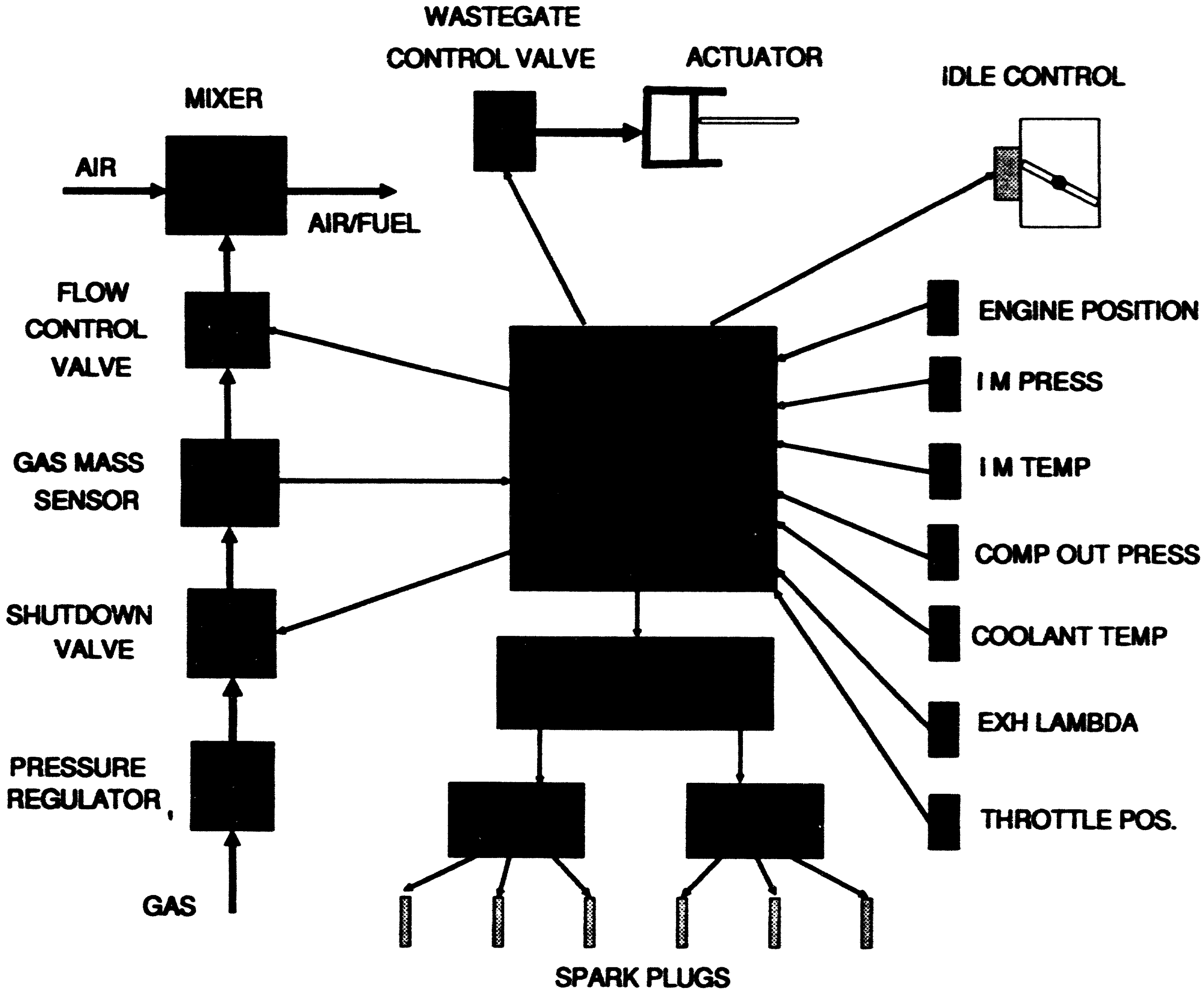
TECHNOLOGY CONCEPTS
ELECTRONIC CONTROLS

* ENGINE MOUNTED ELECTRONICS
  = MINIMIZE CUSTOMER INSTALLATION IMPACT
  = MAXIMIZE PRODUCT CONTROL

* ELECTRONIC CONTROL OF
  = IGNITION SYSTEM
  = GAS SYSTEM
  = MIN/MAX ENGINE SPEEDS
  = BOOST PRESSURE

* ENHANCE DIAGNOSTICS AND TROUBLESHOOTING

(MMK,6/10/93,TO-9)


WASTEGATE
CONTROL VALVE
ACTUATOR
IDLE CONTROL
MIXER
AIR
AIR/FUEL
FLOW
CONTROL
VALVE
GAS MASS
SENSOR
SHUTDOWN
VALVE
PRESSURE
REGULATOR
GAS
ENGINE POSITION
I M PRESS
I M TEMP
COMP OUT PRESS
COOLANT TEMP
EXH LAMBDA
THROTTLE POS.
SPARK PLUGS

DEVELOPMENT STATUS
PERFORMANCE

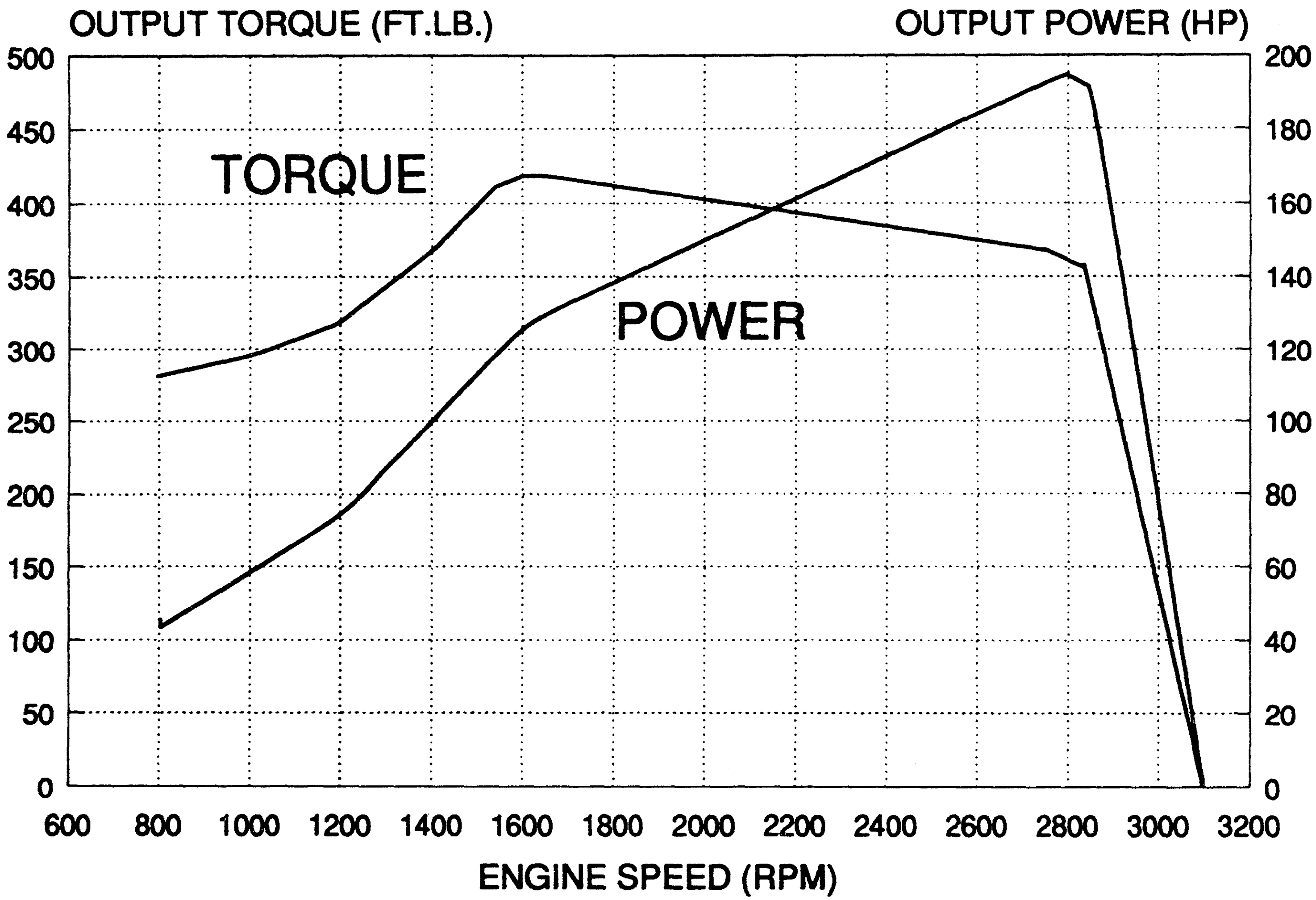
* HAVE DEMONSTRATED THE CAPABILITY TO ACHIEVE THE GOALS

  = POWER
  = TORQUE CURVE SHAPING
  = WASTEGATE CONTROL
  = MIN/MAX ENGINE SPEED CONTROL
  = GAS SYSTEM CONTROL

* HAVE DEMONSTRATED REPEATED PERFORMANCE ON 9 ENGINES

(MMK,6/10/93,TO-6)

B6G NATURAL GAS ENGINE
TORQUE / POWER CURVES



(MMK,5/25/93,TRQ)

DEVELOPEMENT STATUS
EMISSIONS

		NOx	HC	NMHC	PART.
NO CATALYST					
	MIN	1.81	4.40	0.00	0.054
	MAX	2.16	5.59	0.93	0.067
WITH CATALYST					
	MIN	1.73	0.59	0.00	0.009
	MAX	2.28	3.03	0.27	0.019

(MMK,6/10/93,TO-7)

DEVELOPMENT STATUS
MECHANICAL DEVELOPMENT

* ENGINE TESTS

= LAB ENGINE TESTS (OVERSTRESS/ENDURANCE)
= FIELD TEST ENGINES TESTS

* RIG TESTS

= GAS SYSTEM COMPONENTS
= IGNITION SYSTEM COMPONENTS
= VIBRATION TESTING

* QUALIFICATION TESTS

= SENSORS
= ACTUATORS
= CONTROLLER

(MMK,6/10/93,TO-11)

DEVELOPMENT STATUS
FIELD TEST

* PLANNED FIELD TEST ENGINE IN THE FOLLOWING APPLICATIONS

  = SCHOOL BUS
  = SHUTTLE BUS
  = PICKUP/DELIVERY TRUCK

* HAVE ALREADY SHIPPED FOUR FIELD TEST ENGINES

(MMK,6/10/93,TO-10)

B6G TECHNICAL PROGRESS SUMMARY

* PROJECT IS ON SCHEDULE

* HAVE DEMONSTRATED THE PERFORMANCE AND EMISSIONS CAPABILITIES OF THE ENGINE

* MECHANICAL DEVELOPMENT PHASE IS UNDERWAY

  - ENGINE RELIABILITY IS ON TARGET TO ACHIEVE DESIGN GOAL

* ACCUMULATED 3000 HRS OF ENGINE TEST EXPERIENCE

  - BUILT AND TESTED 9 ENGINES

* SHIPPED FOUR FIELD TEST ENGINES

  - SHUTTLE BUS
  - SCHOOL BUS

(MMK,5/31/93,M2-12)

ACKNOWLEDGEMENT

WE ACKNOWLEDGE:

GRI AND SOCAL FOR THEIR PARTICIPATION IN FUNDING THIS PROGRAM.

(MMK,5/29/93,TX-10)

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

CUMMINS B6G: AN ADVANCED TECHNOLOGY NATURAL GAS ENGINE
M.M. Kamel, Cummins Engine Co. Inc.

Q. Anonymous: Can Cummins provide conversion of existing engines?

A. No, the hardware could be purchased, but it would be expensive and there would be no certification.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

DEVELOPMENT OF A STOICHIOMETRIC NATURAL GAS ENGINE FOR USE IN HEAVY DUTY TRUCKS

(unavailable at time of printing)

L. Gettel, G.C. Perry
BC Research

D.H. Smith
IMPCO Technologies

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

DEVELOPMENT OF A STOICHIOMETRIC NG ENGINE FOR USE IN HEAVY DUTY TRUCKS
G.C. Perry, and L.E. Gettel, B.C. Research Corporation

Q. Bernard James, Energy, Mines & Resources Canada: What range is obtained by the truck?

A. The range is 200-250 kilometers.

Q. Bryan Wilson, Colorado State University: Do you have emissions data?

A. No, emissions have not been measured yet on the vehicle.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

DEVELOPMENT STATUS FOR TWO DEDICATED METHANOL ENGINE COMBUSTION TECHNOLOGIES: DI HOT SURFACE IGNITION AND DI SPARK IGNITED STRATIFIED CHARGE

R. Last
FEV of America

B. Bartunek, N. Schorn, R. Schmidt
FEV Motorentechnik GmbH & Co. KG

Development Status for Two Dedicated Methanol Engine Combustion Technologies: DI Hot Surface Ignition and DI Spark Ignited Stratified Charge

Presented by:
Robert J. Last
FEV Engine Technology, Inc.

At the SAE Fuels and Lubricants Meeting in San Francisco last August, I presented the Phase 1 program results for two engine development programs that FEV has conducted with the support of funding by the U.S. Environmental Protection Agency and co-sponsorship by Volkswagen.

[SLIDES 1 through 3]

The direct injected, hot surface ignition system uses a shielded glow element that is heated at all times during the engine operating cycle. A single spray from a multi-hole nozzle is directed at the shielded cover of the glow plug. The fuel from the ignition spray enters the cover through perforations in its surface and ignites. This results in a torch-like ignition of the main injection quantity.

[SLIDES 2 through 6]

The DI, spark ignition combustion process is characterized by peripheral injection in a relatively deep, compact combustion chamber and the nearly simultaneous provision of a spark ignition source near the wall of the bowl. The fuel injection is accomplished with a two-spring injection nozzle holder. Mixture formation is supported by a relatively high swirl (4.0). Through adaptation of the two injector stages, a certain rate-shaping effect is possible, allowing control of the injection duration and the position of the spray cone relative to the spark plug. In comparison with traditional Otto engines, the higher compression ratio with this concept requires that a sufficiently large number of multiple sparks occur over a period of approximately 0.8 to 1.0 ms. Consequently, smaller electrode gaps are necessary to avoid "blow-off" or quenching effects. Because of the deep, slightly reentrant bowl shape, the spark plug protrusion must be relatively deep, requiring a long electrode length.

The Phase 1 results for the DI hot surface ignition concept reported near ULEV emissions levels as well as cold startability at -29°C with excellent driveaway characteristics and diesel-like fuel economy. The potential for very low emissions from the DI Spark Ignited, stratified charge concept was also demonstrated.

In addition to the very encouraging results that came out of Phase 1, the need for a number of improvments was also recognized, if the true potential of these concepts was to be realized. Most of the recommendations were related to the desire to dynamically adjust the engine for low emissions and to control the fuel system. The motivation for considering electronic control of the engines included the following considerations:

[SLIDE 7]
[SLIDE 8]

With these goals in mind, FEV commenced a Phase 2 effort with funding support by the U.S. Environmental Protection Agency and the assistance of Volkswagen.

Additionally, Robert Bosch provided limited technical support and allowed the use of some of their componentry in the design and development of the controller. I would be remiss in not acknowledging the support of these organizations.

Phase 2 was directed at adapting and developing an electronically controlled injection pump, EGR system and integration of a separate electronic ignition system, in the case of the DI SI engine. As a result of these efforts, the first fully electronic dedicated methanol engine concept for direct injection has been developed. Today, I would like to provide a brief overview of the control system concept and identify areas in which we feel additional development is necessary to ultimately provide a competitive methanol engine design concept.

The primary functions of the controller include:

[SLIDE 9]

1. INJECTION QUANTITY CONTROL

The primary function of an electronic engine controller for DI engines is, of course, the governing of the injection quantity. In the FEV IEEC controller, the fuel injection quantity is controlled in the following manner.

[SLIDE 10]

Based upon the requested engine operational point (foot pedal input), the controller performs any modifcations of the request that might be necessary due to the operating state of the engine (such as idle, full load, startup and/or need for temperature compensation) and requests a certain injection quantity. This is referred to in the figure as FQ_SOLL. The difference between the requested fuel quantity and the reported fuel rack position is then determined and a calculation takes place, as indicated in the figure. Depending upon whether the requested injection quantity is less than or greater than the reported quantity, a signal is output to a rotary torque motor which, in turn, drives the fuel rack to either higher or lower fuel delivery positions.

The initial development testing with the electronic controller has indicated a need for better temperature compensation of the fuel rack position feedback sensor. Typically, such sensors have non-linear voltage characteristics and exhibit a certain drift as a function of the temperature in the vicinity of the sensor. This temperature effect has a more significant influence on the engine operating characteristics than originally anticipated. FEV has, therefore, recommended that this problem be addressed in future development efforts with the controller.

In addition to temperature compensation, FEV has recommended the use of a self-calibration circuit in the controller. This circuit would compare the output of the fuel rack position sensor at a known angular position (such as the full load mechanical stop) with a calibration value which is stored in a EPROM. When the sensor deviates from the correct value, this "self calibration" circuit would apply a scalar correction factor to the sensor output, in an attempt to return it to the correct calibration.

2. BEGINNING OF INJECTION

During the course of development for both of the passenger car methanol engine concepts which are being developed by FEV, the need has been demonstrated for an injection timing strategy which is both load and speed dependent.

[SLIDE 11]

Under low load conditions, advanced timing is necessary to ensure good ignition quality as well as low HC and CO emissions. Under high, part load conditions where high temperatures prevent increased HC emissions, retarded timing is employed to reduce NOx emissions and to ensure good fuel economy. However, under high load, high speed conditions, it becomes necessary to re-advance timing because of the length of the injection event. Clearly, these considerations call for a flexible timing strategy that can only be acheived with electronic timing control.

The AMBAC Model 100 methanol compatible, electronic fuel injection pump is being used in both of these programs. The beginning of injection is controlled in closed loop through an evaluation of the output sigals from two vane sensors mounted inside the pump housing One sensor is located on the pump cam shaft and the other on the driven shaft which rotates the hydraulic head of the injection pump. The controller calculates a phase difference between the two sensors which is related to the BOI and then provides an appropriate driver signal to a linear magnet which, in turn, positions a helical spline gear to adjust the timing. In this manner, the timing for the <u>fuel delivery</u> from the injection pump is controlled in closed loop. However, our recent evaluations with the electronic control system indicate that this control strategy may not be adequate. While the start of fuel delivery is related to BOI, the hydrodynamics in the injection line and nozzle influence the actual BOI to a considerable extent, dependent upon injection pressure and the point in the operating map. Therefore, future efforts are planned to incorporate a needle lift sensor based BOI feedback signal.

3. EXHAUST GAS RECIRCULATION

One of the critical needs that was demonstrated during the Phase 1 vehicle evaluation was the need for closed loop control of the EGR system.

[SLIDE 12]

Under low speed, part load conditions, very high EGR rates are possible, resulting in a substantial reduction in NOx emissions. Under medium speed, part load conditions, most of the NOx reduction is acheived within the first 10% of EGR fraction and more sensitivity is observed with regard to higher EGR rates, therefore the EGR rate drops off more rapidly. Under high speed conditions, the sensitivity of the combustion process to higher EGR rates increases substantially and, therefore, EGR must be limited under these conditions.

[SLIDE 13]

However, despite EGR sensitivity (due to misfiring) in both engine concepts, a substantial reduction in NOx is possible with hot EGR. In general, under low load conditions, the application of hot EGR leads to a slight parallel improvement in HC emissions, since the intake air is preheated by the EGR. At higher EGR rates, the lower O_2 content results in a deterioration in flame speed and ignition characteristics, and HC concentration increases. However, this higher concentration is offset at part load by the fact that the exhaust gas mass flow is signficantly lower.

[SLIDE 14]

By properly "tailoring" the EGR and BOI strategy, it is possible to reduce NOx without a significant penalty in HC or BSFC. However, this ability requires flexible, electronic, closed loop control of both EGR and timing.

This approach is possible with both the HSI engine as well as the DI SI stratified charge engine. Although the spark ignited engine is somewhat more sensitive to EGR, as indicated here in the EGR map for the engine.

[SLIDE 15]

Flexible, dynamic EGR control capability was built into the electronic control system during the development of the electronic controller. A duty cycle signal from the IEEC unit, defining the desired EGR valve lift is provided to a solenoid, which modulates between vacuum pump and ambient pressure as necessary to actuate the EGR valve. An air mass flow sensor provides a feedback signal, indicating the actual air mass flow to the controller. The maximum air mass flow for this particular operating point occurs under conditions of no EGR. This value is stored in an EPROM. The controller then compares the actual air mass flow value with the maximum value, stored in EPROM. An actual EGR rate can, thus, be calculated and adjusted, resulting in closed loop control of the EGR.

4. IGNITION TIMING CONTROL

Although the controller architecture was designed to include it, the current controller concept does not include the capability for spark timing control. Currently, this remains a rather critical limitation for the DI SI stratified charge engine in terms of realization of the true potential engine performance.

[SLIDE 16]

The time difference between BOI and ignition defines the degree of in-cylinder homogenization of the air/fuel mixture. Ignition must occur during the period corresponding to the injection duration. Under part load conditions, very early injection timing (about 21°BTDC) and a (max) 2 - 3° later spark timing is necessary to acheive a good combination of low HC emissions and acceptable BSFC. However, under high load conditions, more homogenization is necessary for good air utilization and good BSFC. Therefore, the ignition timing should be very late in comparison with the injection timing to acheive the best characteristics. Clearly, flexible, independent control of both injection and ignition timing are necessary.

Unfortunately, the desired injection/ignition timing strategy is currently not possible with the ignition system that is being utilized on the vehicle. The ignition timing device that is currently available uses an engine speed dependent timing control function. After a signal for dynamic BOI has been registered, a programmed delay time occurs before spark ignition takes place. The time delay calibration is a function of engine speed and is controlled between 1° crank angle at low speed and 6° crank angle at rated speed. This system, while adequate, represents a compromise from the ideal ignition timing flexiblity.

The injection timing for the DI SI engine is shown here and represents the typical compromise between best timing at discrete steady-state points and a smooth transition for good electronic control system function.

[SLIDE 17]

The corresponding ignition timing here. Clearly, it is not currently possible to provide the desired residence time under all load and speed conditions and, consequently, the full potential of the in-cylinder homogenization concept cannot be taken advantage of.

[SLIDE 18]

FEV has recommended the incorporation of this feature into future direct injected, spark ignited vehicle development activities.

5. DRIVEABILITY/ACCELERATION

Numerous points exist in the engine map, from which accelerations typically begin during the FTP-75 cycle. These points are of particular concern due to the heavily weighted contribution of emissions peaks that occur during accelerations to the overall engine emissions characterization. In diesel applications, electronic controllers typically provide a smoke limitation feature that prevents localized overfuelling during accelerations by limiting the rate of increase of the fuel injection quantity. This is done as a function of the available air mass flow. In the methanol engine, where smoke is not a problem, this type of control feature can be utilized for a different purpose. The FEV engine controller uses this capability as an indirect Lambda control under acceleration conditions. The rate of injection quantity increase is limited, through the use of a special look up table that interacts with the EGR and BOI control systems. Hence, the EGR and BOI characteristics can be fine-tuned to reduce or eliminate acceleration induced emissions peaks.

6. IDLE SPEED CONTROL

The FEV controller also features a sophisticated P,I,D governor for idle speed and an integrated glow plug controller for the HSI engine. The glow plug controller feature allows special cold start and warm-up strategies as well as flexible, dyanamic control of the hot surface ignition system energy supply during engine operation.

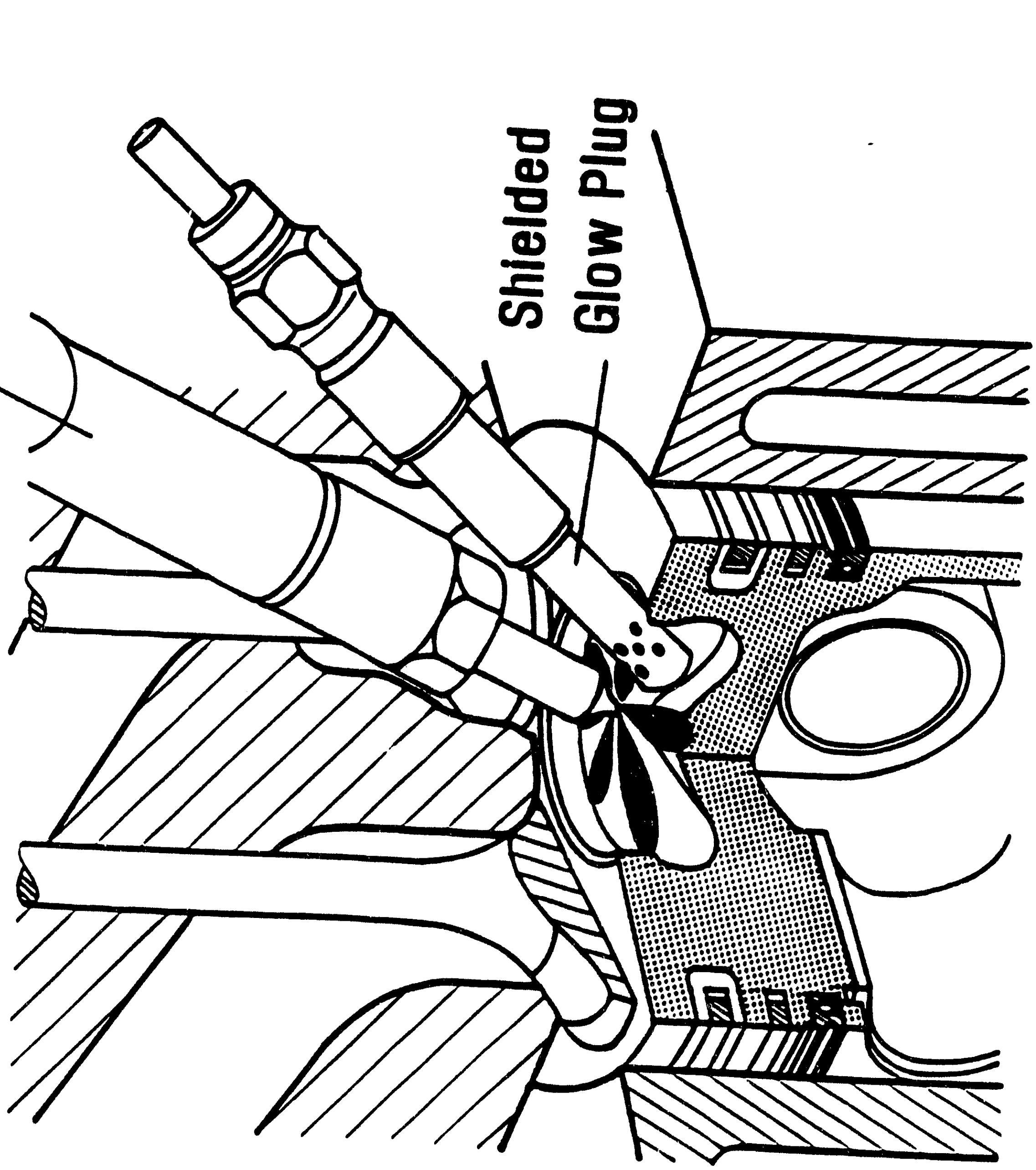
The controller was designed with the intent of upgradeability, including the future potential for spark timing control and variable geometry turbocharger control. However, these features have not yet been incorporated into the design.

7. SUMMARY AND CONCLUSIONS

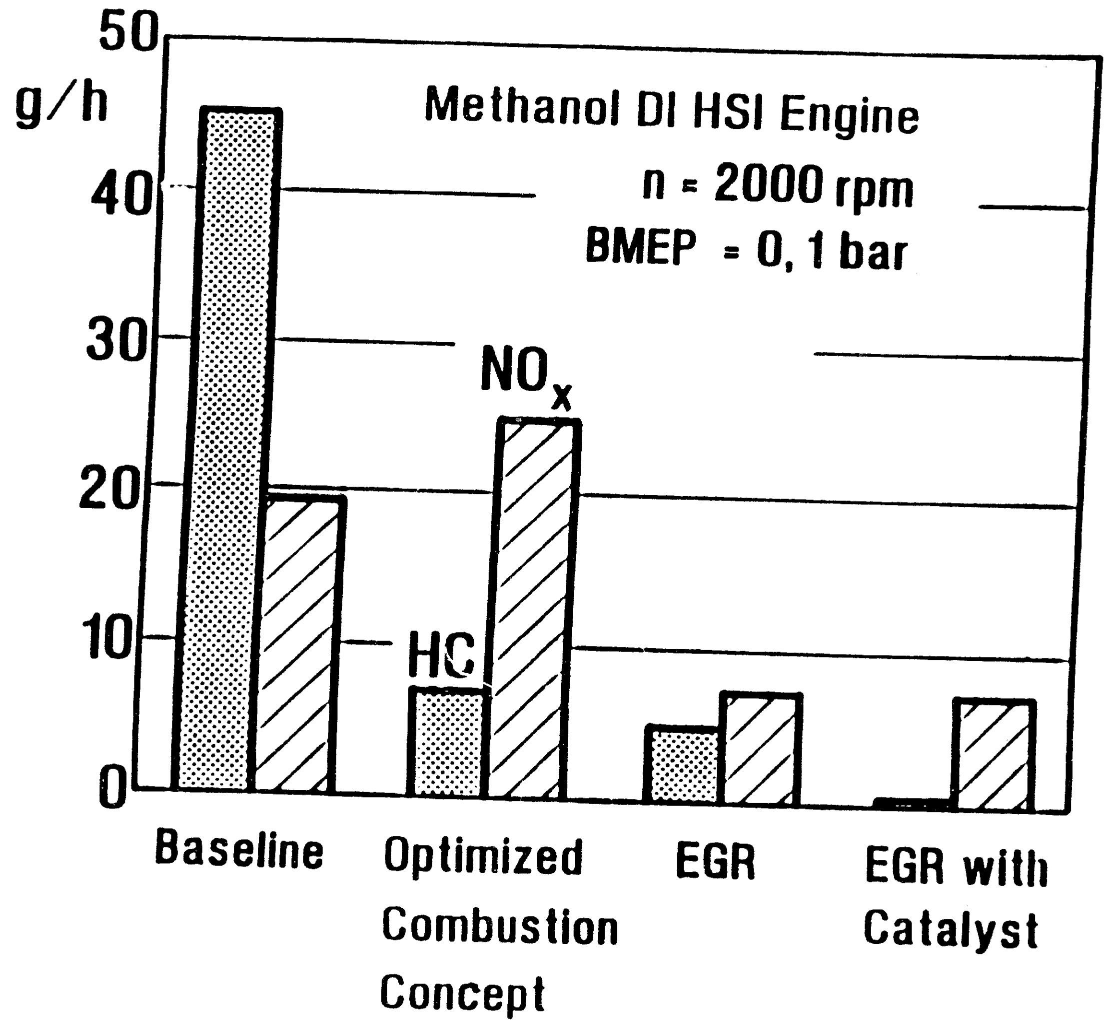
In addition to the basic consideration of incorporating independent spark timing control, the development steps which should be considered in the near term include the following:

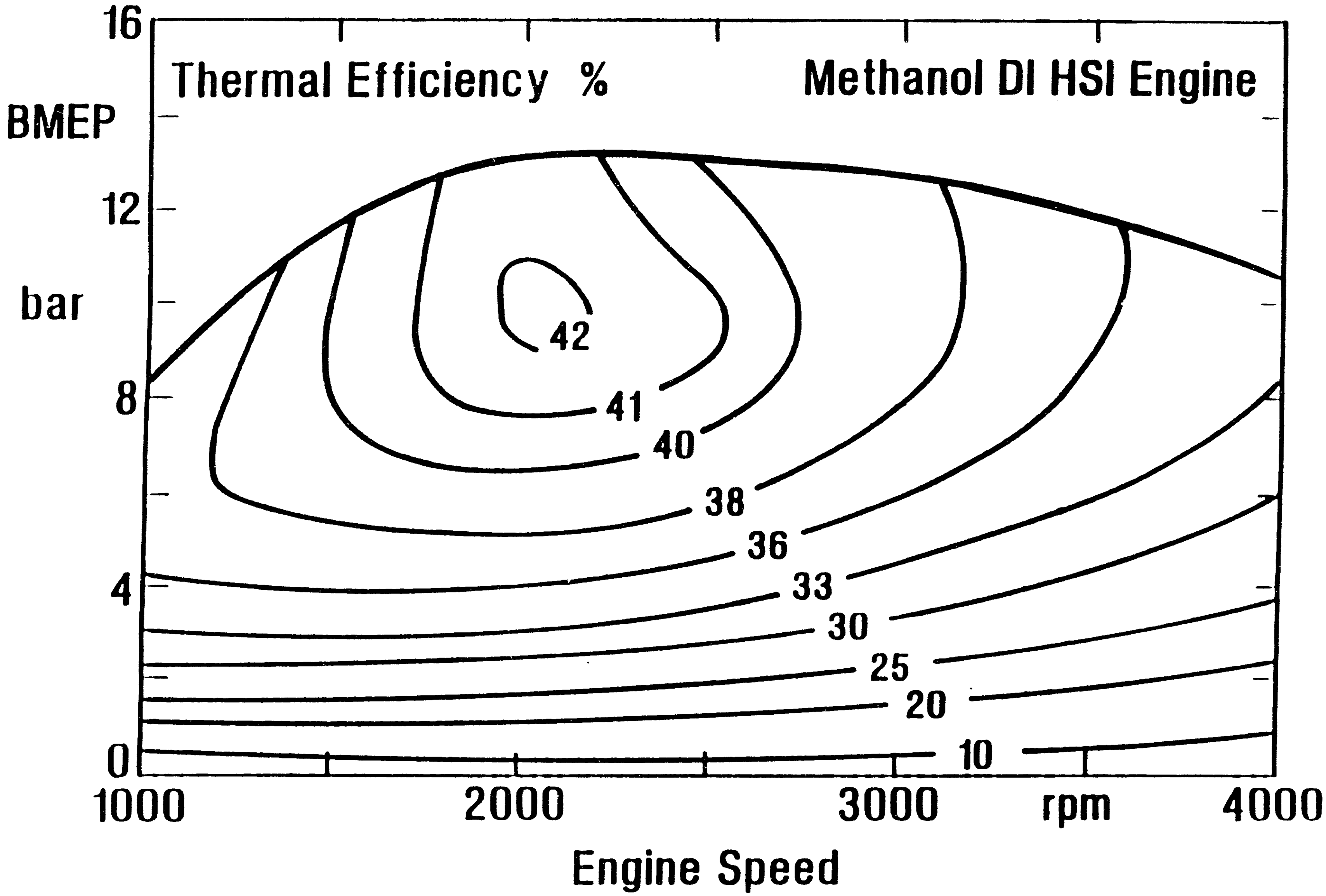
[READ SLIDE 19]

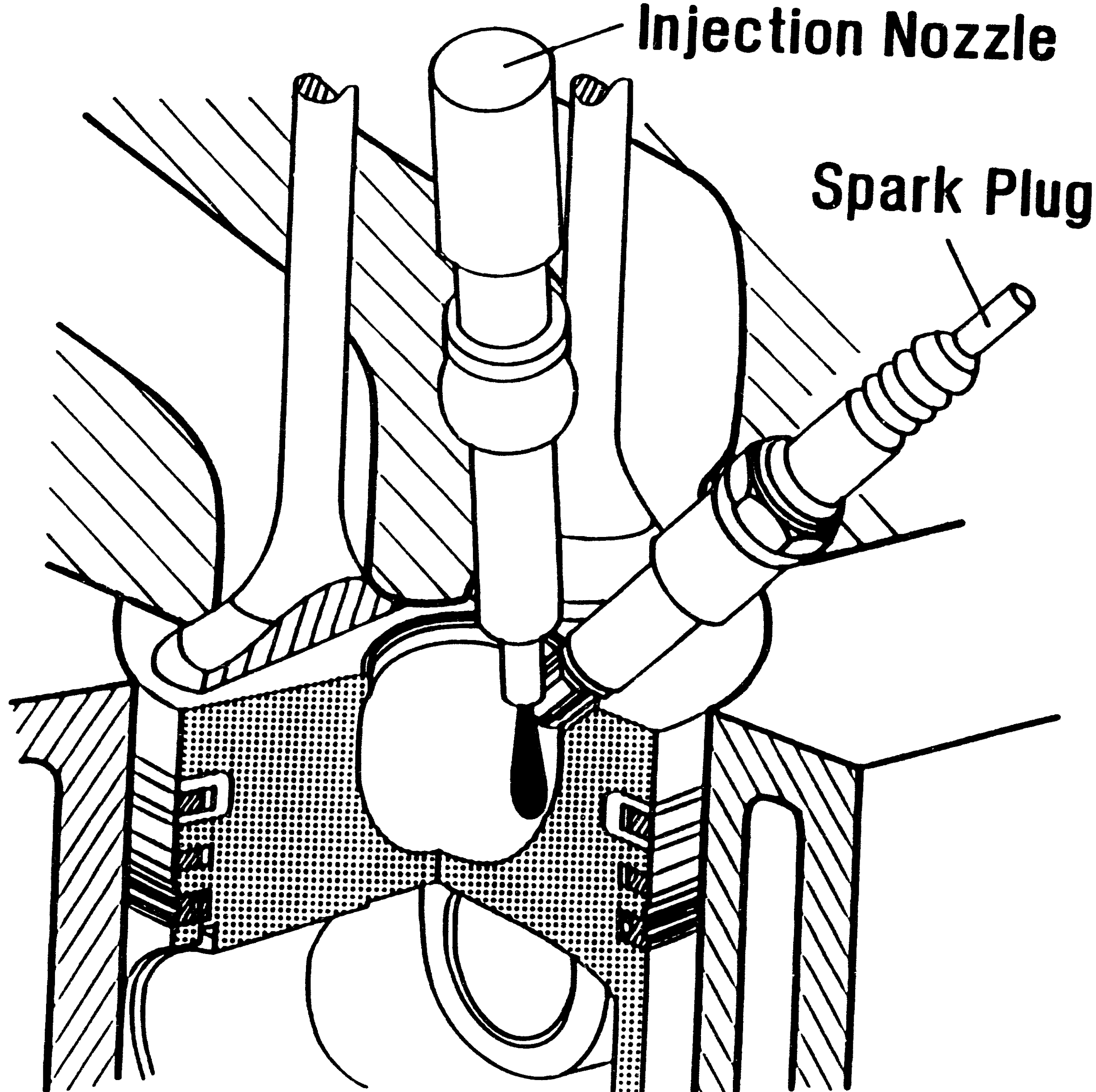
Although recent testing has indicated a need for improvements in the control concept, the FEV IEEC represents a significant development from the standpoint of dynamic control of a methanol engine. When fully developed, FEV believes that extremely low emissions values will be possible with both of these methanol engine concepts. Although the development of these engines on a steady-state basis is nearly complete, a considerable effort is still necessary to dynamically optimize the engine/controller system in a vehicle. Accordingly, these efforts represent FEV's recommendations for near term development goals for these technologies.

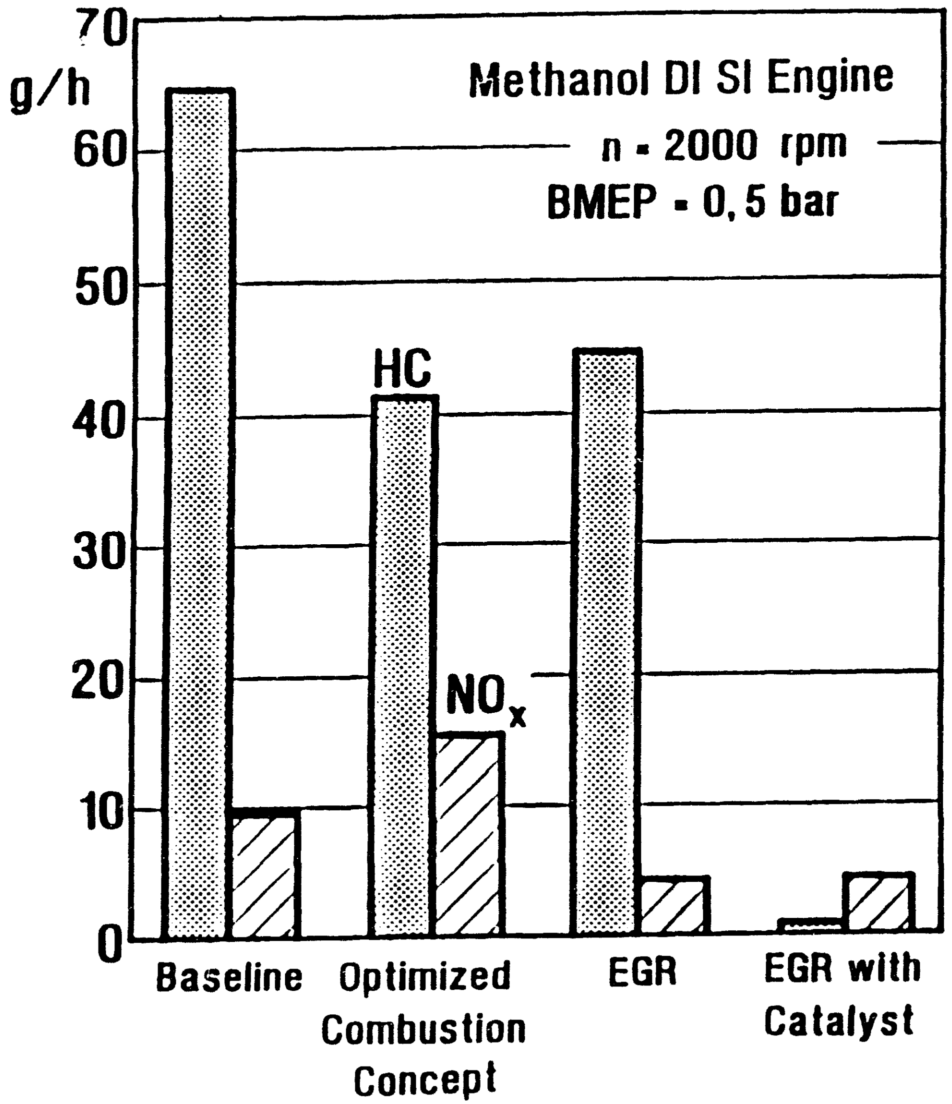


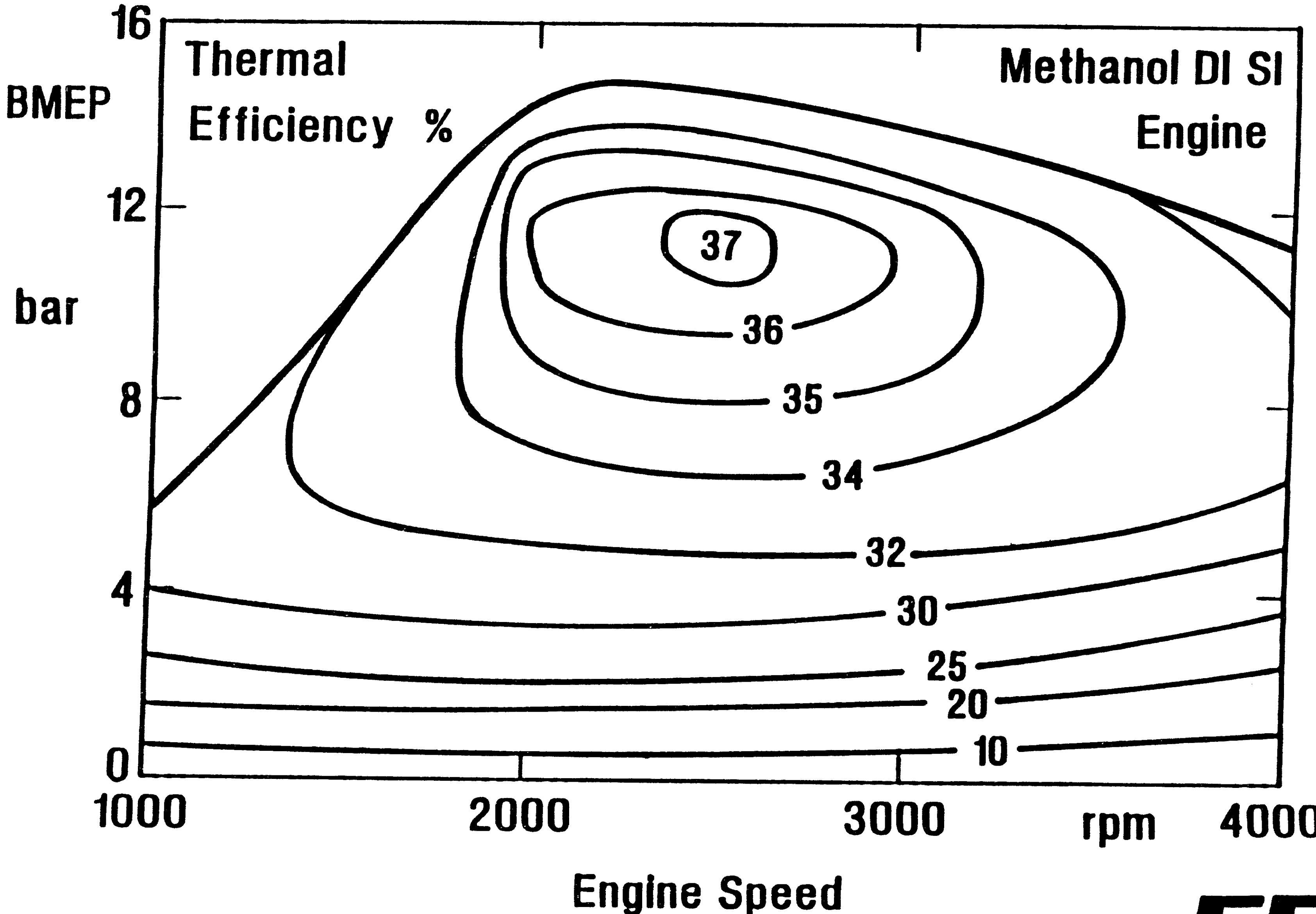
Injection Nozzle
Shielded
Glow Plug


50
g/h
40
30
20
10
0
Methanol DI HSI Engine
n = 2000 rpm
BMEP = 0,1 bar
NOx
HC
Baseline
Optimized Combustion Concept
EGR
EGR with Catalyst


Thermal Efficiency %
Methanol DI HSI Engine
BMEP
bar
16
12
8
4
0
42
41
40
38
36
33
30
25
20
10
1000
2000
3000
rpm
4000
Engine Speed


Injection Nozzle
Spark Plug


g/h
70
60
50
40
30
20
10
0
Methanol DI SI Engine
n = 2000 rpm
BMEP = 0,5 bar
HC
NO_x
Baseline
Optimized Combustion Concept
EGR
EGR with Catalyst



Thermal Efficiency %
Methanol DI SI Engine
BMEP bar
16
12
8
4
0
1000
2000
3000
rpm
4000
Engine Speed
37
36
35
34
32
30
25
20
10

FEV

Reasons for Electronic Injection System Control

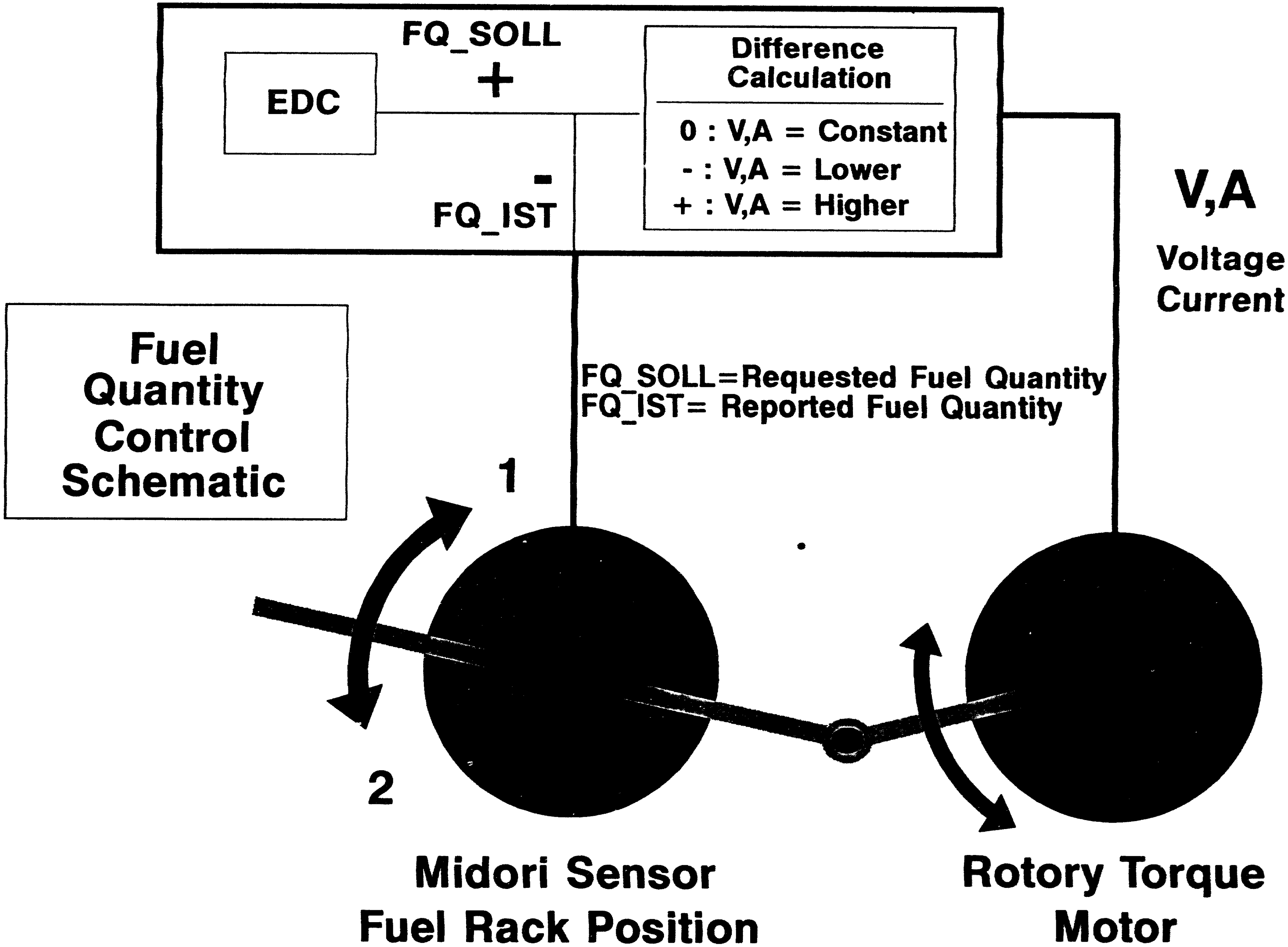
- Control of injection timing as a function of load and speed can only be achieved through complicated and inexact mechanical means (plunger helices and speed advance devices).
- Temperature compensation is not possible with the mechanical system.
- Rate of injection quantity increase cannot be directly controlled in a mechanical system as a means of avoiding transient HC peaks.
- A mechanical system is, in principal, more subject to hysteresis and accuracy problems and requires frequent readjustment and calibration.

Reasons for Electronic Injection System Control

- In-line injection pumps generate a significant level of operating noise (one plunger for each cylinder) in addition to the combustion noise from the engine.
- Due to the number of pumping elements and generally high pressure levels, in-line pumps are generally more expensive than rotary pumps.
- Use of a mechanical system requires separate controllers for EGR, glow plug power and spark timing control. The use of an electronic engine controller allows integration of the pump timing and quantity control with these separate control systems.
- Closed loop control of EGR is not possible with the mechanical system.

FEV IEEC Controller Primary Functions

- Injection Quantity Control
- Beginning of Injection
- Exhaust Gas Recirculation
- Cold Start and Warm-Up
- Driveability and Acceleration
- Idle Speed Control
- Glow Plug Power Control


EDC
FQ_SOLL
+
-
FQ_IST
Difference Calculation
0 : V,A = Constant
- : V,A = Lower
+ : V,A = Higher
V,A
Voltage Current
Fuel Quantity Control Schematic
FQ_SOLL=Requested Fuel Quantity
FQ_IST= Reported Fuel Quantity
1
2
Midori Sensor Fuel Rack Position
Rotory Torque Motor

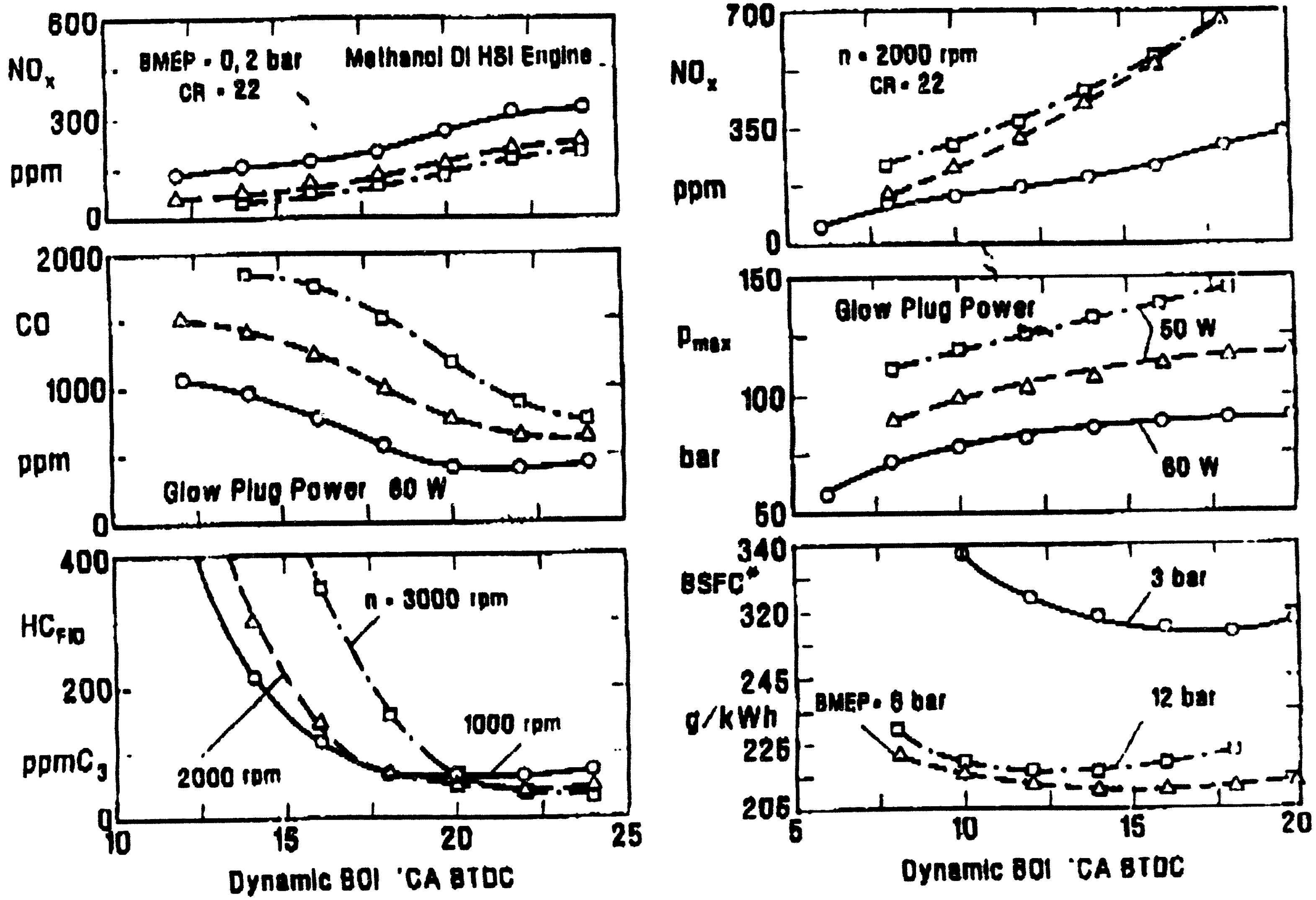
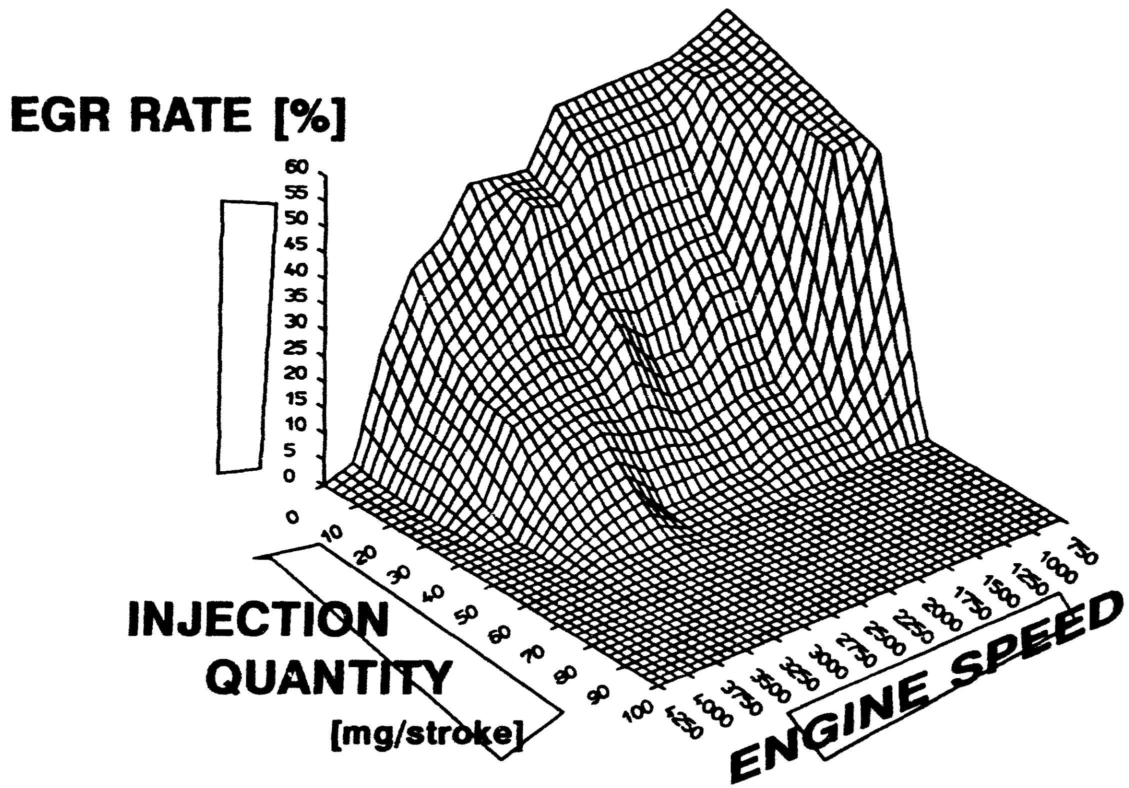
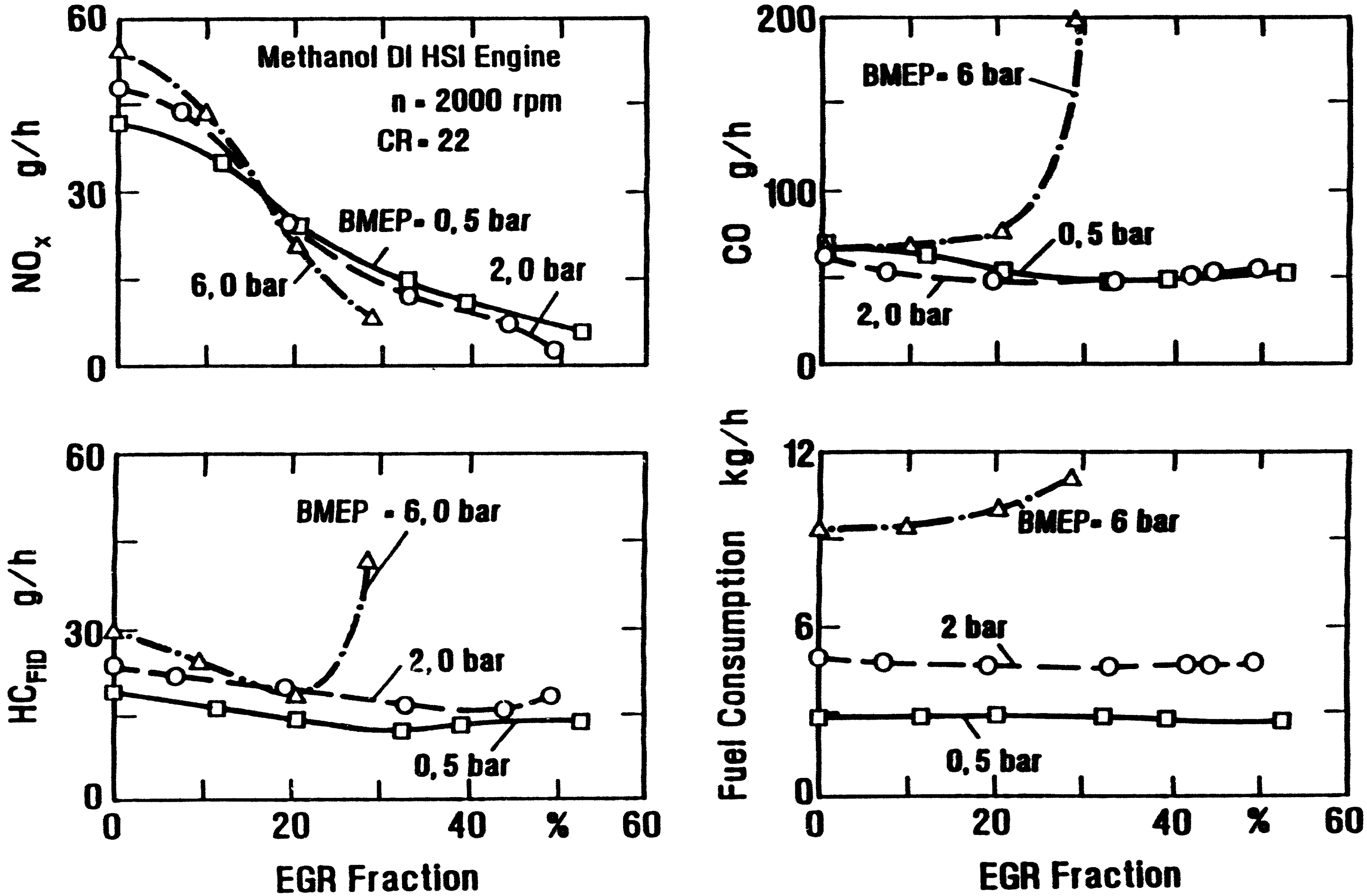


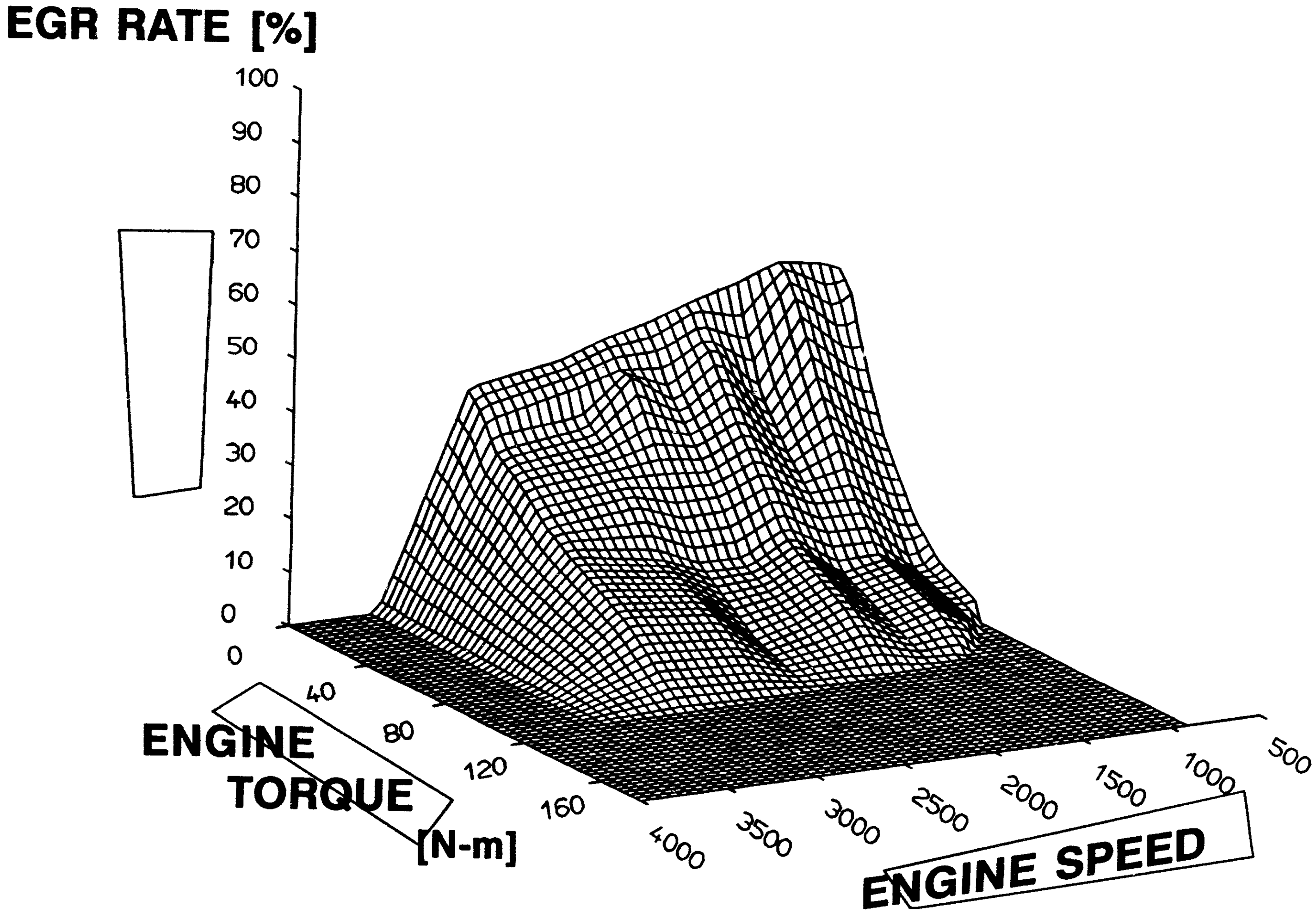
Figure 8[1] : Influence of Dynamic Injection Timing on the Operational Behavior of the DI HSI Methanol Engine

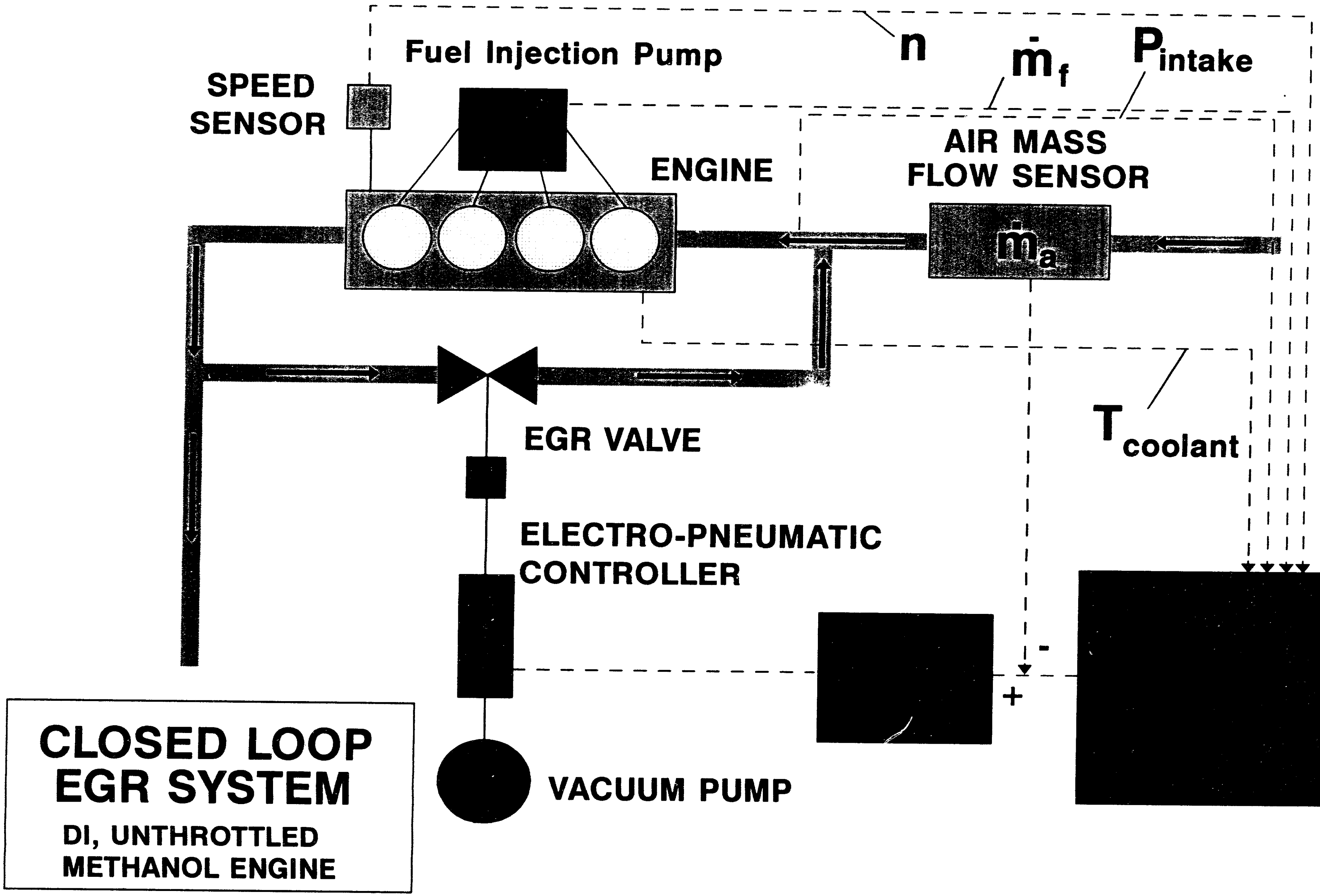
VW 1.9L DI HSI METHANOL ENGINE
EGR RATE [%]



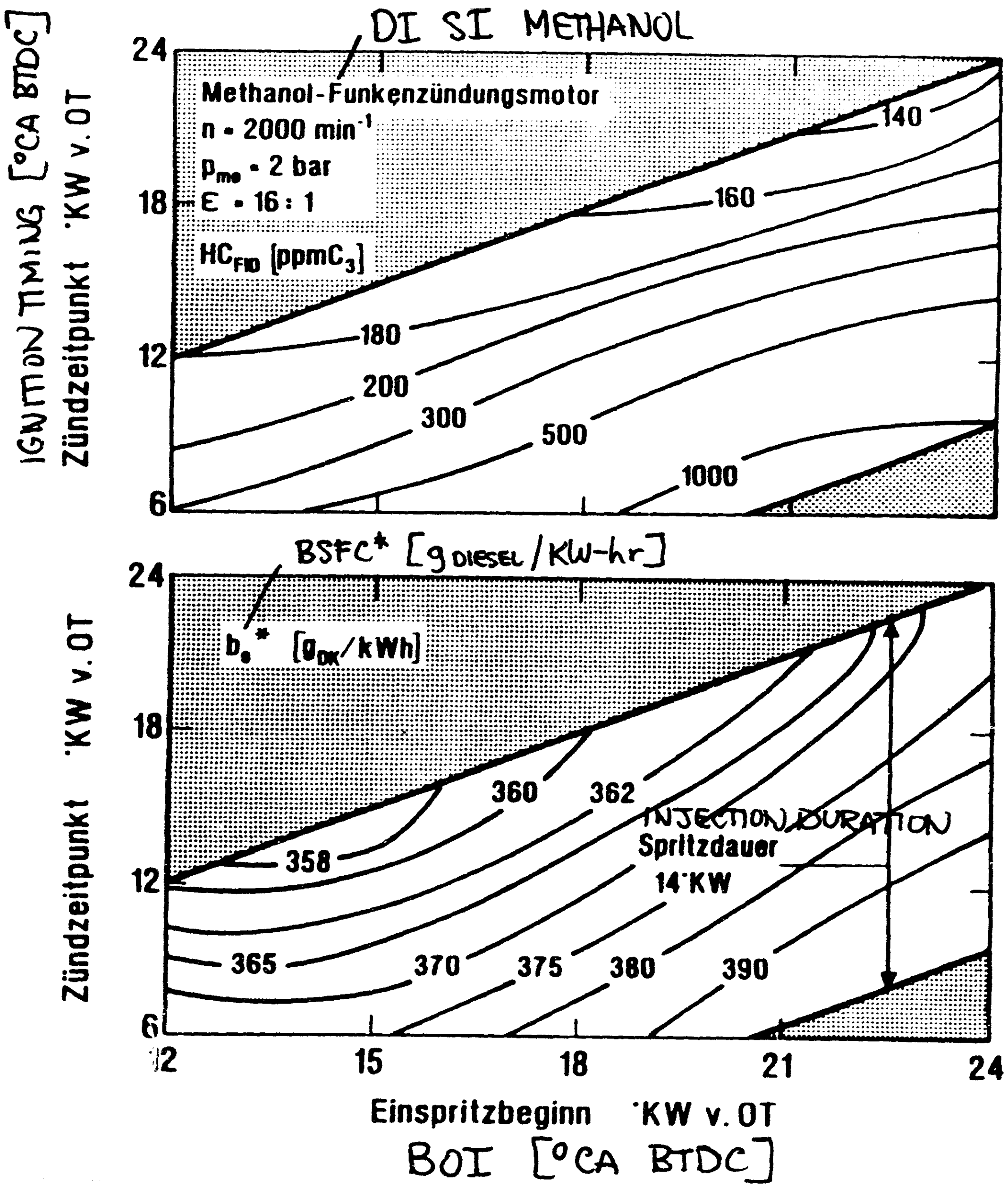

Methanol DI HSI Engine
n = 2000 rpm
CR = 22
NO_x g/h
BMEP = 0,5 bar
6,0 bar
2,0 bar
CO g/h
BMEP = 6 bar
0,5 bar
2,0 bar
HC_{FID} g/h
BMEP = 6,0 bar
2,0 bar
0,5 bar
Fuel Consumption kg/h
BMEP = 6 bar
2 bar
0,5 bar
EGR Fraction
EGR Fraction

VW 1.7L DI SI METHANOL ENGINE

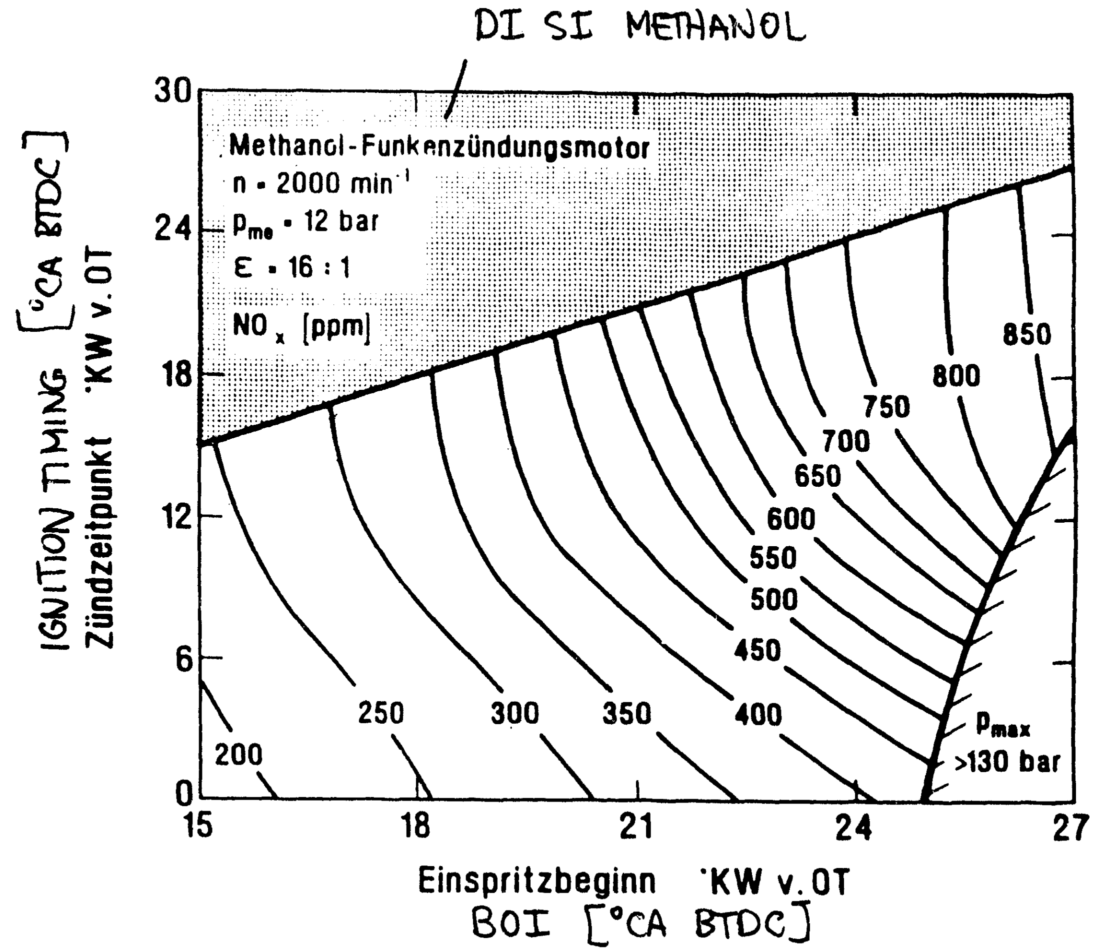


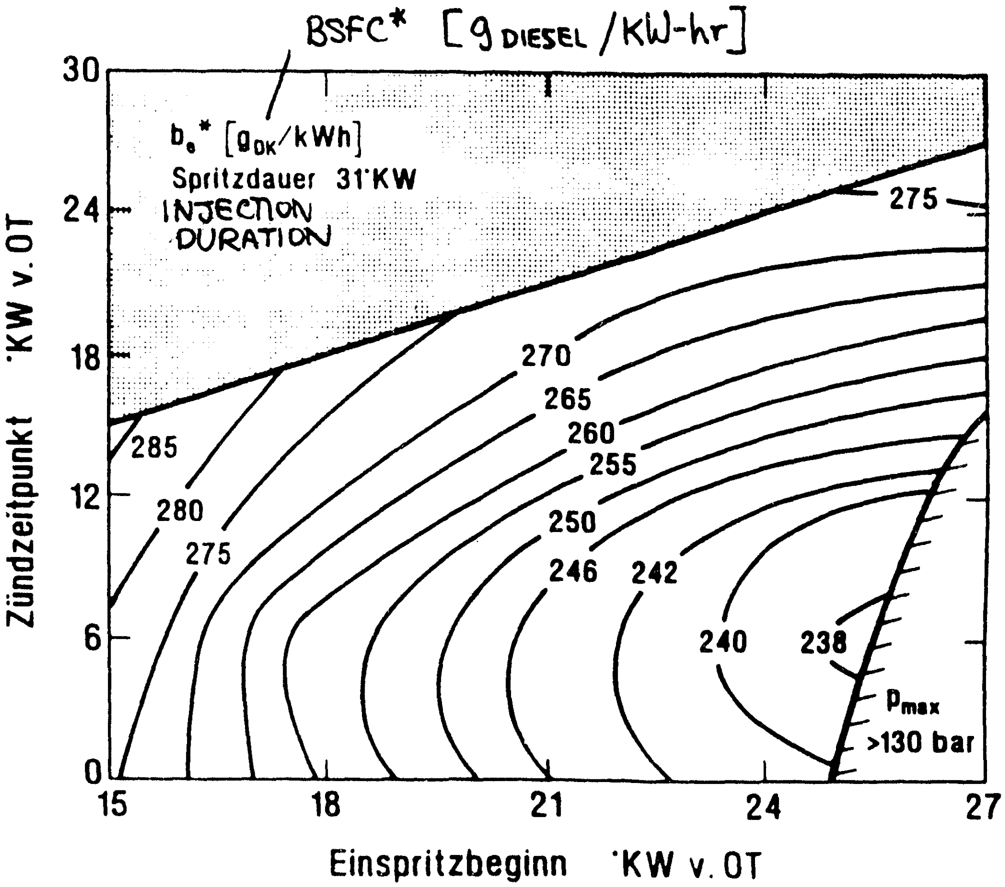


Fuel Injection Pump
SPEED SENSOR
ENGINE
n
$\dot{m}_f$
P_{intake}
AIR MASS FLOW SENSOR
$\dot{m}_a$
EGR VALVE
$T_{coolant}$
ELECTRO-PNEUMATIC CONTROLLER
-
+
VACUUM PUMP
CLOSED LOOP EGR SYSTEM
DI, UNTHROTTLED METHANOL ENGINE

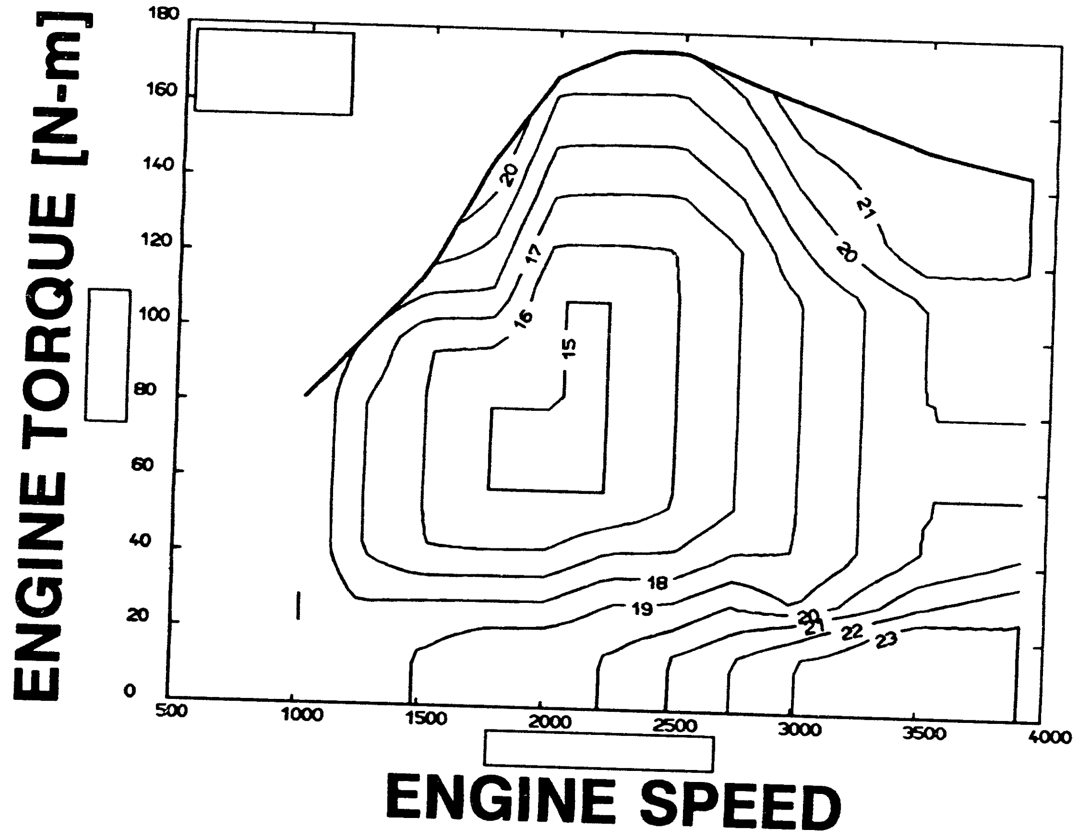


DI SI METHANOL
Methanol-Funkenzündungsmotor
n = 2000 min⁻¹
p_me = 2 bar
ε = 16 : 1
HC_FID [ppmC_3]
140
160
180
200
300
500
1000
IGNITION TIMING [°CA BTDC]
Zündzeitpunkt °KW v. OT
24
18
12
6
BSFC* [g DIESEL / KW-hr]
b_e* [g_DK/kWh]
358
360
362
365
370
375
380
390
INJECTION DURATION
Spritzdauer
14°KW
12
15
18
21
24
Einspritzbeginn °KW v. OT
BOI [°CA BTDC]

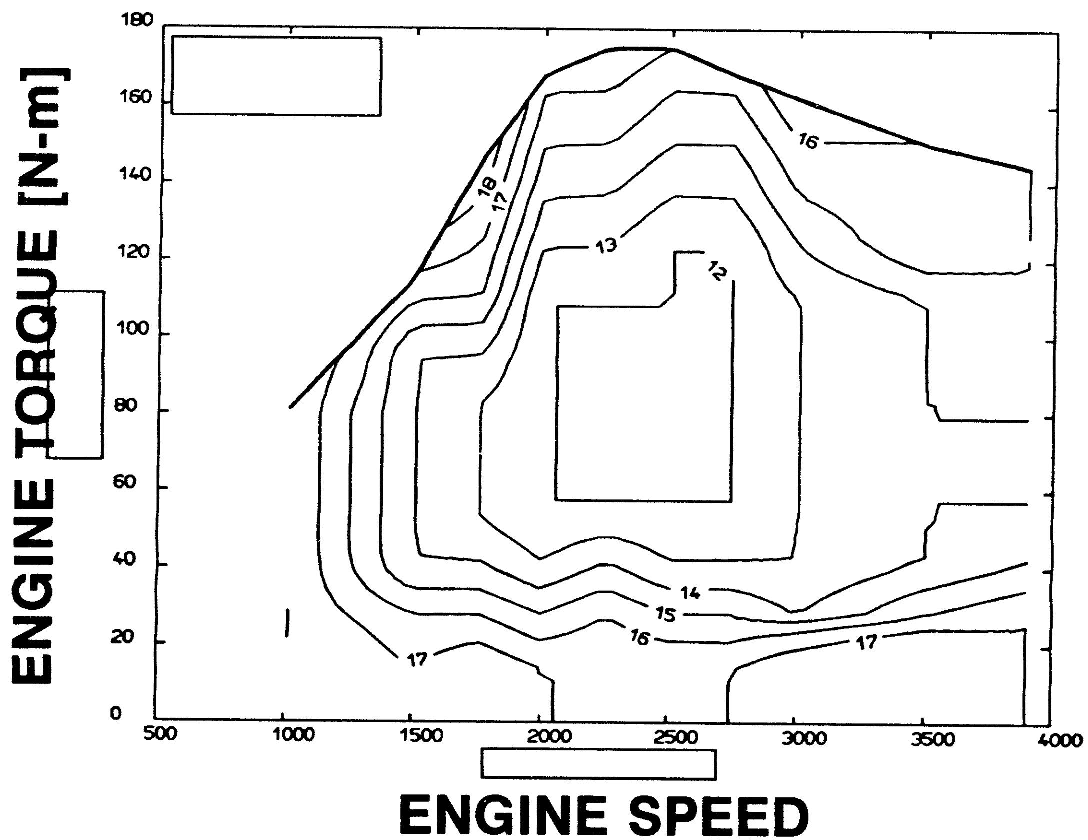

DI SI METHANOL
Methanol-Funkenzündungsmotor
n = 2000 min⁻¹
p_me = 12 bar
ε = 16 : 1
NO_x [ppm]
IGNITION TIMING [°CA BTDC]
Zündzeitpunkt °KW v.OT
200
250
300
350
400
450
500
550
600
650
700
750
800
850
p_max >130 bar
Einspritzbeginn °KW v.OT
BOI [°CA BTDC]


BSFC* [g DIESEL /KW-hr]
b_e* [g_DK/kWh]
Spritzdauer 31°KW
INJECTION DURATION
Zündzeitpunkt °KW v.OT
275
270
265
260
255
250
246
242
240
238
285
280
275
p_max >130 bar
Einspritzbeginn °KW v.OT

VW 1.7L DI SI Methanol Engine
Injection Timing



VW 1.7L DI SI METHANOL ENGINE IGNITION TIMING



Future Development Efforts
Electronic Engine Control System

- Further development is necessary with regard to the stability of the injection pump feedback signals as well as the interaction between the controller and the pump.
- Temperature compensation for the Midori sensor must be integrated into the control system concept.
- Closed loop control of the start of fuel delivery is not sufficient. A needle lift based, closed loop control of the actual BOI event should be incorporated.
- Nearly all mechanical position sensors are subject to hysteresis, accuracy and drift problems. A self calibration circuit should be incorporated into the control system.
- The fuel rack position feedback signal is critical to nearly every engine control system. The reliability of this position sensor must be improved.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS

AND SPEAKER RESPONSES

DEVELOPMENT STATUS FOR TWO DEDICATED METHANOL ENGINE COMBUSTION TECHNOLOGIES: DI HOT SURFACE IGNITION AND DI SPARK IGNITED STRATIFIED CHARGE
R.J. Last, FEV Engine Technology Inc.

Q. Robert Siewert, General Motors: One of your slides showed a large reduction in NOx emissions.

A. Yes, that was showing the influence of exhaust gas recirculation (EGR).

Q. What was the variation in EGR?

A. Under low load conditions, EGR rates were up to 50 percent. As the load was increased, percent EGR decreased sharply. The first 10 percent EGR normally gives the largest amount of NOx reduction.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

FUEL CELL POWERED ZEV BUS

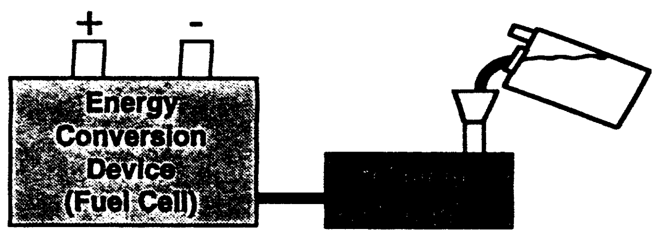
P. Howard
Ballard Power Systems

Ballard

Outline

- Introduction
  - Technology
  - Company
  - Marketing Approach
  - Transit Bus Market
- Demonstration Program - 32′ ZEV PEM Fuel Cell / Electric Bus
  - Purpose
  - Organization
  - Scope
  - Performance
  - Technical Approach
  - Achievements/Results
- Commercialization Plan - 40′ ZEV PEM Fuel Cell / Electric Transit Bus
  - Overall Plan
  - Commercial Prototype
  - Motive Stack Development
- Alliances
- Benefits
- Acknowledgements

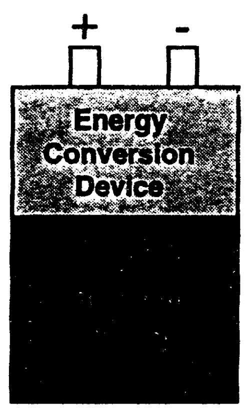
Fuel Cell Technology



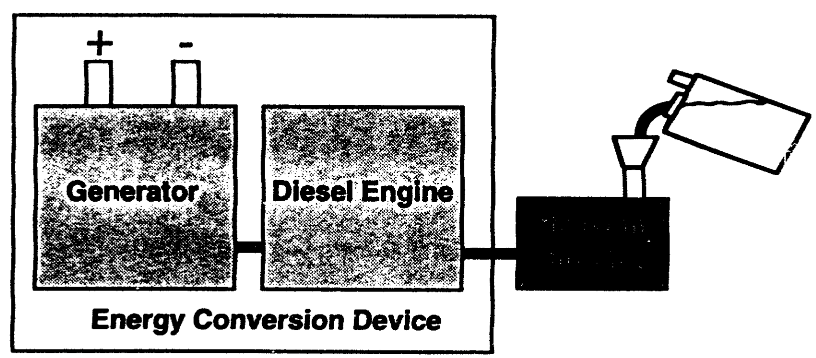
Fuel Cell System

Advantages

- Electricity Without Combustion
- Continuous Production of Electricity as Long as Fuel Supplied
- Environmentally Clean
- High Efficiency
- Low Noise
- Modular and Compact



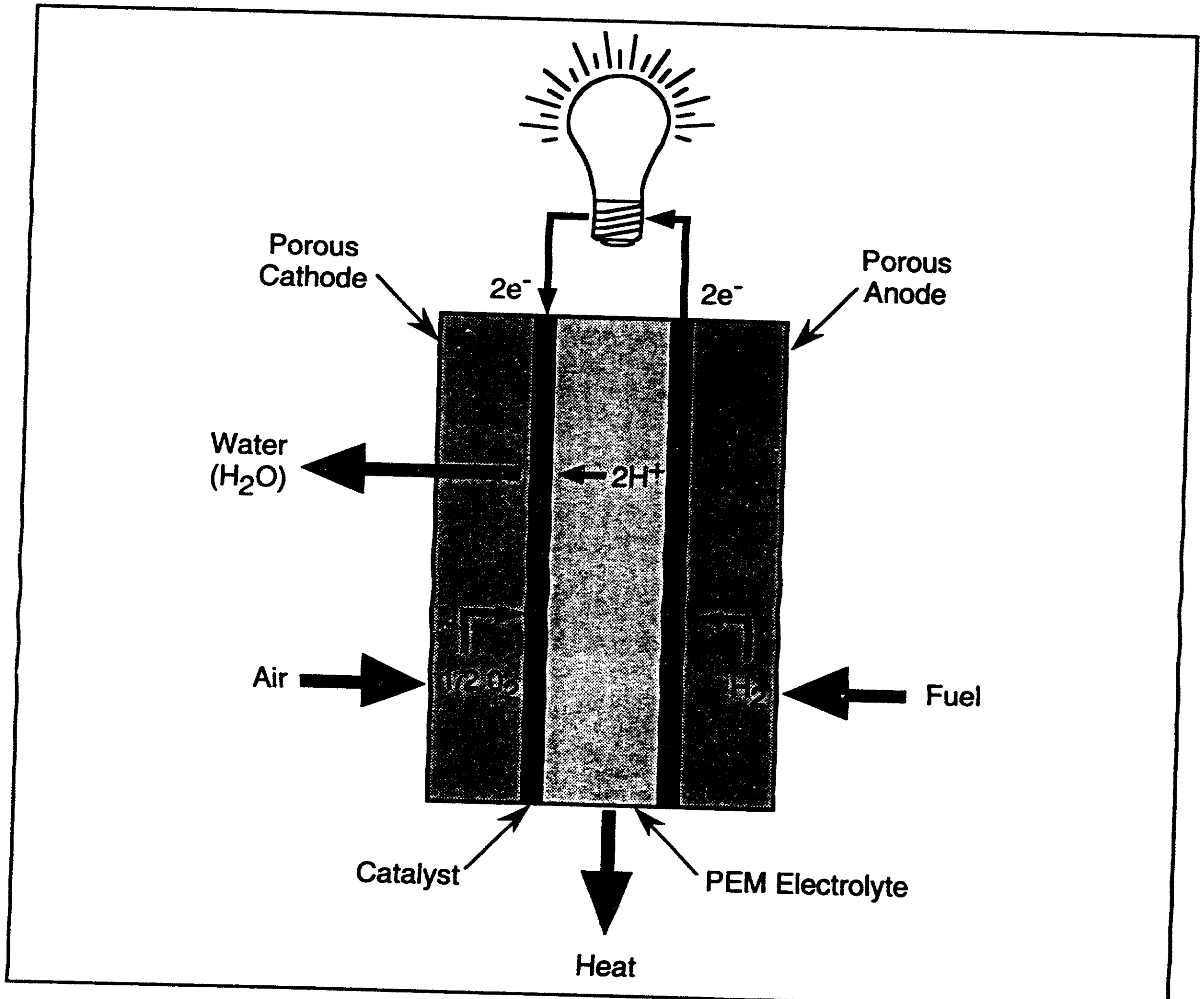
Battery



Diesel/Generator Set

Ballard

Proton Exchange Membrane Fuel Cell



Ballard

Company

- Business - Develop/Manufacture/Market PEM Fuel Cell Systems
- Incorporated 1979
  - Began PEM Fuel Cell Development in 1984
  - Membrane Research (BAM)
  - Battery Manufacturing (BBS)
- Employees - 150
- 60,000 ft^2 in North Vancouver, British Columbia

Marketing Approach

- Market "Push/Pull"
- OEM "Push" - OEMs Adapt Ballard Fuel Cell Systems
- End User "Pull" - Demonstration Programs
    - Secure Programs in Motive/Utilities/Military Sectors
    - End Users Motivate OEMs
    - Government Funding Assistance
- Bus Program - End User is BC Transit

Ballard

Market Creation

		Air Quality Regulations (Emissions, gm/mile)			Implementation Schedule									
		HC	NOx	CO	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
	Tier 1 Standard	0.250	0.4	3.4	80%	85%	80%	73%	48%	23%				
TLEV	Transitional Low Emission Vehicle	0.250	0.4	3.4	10%	15%	20%							
LEV	Low Emission Vehicle	0.075	0.2	3.4				25%	48%	73%	96%	90%	85%	75%
ULEV	Ultra Low Emission Vehicle	0.040	0.2	1.7				2%	2%	2%	2%	5%	10%	15%
ZEV	Zero Emission Vehicle	0.000	0.0	0.0					2%	2%	2%	5%	5%	10%

- California Legislation — 2% ZEV Cars in 1998; Bus / Locomotive / Truck in Draft
- ICE ***cannot*** meet ZEV — Electric Vehicle Market Created
- Credit Market — CARB Mobile Source Emission Credit

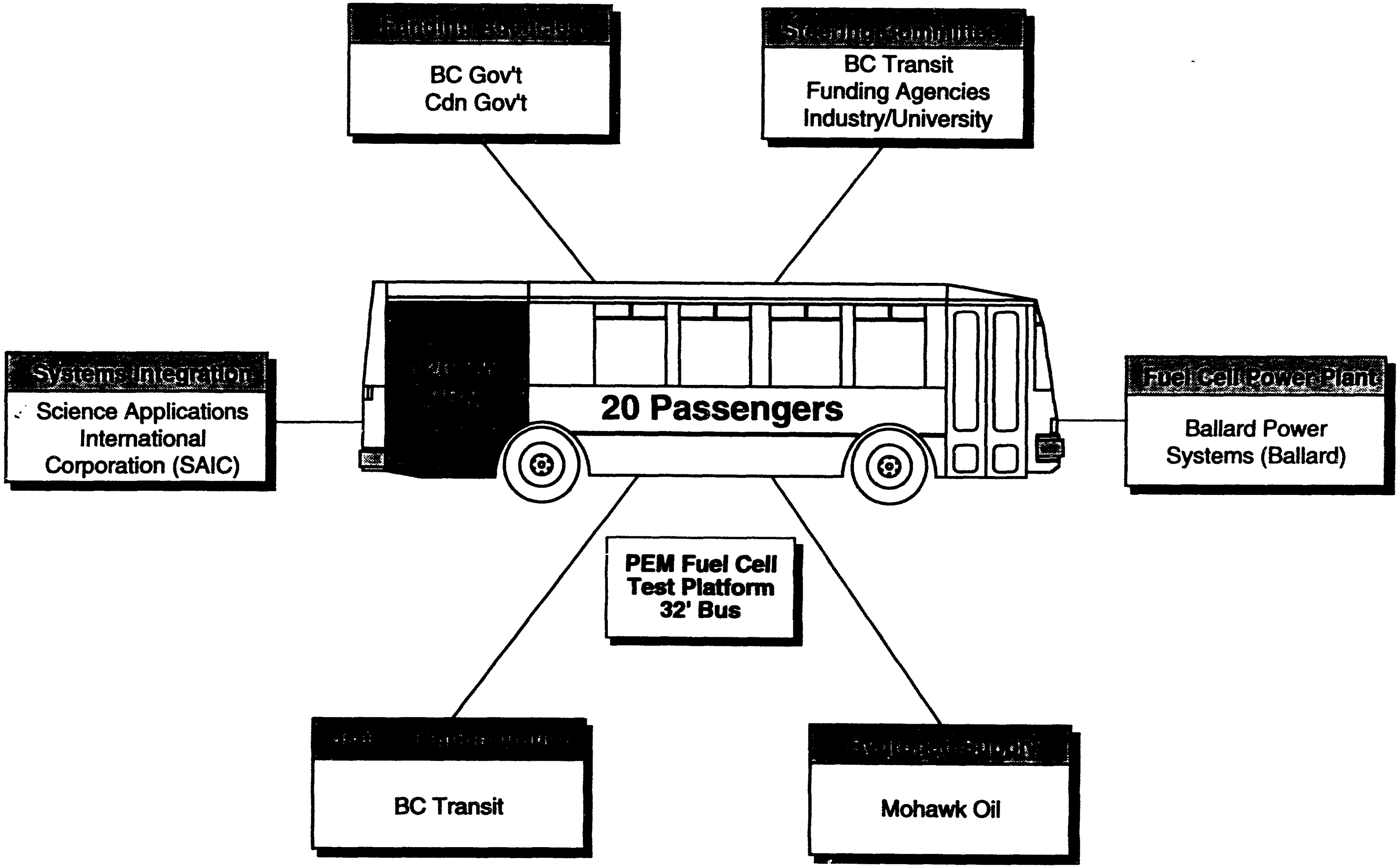
Ballard

Transit Bus Choices

- Electrified Line - Trolley / Third Rail
- Battery
- Fuel Cell

Demonstration Program - Purpose

- Show PEM Fuel Cell Transportation Capability
- Advance Market Acceptance
  - OEMs
  - End Users
- Accelerate Commercialization
  - Market Entry Bus in 1996
  - Commercial Bus in 1998



Demonstration Program Organization

Ballard

Demonstration Program - Scope

- Transit Bus - Powered by Ballard PEM Fuel Cells
- Zero Emission Vehicle (ZEV) - Hydrogen
- Performance $\geq$ Diesel "Driver Acceptability"
- October 1990 to March 1993 - 30 Months
- $4.84 Million Assistance
- Demonstrate with a Transit Authority

Ballard

Demonstration Program - Performance

- White Book Requirements (UMTA)

Top Speed	60 mph (95 km/h)
Gradability	Maintain 44 mph (70 km/h) on 2.5% grade
	Maintain 7 mph (11 km/h) on 16% grade
Acceleration	0 to 30 mph (50 km/h) in 19 seconds
Range	350 miles (560 km)

- Meets or Exceeds White Book Performance
- Range to be met in Commercial Prototype

Ballard

Demonstration Program - Technical Approach

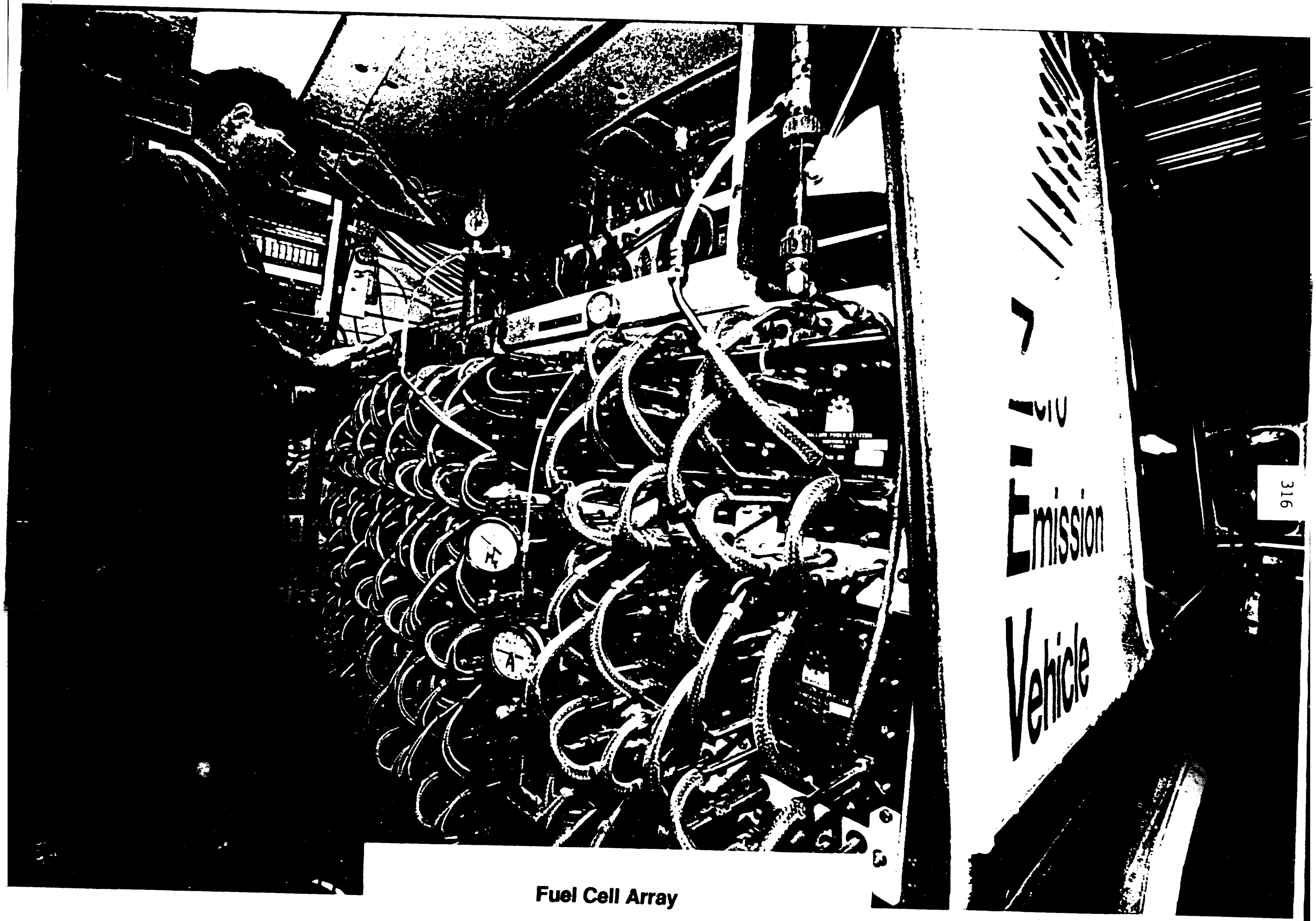
- Ballard MK5 Stack - 20 Vdc/5kW
- Hydrogen Fuel Storage @ 3000 psi
- 32′ Light-duty Transit Bus
- Commercial Components for Ancillaries
- Automotive Compressor/Turbocharger for Air Pressurization
- Conventional, Reliable DC Motor and Control
- Weight Tradeoff
  - Range - 100 miles (160 km)
  - Passengers - 20

315

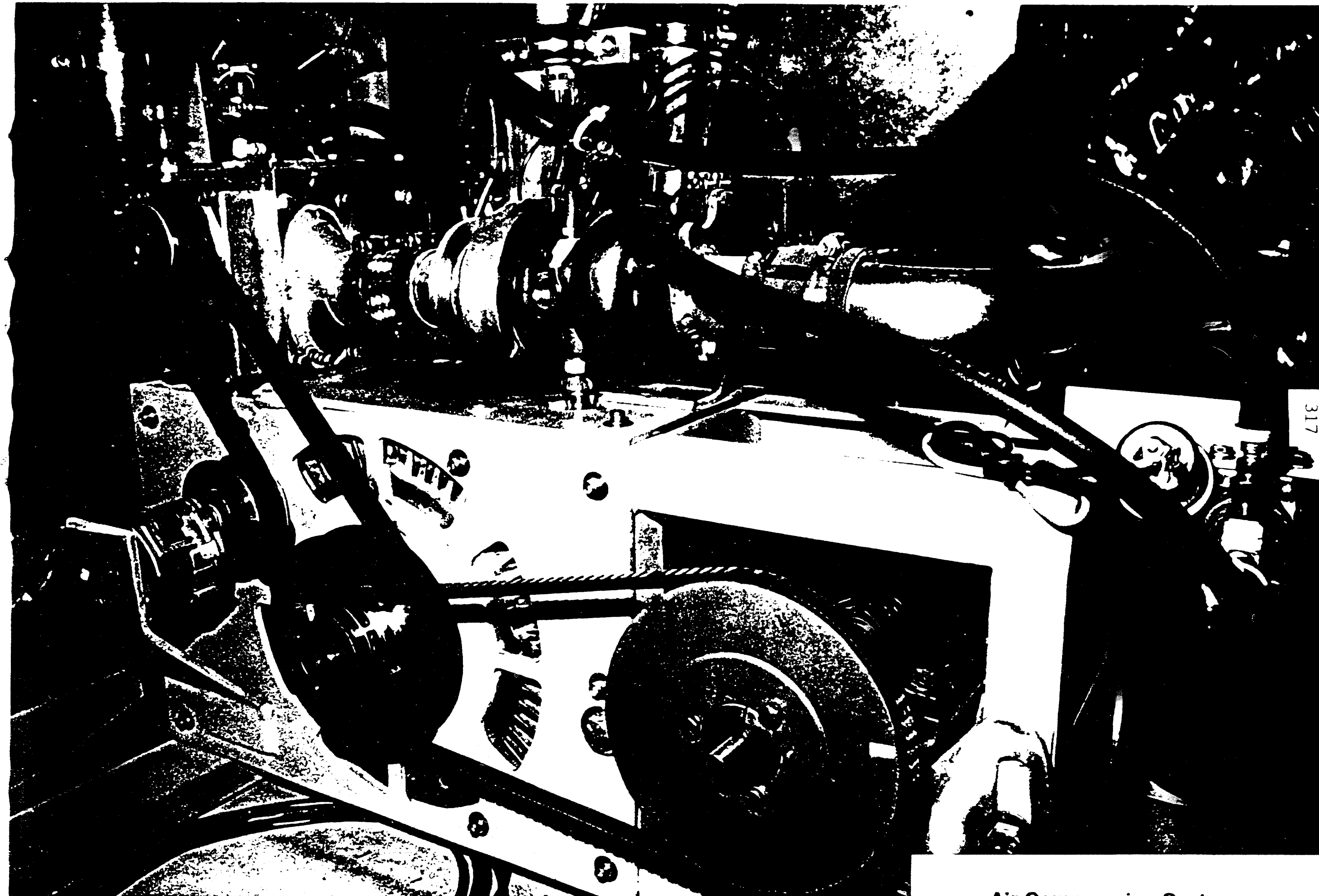
Ballard

PEM Fuel Cell Powered Transit Bus
Zero Emission Vehicle (ZEV)

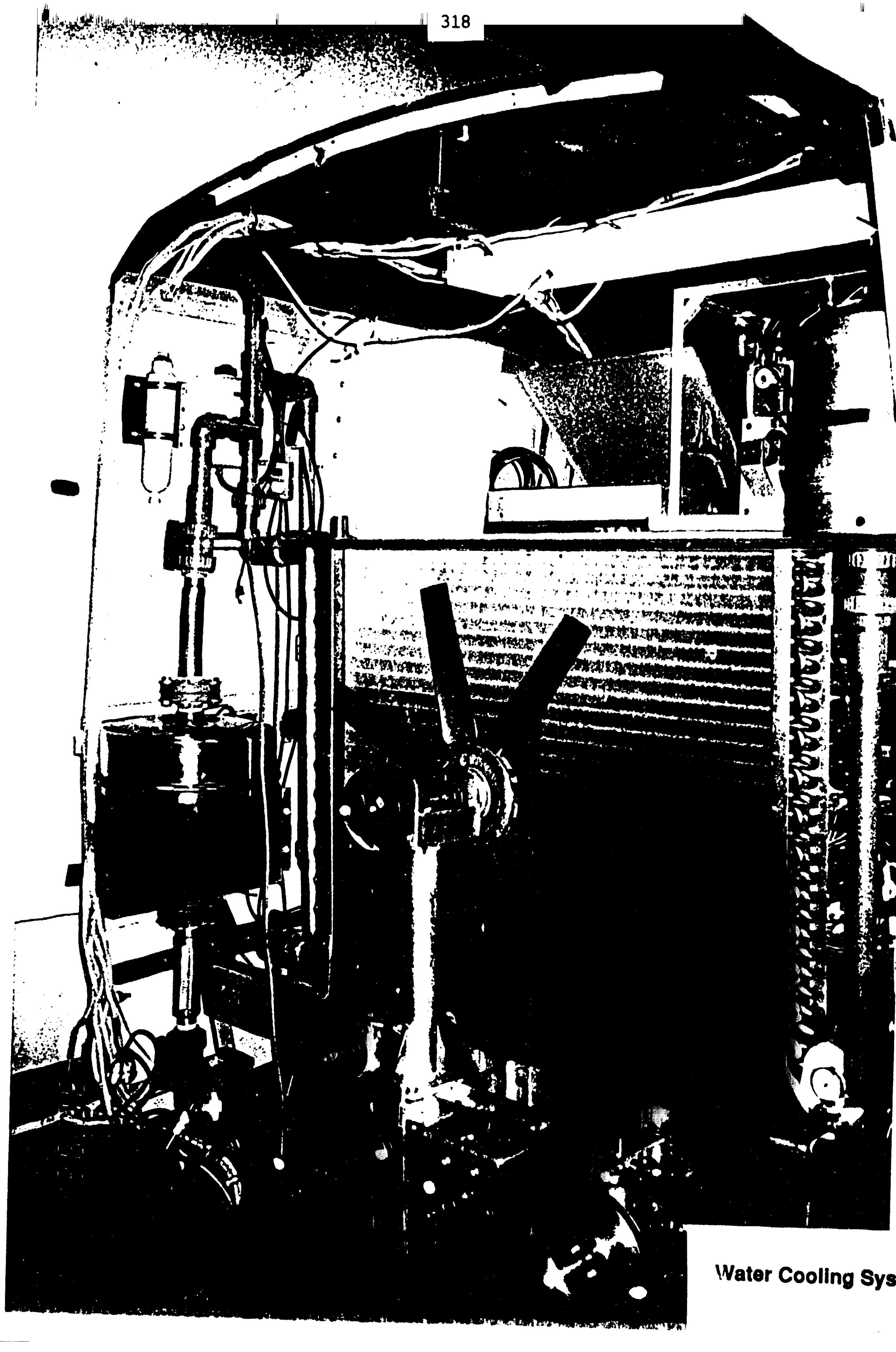
Bus Illustration



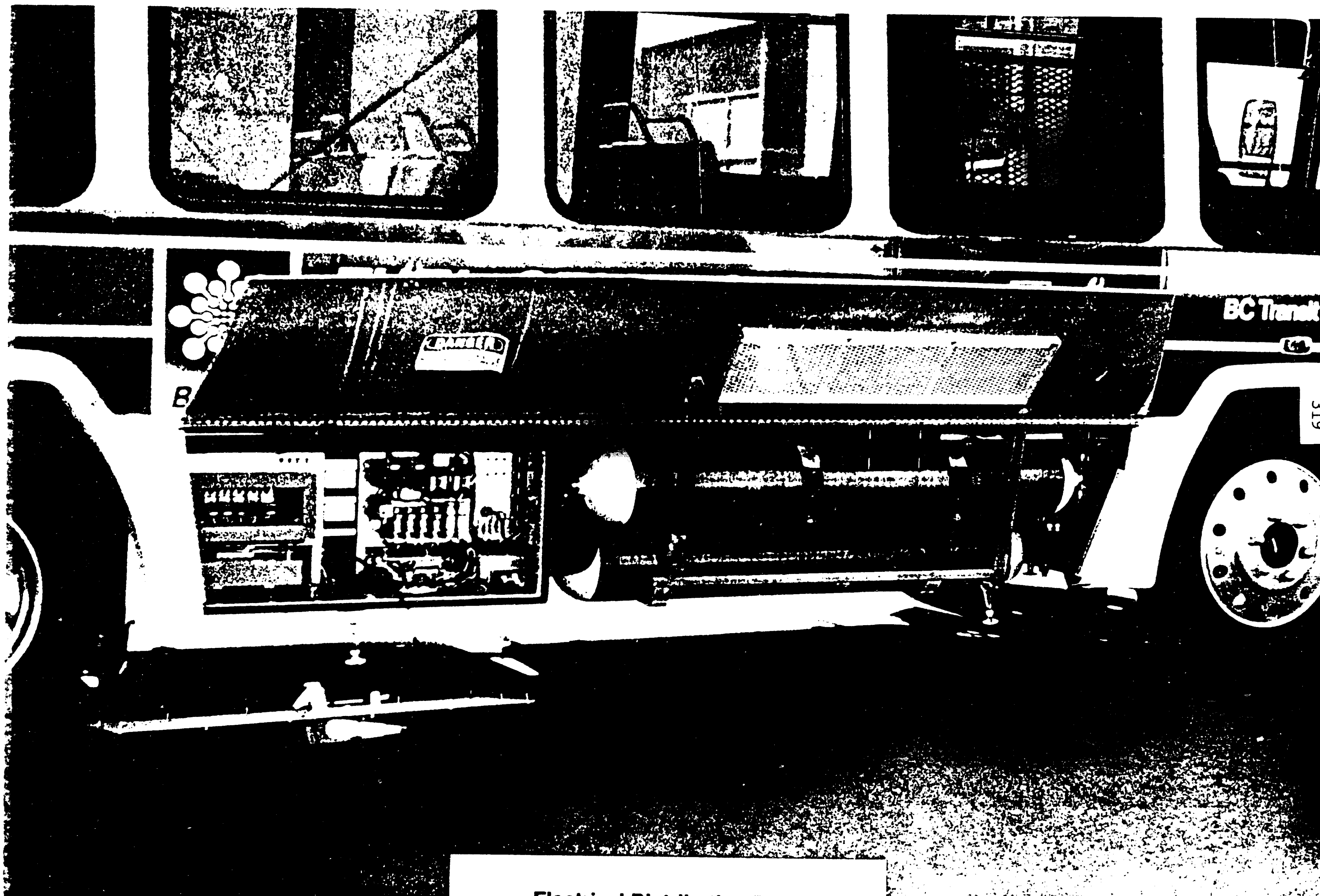
Fuel Cell Array



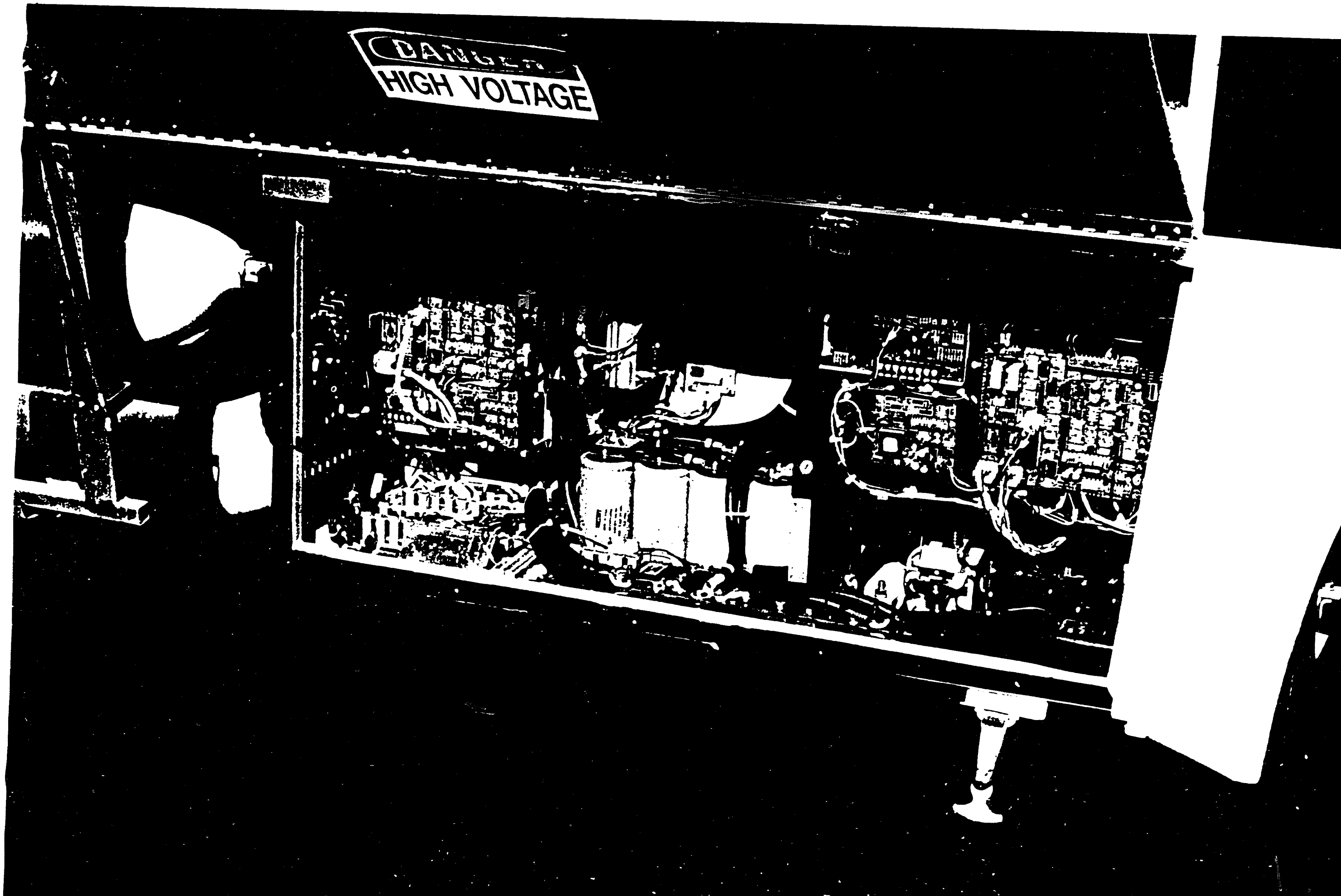
Air Compression System



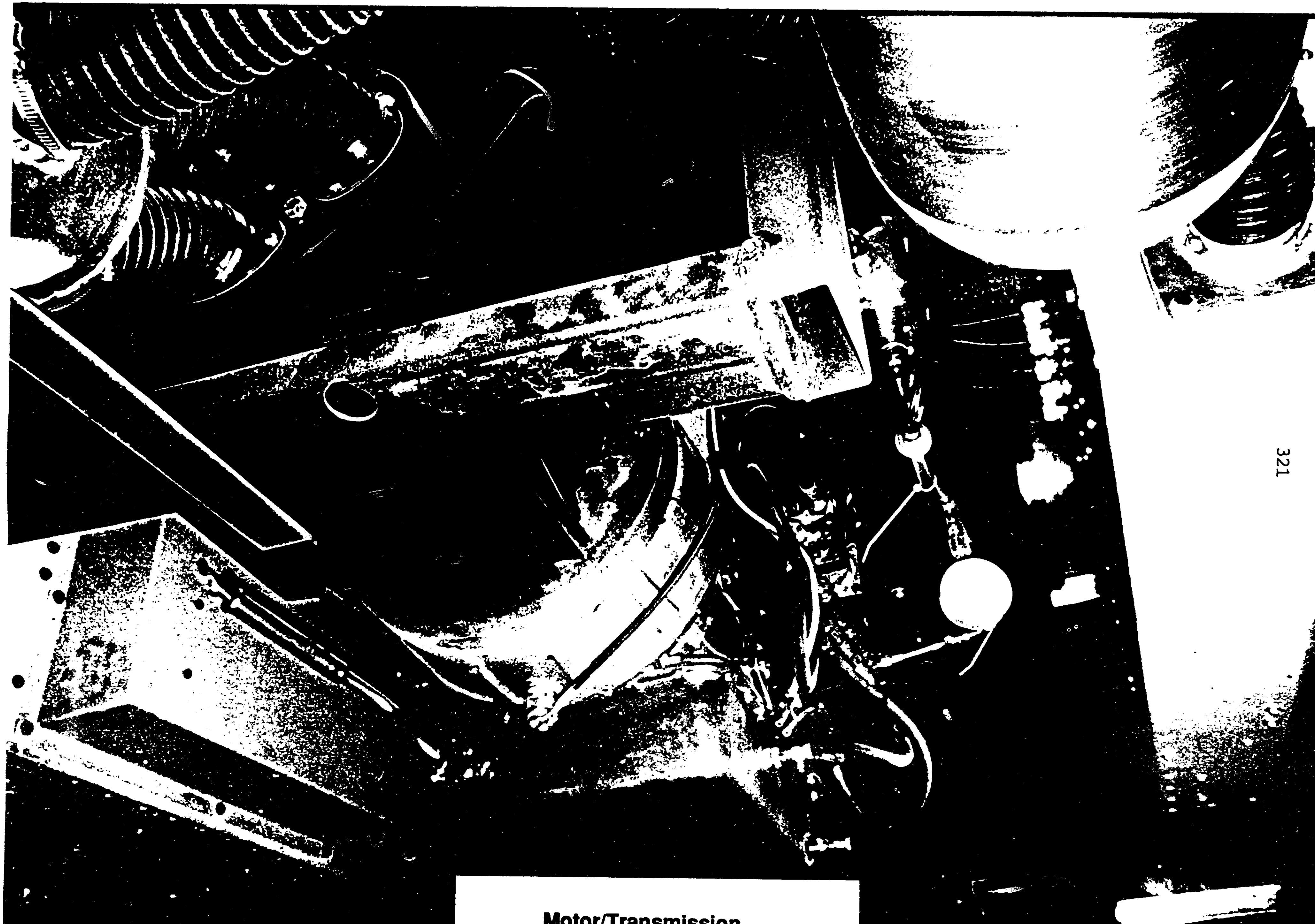
Water Cooling System



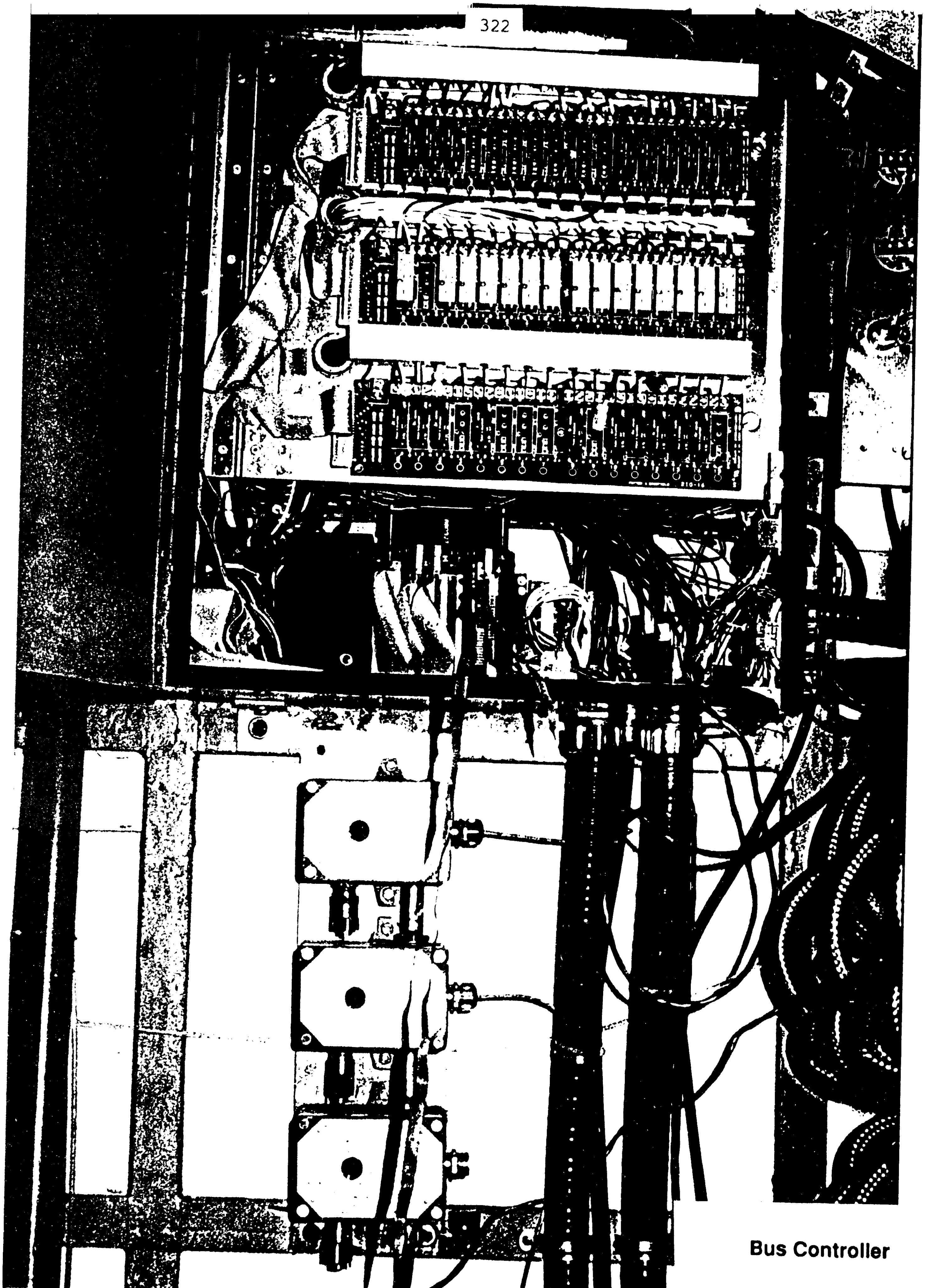
Electrical Distribution Panel



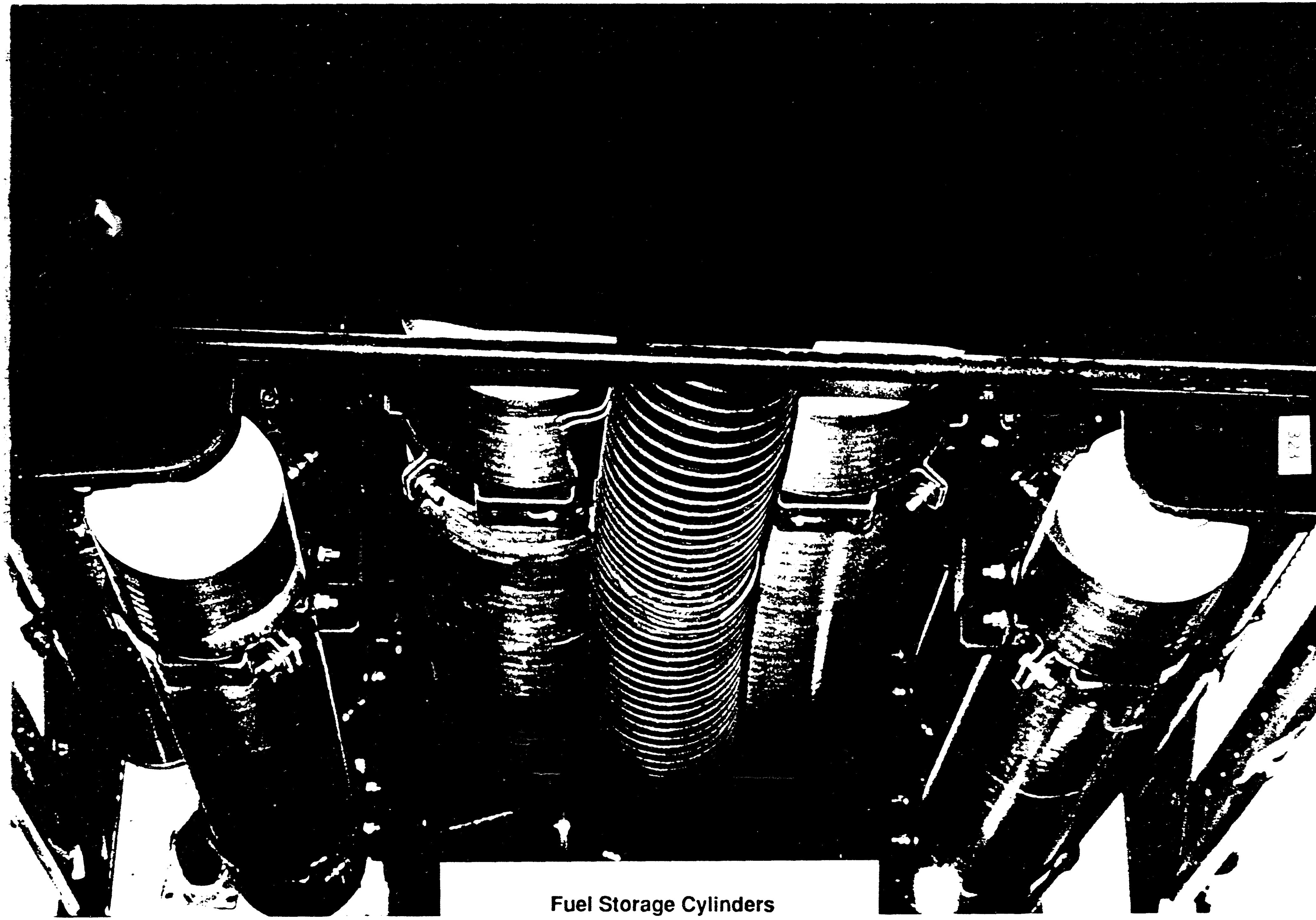
Motor Controller



Motor/Transmission



Bus Controller

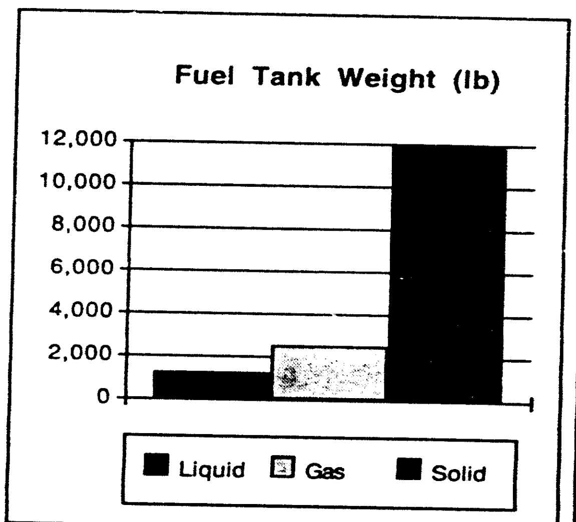


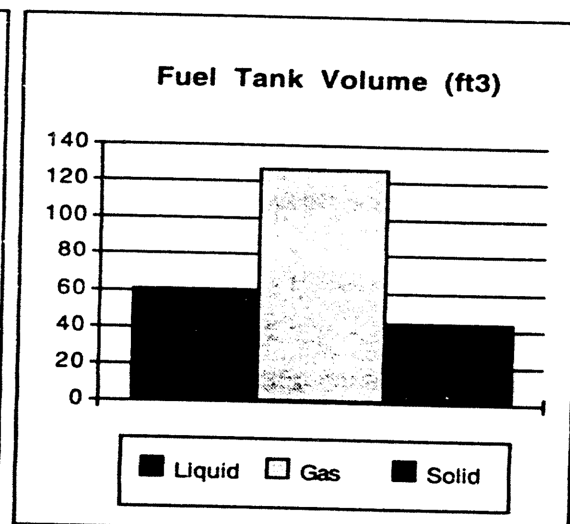
Fuel Storage Cylinders

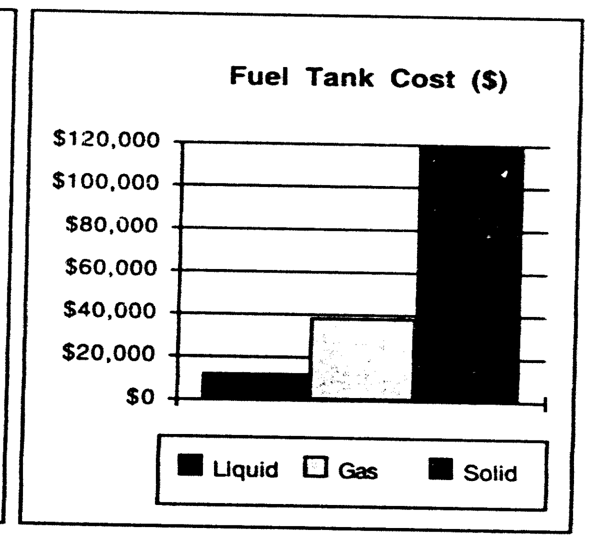
Ballard

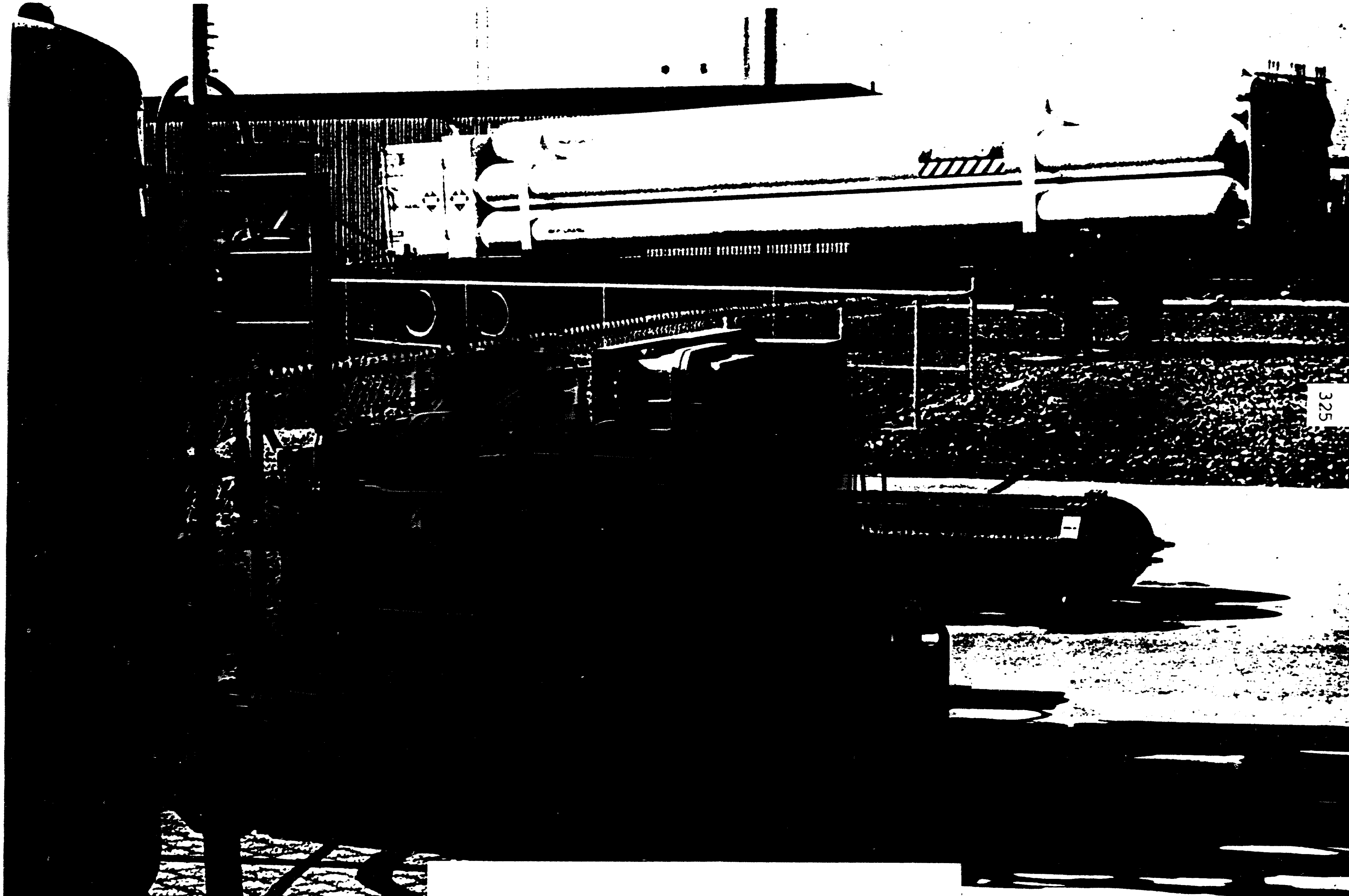
Fuel Storage/Range

- Hydrogen is Required to Meet ZEV Requirement
- Method must be Demonstratable Today — Liquid at -253°C / Gas at 5000 psi
- Bus Range of 350 miles - 180 lb/300 gallons Hydrogen









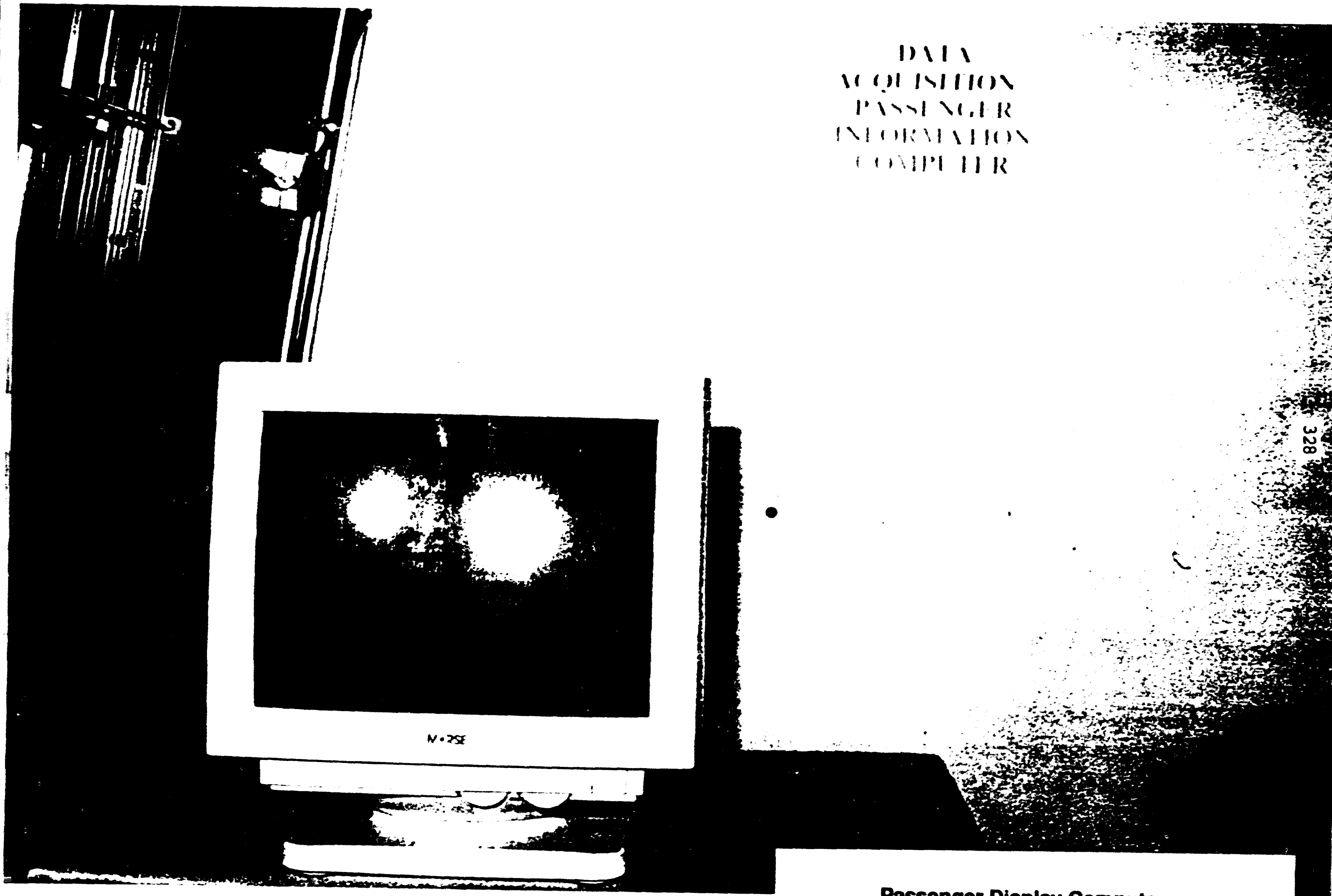
Refuelling Facility

Ballard

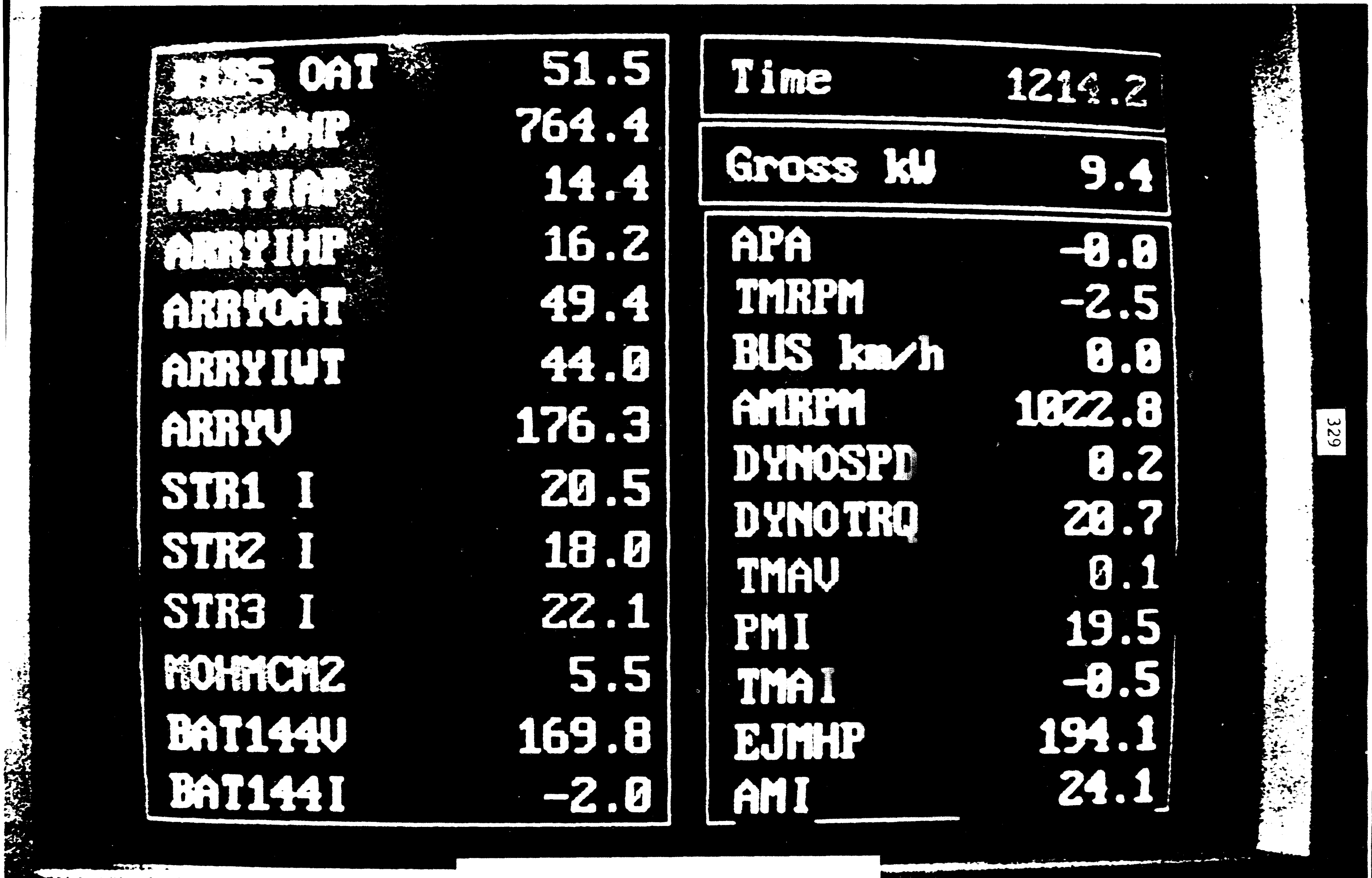
Refuelling/Cost

- Point Source Production
  - Natural Gas Reforming
  - Water Electrolysis
- Well Developed Commercial Technology - Suited for a Bus Depot
- Hydrogen Fuel Cost ~ $0.75/lb ($0.45/gallon)
- Fuel Cost/Mile - Comparable to ICE with Diesel

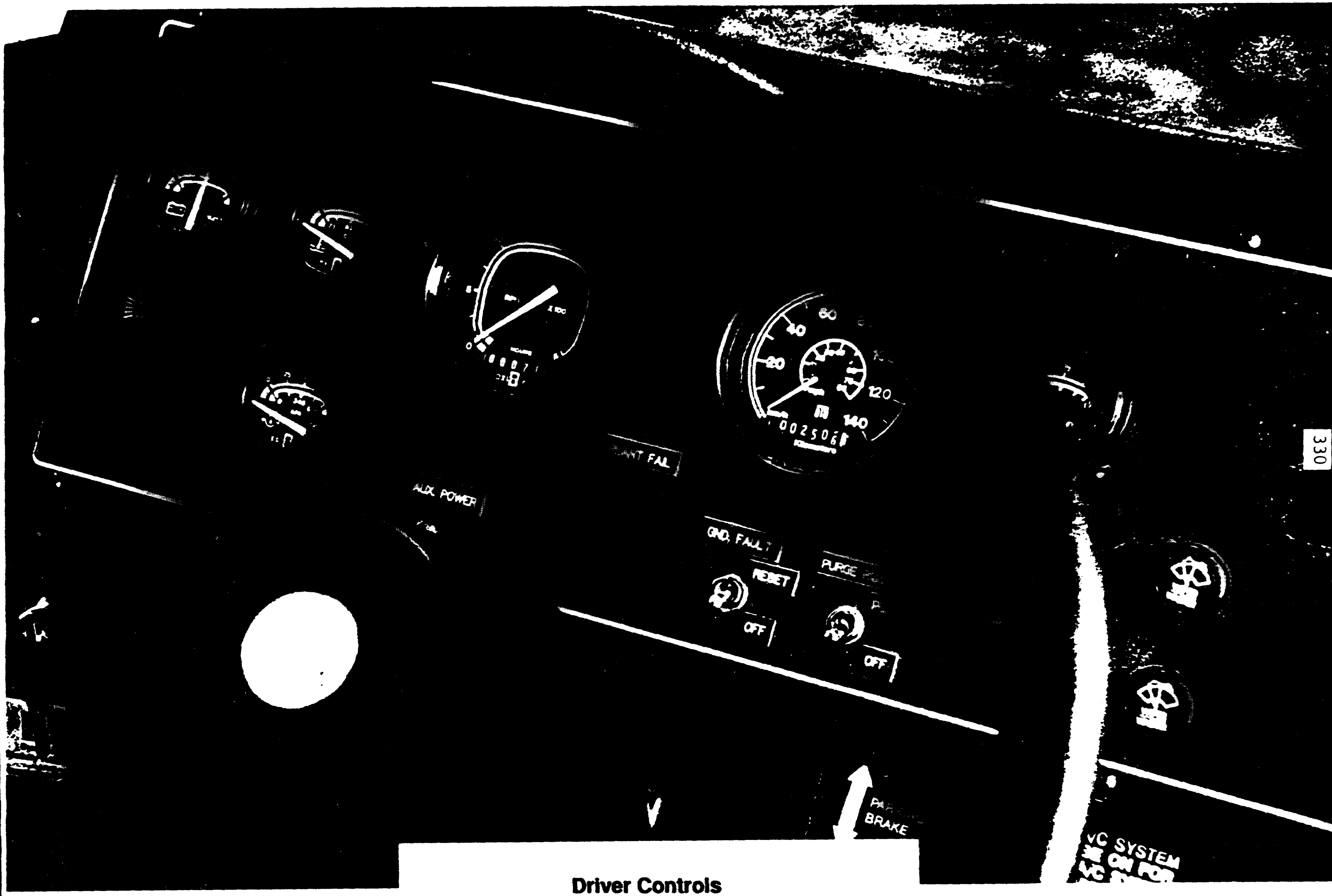
Bus Interior



Passenger Display Computer



Display Information



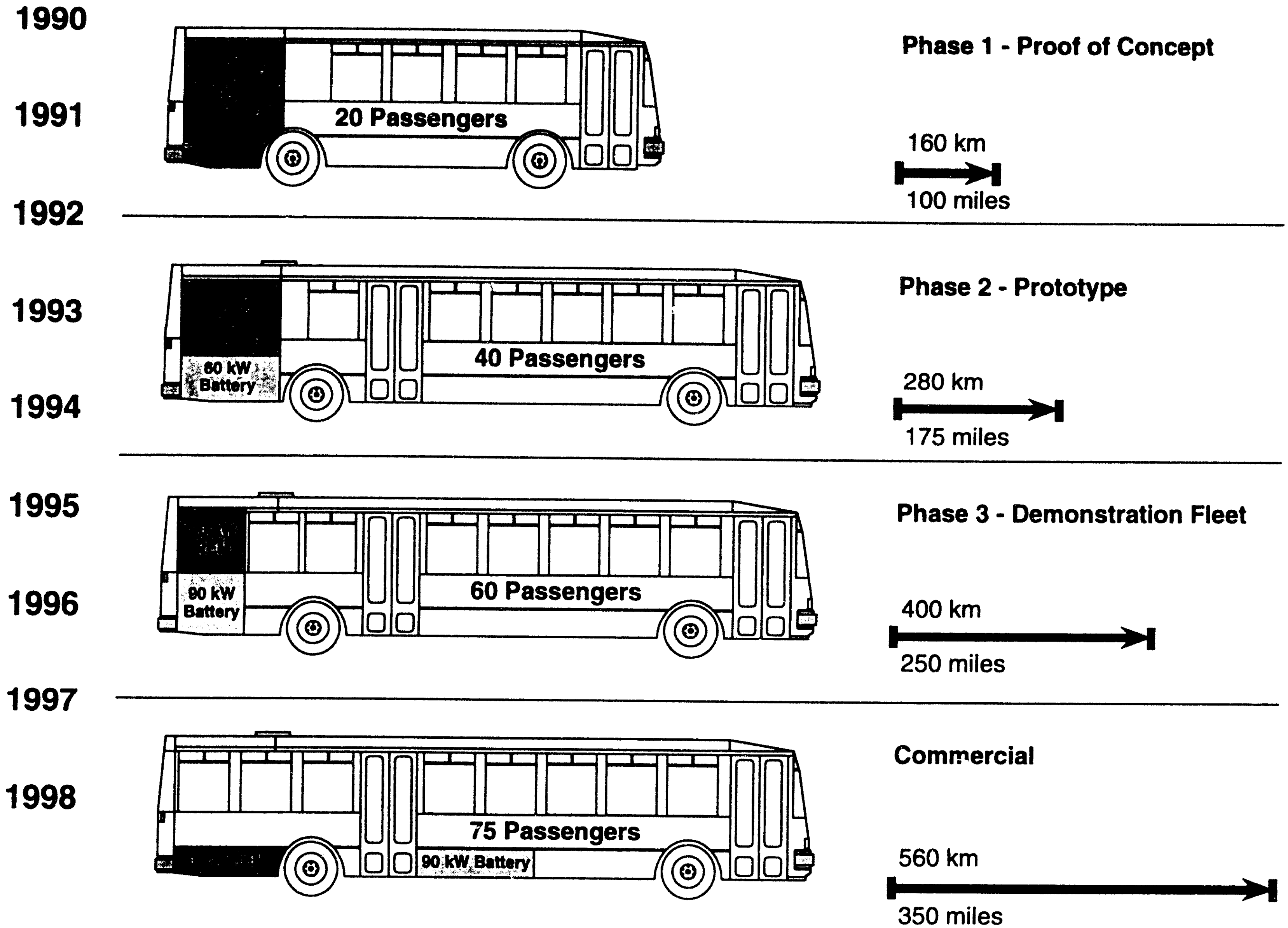
Driver Controls

Complete Bus/Wheelchair Lift

Ballard

Demonstration Program - Achievements

- Startup — Instantaneous - 4 seconds
- Dynamic Response —
  - Accelerator Command
  - Rapid Response < 0.1 second
  - Simulated Routes
- Full Power (Air) —
  - Highest Power - 120 kW
  - Highest Voltage - 280 Vdc
  - Largest System - 24 stacks
- Efficiency — 47%
- Bus Works



Commercialization Plan

Ballard

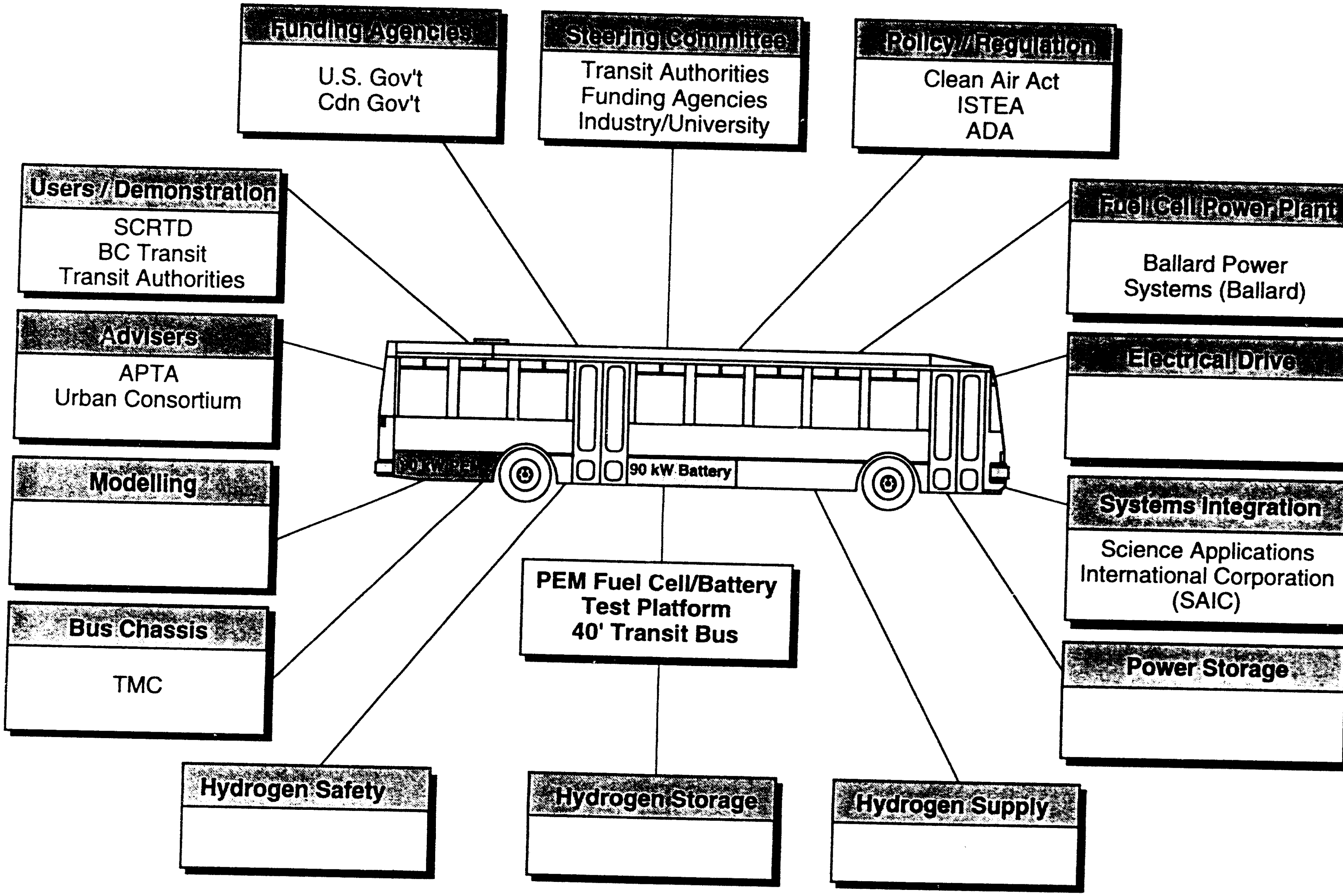
Phase 2 - Commercial Prototype - Scope

- 40′ ZEV PEM Fuel Cell / Electric Transit Bus — Design/Fabricate/Test; Demonstrate
- 32′ ZEV PEM Fuel Cell / Electric Bus — Evaluation/Reliability Testing; Showcase in Various Cities
- April 1993 to September 1995 - 30 Months
- $6 Million Funding Assistance

Ballard

Phase 2 - Commercial Prototype - Technical Approach

- Ruggedize / Repackage PEM Fuel Cell Power Plant
  - Air Compression
  - Cooling System
  - Control System
- Add Battery Hybrid / Regeneration - 240 HP (180 kW)
- 40′ Transit Duty Bus
  - Improved Electric Propulsion
  - Fuel Storage Integration
  - Air Conditioning



Alliance Structure

Benefits

- Economically Efficient
- Environmentally Sound
- Competes in Global Economy
- Air Quality Goals - No Pollutants
- Energy Security Goals
- Economic Growth - Emerging $1 billion Market

Acknowledgements

- Energy, Mines and Resources Canada / CANMET
- British Columbia Ministry of Energy
- British Columbia Ministry of Advanced Education
- BC Transit

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

BALLARD FUEL CELL POWERED ZERO EMISSION BUS
Paul Howard, Ballard Power Systems, Inc.

Q. Rodica Baranescu, Navistar International: Is there a concern abut hydrogen diffusion and embrittlement?

A. Yes, we are aware of the hydrogen purge and are working with others on the problem.

Q. Anthony Bobelis, Brooklyn Union Gas Co.: I understand that fuel cells are sensitive to CO in the air. How do you purify the air?

A. That is one of our concerns. We plan to convert the carbon monoxide to carbon dioxide, and we have technology to remove the carbon dioxide. There is a lot to learn about the effect of contaminants.

Q. Mostafa Kamel, Cummins Engine Co.: What other fuels could be used in the fuel cell?

A. We have considered methanol and natural gas which are being used in two other programs being developed.

Q. What is the top gas temperature?

A. The fuel cell operates on 160 to 180° F.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

DESIGN OPTIONS FOR HYBRID-ELECTRIC VEHICLES USING ULTRACAPACITORS

A. Burke
INEL Battery Laboratory, EG&G Idaho Inc.

Idaho
National
Engineering
Laboratory

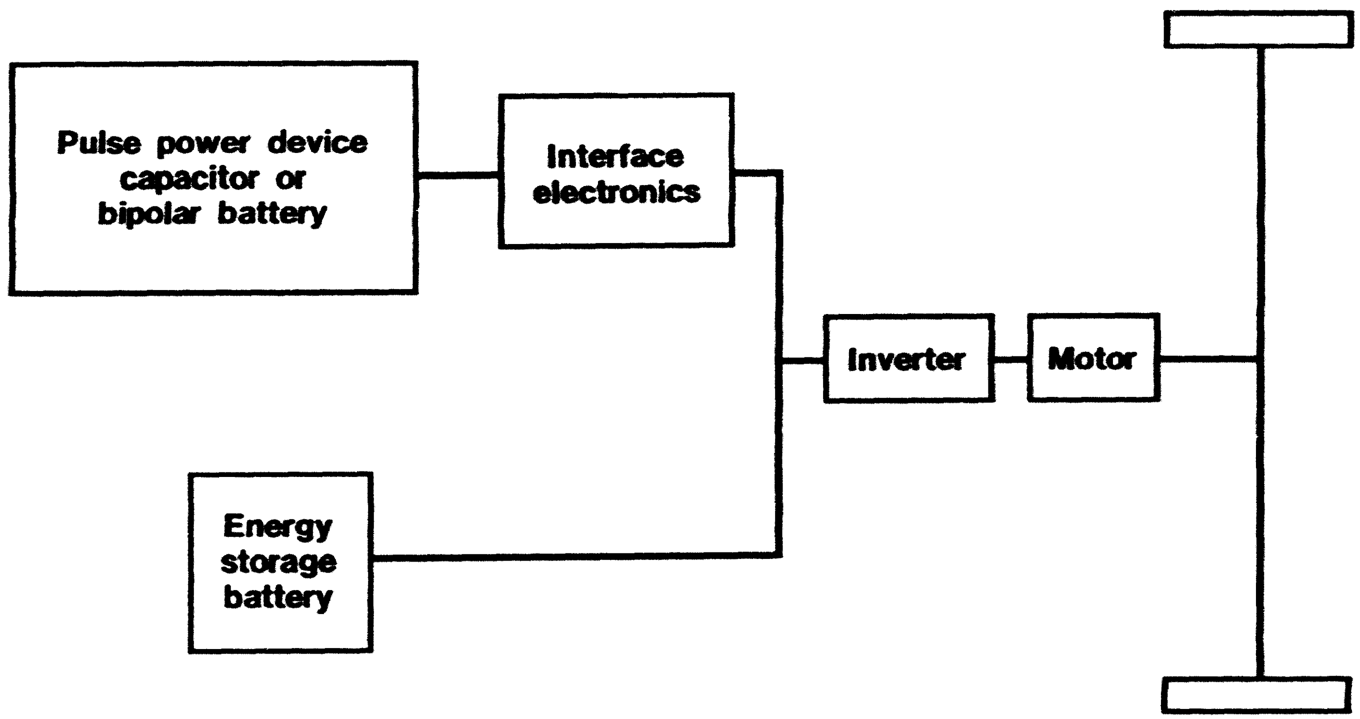
DESIGN OPTIONS FOR HYBRID-ELECTRIC VEHICLES USING ULTRACAPACITORS

Andrew F. Burke
INEL Battery Laboratory
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

1993 Windsor Workshop on Alternative Fuels
Toronto, Canada
June 14-16, 1993

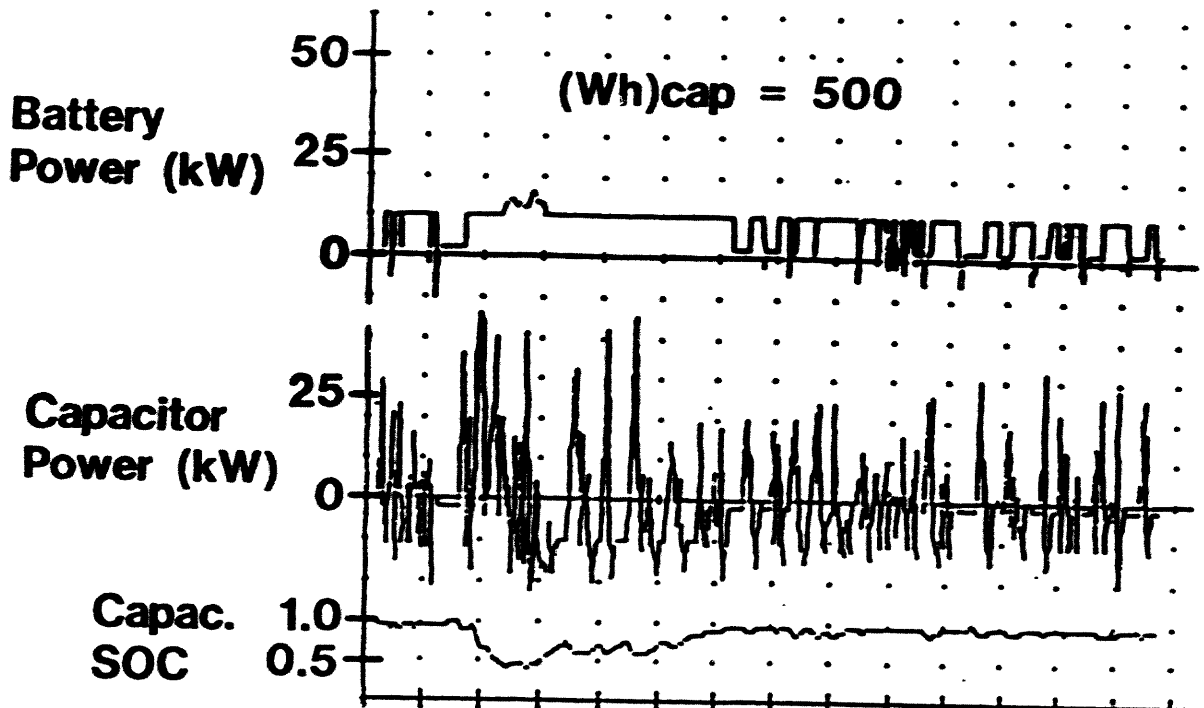
Work supported by the U.S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy (CE)
Under DOE Idaho Operations Office Contract DE-AC07-76ID01570

Schematic of an Electric Vehicle Propulsion System, Including Battery Load Leveling



A91 2942

Load-Leveled Battery Discharge on the FUDS Cycle



1-0357

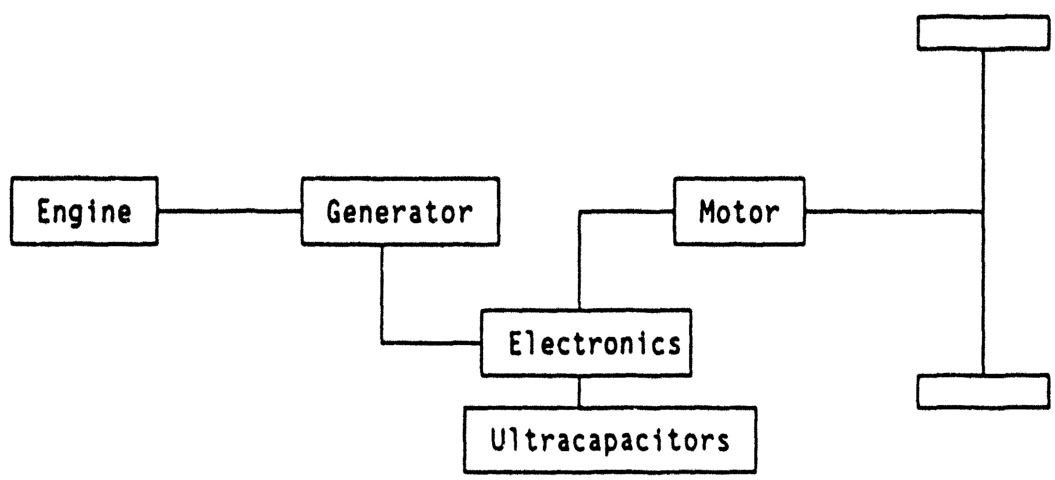


Figure 8. Engine-electric driveline schematic using ultracapacitors.

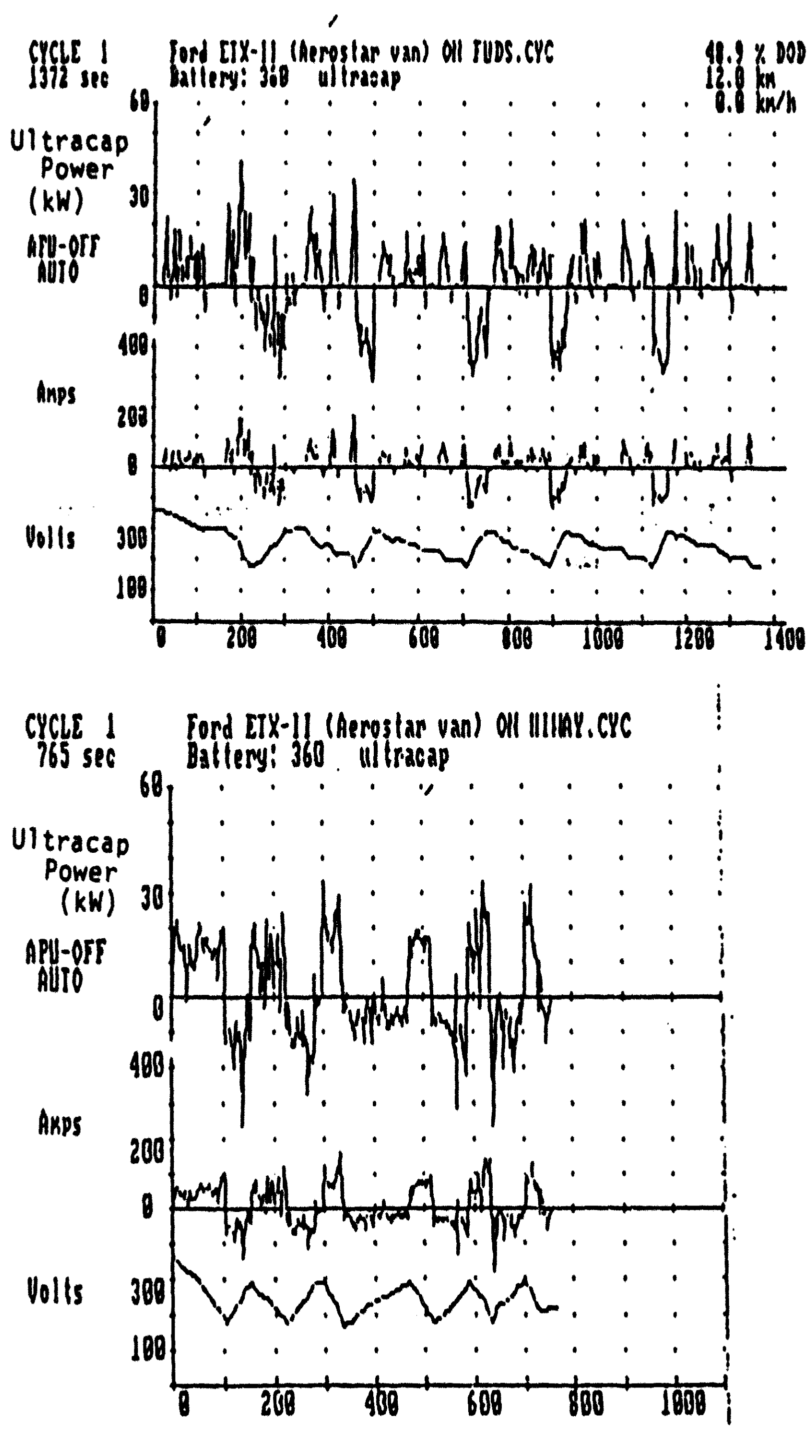


Figure 9. Ultracapacitor charge/discharge on the FUDS and FHWC cycles wth an APU.

Table 6. Series hybrid electric range, fuel economy, and acceleration characteristics.

Vehicle Type	Electric				Series Hybrid				Acceleration Times (sec)	
	FUDS		FHWC		FUDS		FHWC			
	Wh/km	Range[1] (km)	Wh/km	Range (km)	mpg[2]	Effic. (%)[3]	mpg	Effic. (%)	0-48 km/h	0-80 km/h
Minivan	185	93	188	86	26.1	0.85	26.4	0.88	4.7	12.1
Microvan	136	96	132	93	35.6	0.85	37.5	0.88	4.7	12.5
Compact Car	116	99	103	107	41.9	0.86	47.8	0.87	4.3	11.0
(1) Useable range to DOD = 80%										
(2) Gasoline fuel and min bsfc = 300 gm/kWh										
(3) Average efficiency from engine output to inverter input										

Table 7. Engine-electric vehicle characteristics using ultracapacitors.

Vehicle				Motor/Generator			Ultracapacitors		
Type	Weight (kg)	C_DA (m^2)	fr (%)	Motor (kW)	Generator (kW)	Weight (kg)	Wh	(Wh/kg)	Max Power (kW)
Minivan	1501	1.16	0.85	56	25	85	500	5.9	60
Microvan	1200	0.759	0.85	37.5	20	68	400	5.9	46
Compact Car	1150	0.495	0.85	37.5	20	68	400	5.9	42

Table 8. Fuel economy of the engine-electric vehicles using ultracapacitors.

Vehicle Type	Fuel Economy (mpg)			
	FUDS		FHWC	
	Engine-Electric	Conventional ICE [1]	Engine-Electric	Conventional ICE
Minivan	33.1	18	30.5	22
Microvan	45.3	---	44.3	---
Compact Car	51.5	27	56.1	36
(1) 1992 EPA fuel economy rating for cars in this class				

SAE TECHNICAL
PAPER SERIES

930042

On-Off Engine Operation for Hybrid/Electric Vehicles

A. F. Burke
EG & G Idaho, Inc.

**Reprinted from:
Electric and Hybrid Vehicle Advancements
(SP-969)**

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL

International Congress and Exposition
Detroit, Michigan
March 1-5, 1993

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (412)776-4841 Fax:(412)776-5760

920447

Hybrid/Electric Vehicle Design Options and Evaluations

A.F. Burke
EG&G Idaho, Inc.

ABSTRACT

Various aspects of the design and evaluation of hybrid/electric vehicles are considered with emphasis on the consequences of utilizing advanced electric driveline components such as AC motors/electronics and ultracapacitors. Special attention is given to series hybrid drivelines, because they benefit much more directly than parallel hybrid drivelines from the recent large improvements in the specific weight and volume of electric drive motors/electronics. The results of the present study indicate that series hybrid vehicles with an electric range of 90-100 km and good acceleration performance (0-88 km/h acceleration times of less than 12 seconds) can be designed with a powertrain weight and volume comparable to that of a parallel hybrid of the same performance. The driveline efficiencies of the series and parallel designs for both city and highway driving differ by less than 15 percentage ponts. The control of the series hybrid driveline is expected to be significantly simpler than that of the parallel hybrid system and in addition, meeting the California ULEV emission standards should be less difficult for the series hybrid design, because the start of its engine can be delayed until the catalyst is warm without affecting vehicle driveability.

Simulation results for series hybrid vehicles on the FUDS and the Federal Highway cycles indicate that their fuel economy (miles per gallon) operating in the hybrid mode will be 25-50% greater than conventional ICE vehicles of comparable interior size. Hybrid/electric vehicles using ultracapacitors to load level the engine in the driveline showed even a greater potential improvement in fuel economy. Load leveled operation of the engine may make it less difficult to use high specific power engines, such as two-stroke and gas-turbine engines, in light duty vehicles having stringent emission control requirements.

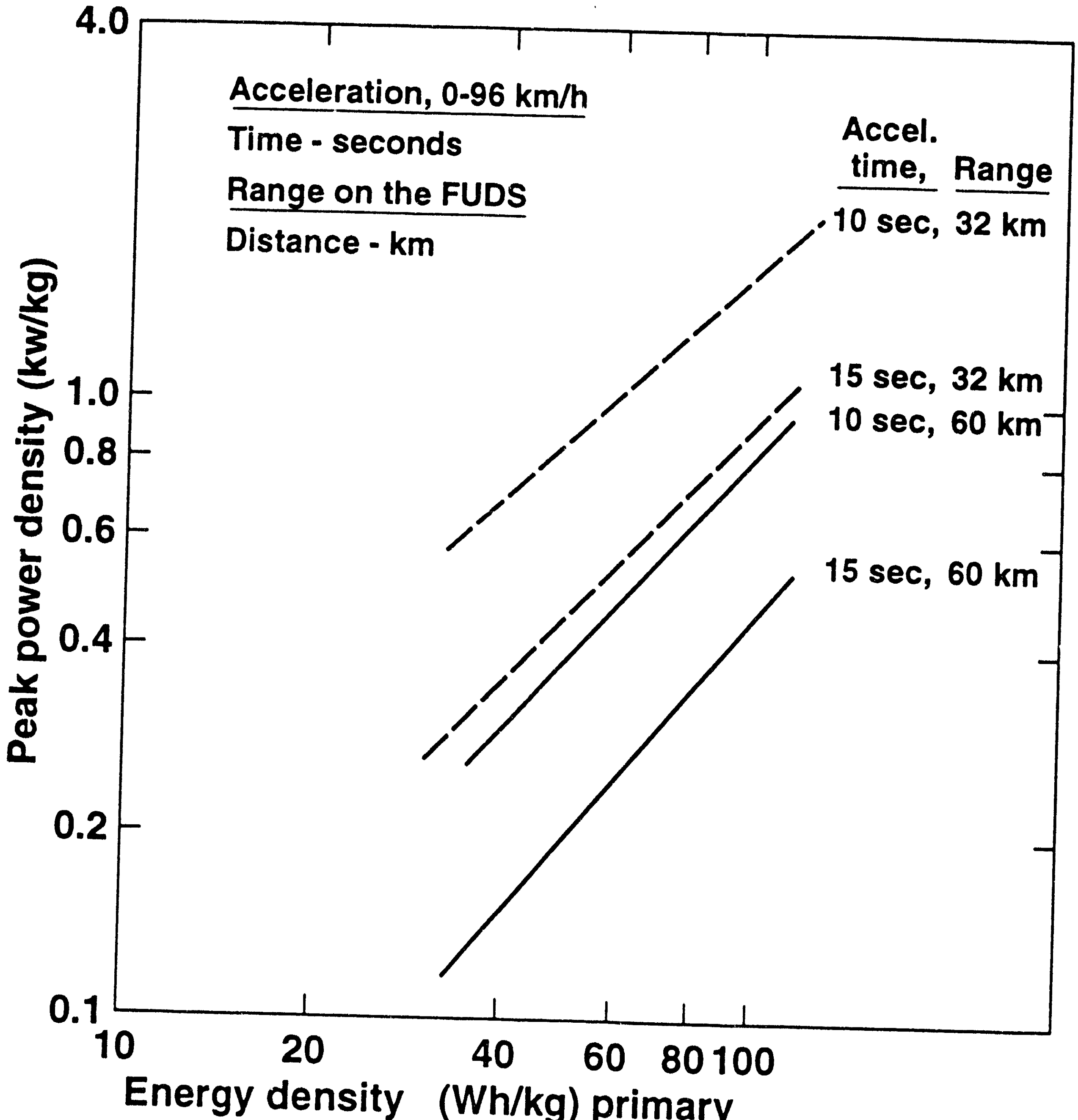
Work supported by the U.S. Department of Energy Assistant Secretary for Conservation and Renewable Energy (CE), under DOE Idaho Field Office, Contract DE-AC07-76ID01570.

INTRODUCTION

Hybrid/electric vehicles, which utilize both an electric driveline and an engine to provide the power and energy for propulsion, have been studied for the last 20 years. Hybrid propulsion systems are used primarily to overcome the range limitation of pure electric vehicles powered by batteries alone. A number of hybrid vehicles have been built and tested to demonstrate the viability of various hybrid powertrain approaches. Much of the engineering activity on hybrid vehicles occurred between 1978 and 1984 as part of the response of the United States to the oil crises of 1973 and 1979.

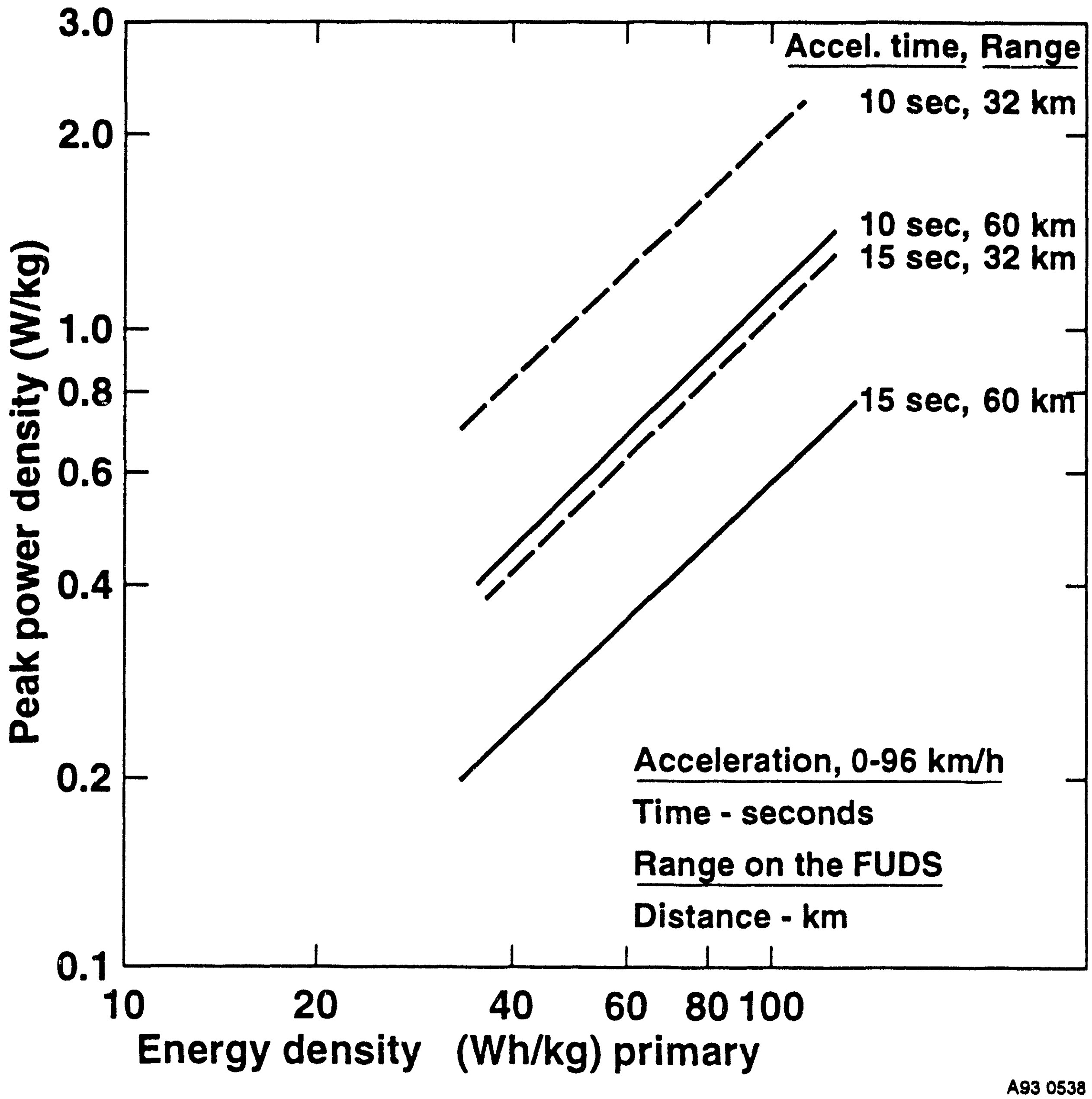
In recent years, interest in hybrid vehicles has been relatively low and most of the work on vehicles using electri

Peak Power Density Requirements for the Primary Energy Storage Unit in a Compact Car Without a Pulse Power Unit

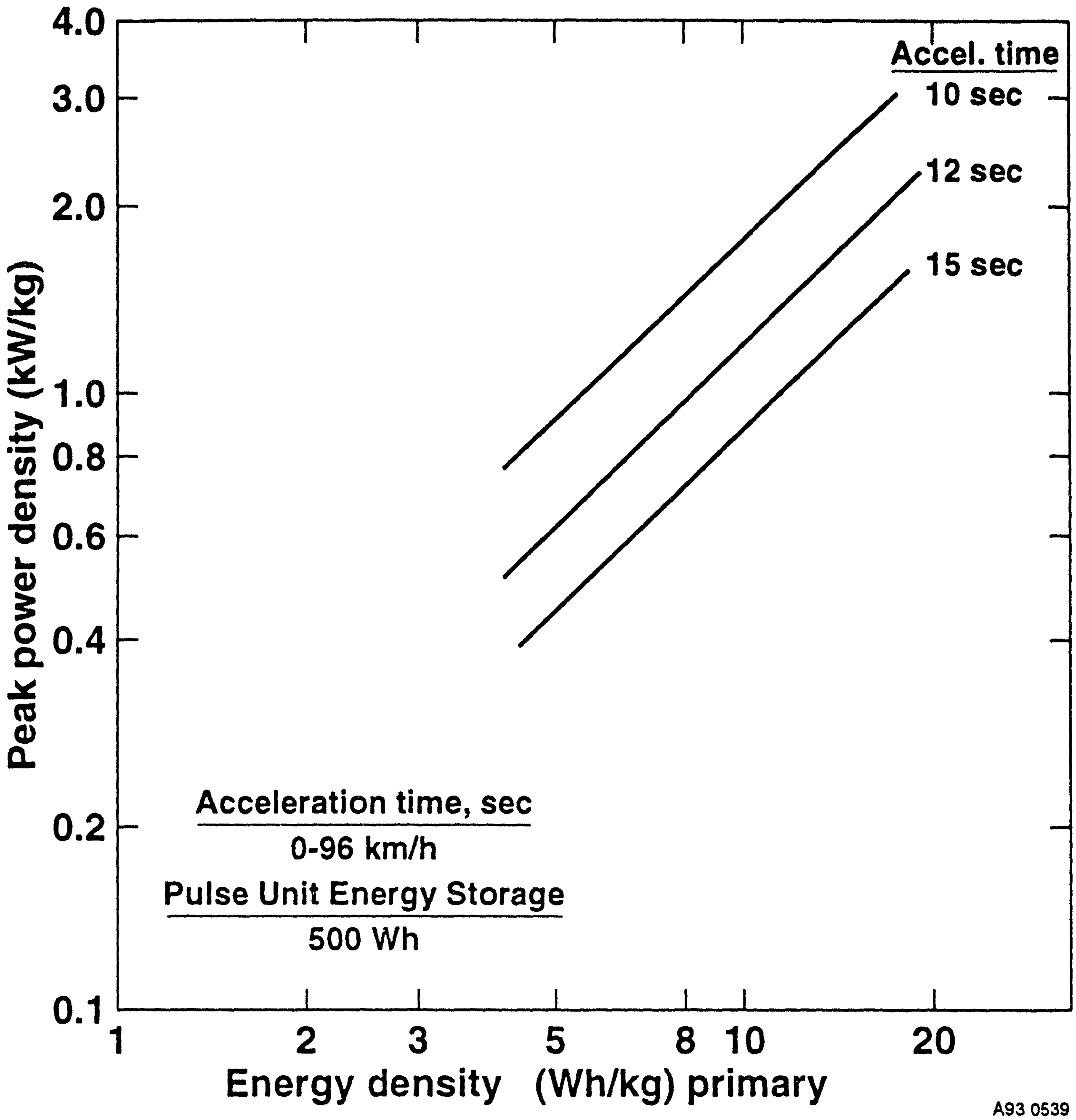


A93 0537

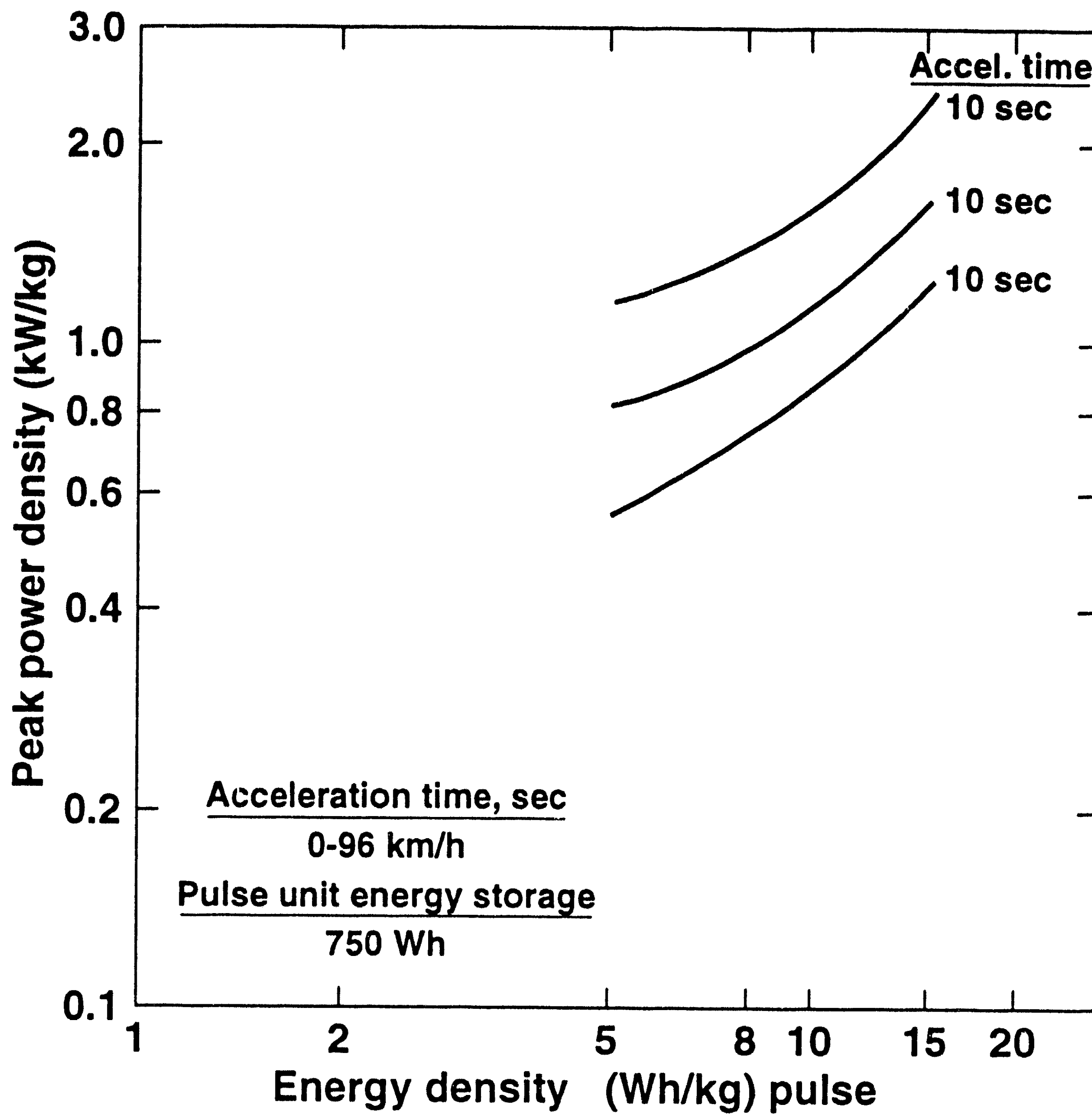
Peak Power Requirements for the Primary Energy Storage Unit on a Minivan Without a Pulse Power Unit



Peak Power Density Requirement for a Pulse Power Unit in a Compact Car

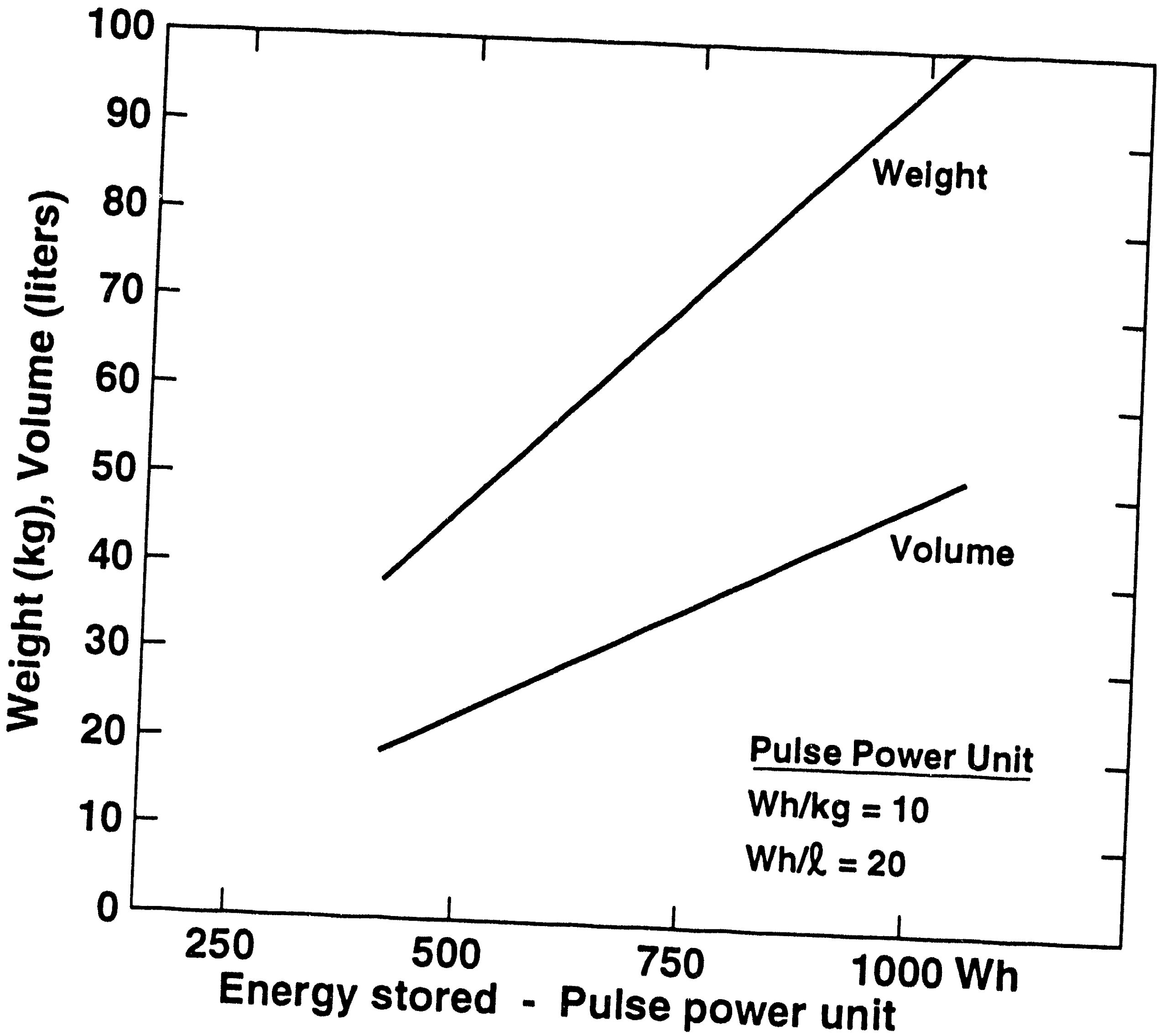


Peak Power Density Requirement for a Pulse Power Unit in a Minivan



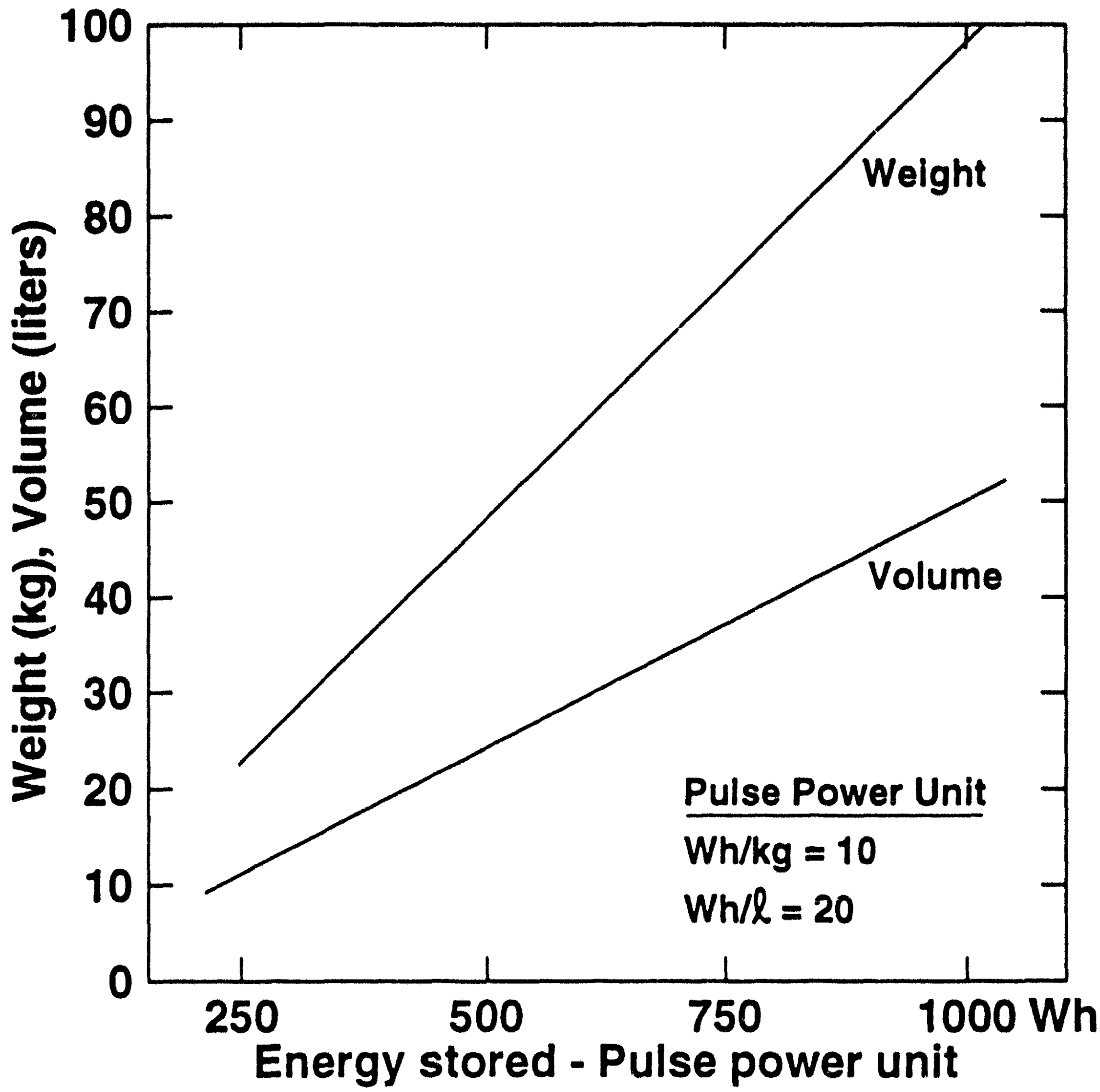
A93 0540

Weight and Volume of the Pulse Power Unit for Different Energy Storage Capacity (Wh) for a Minivan



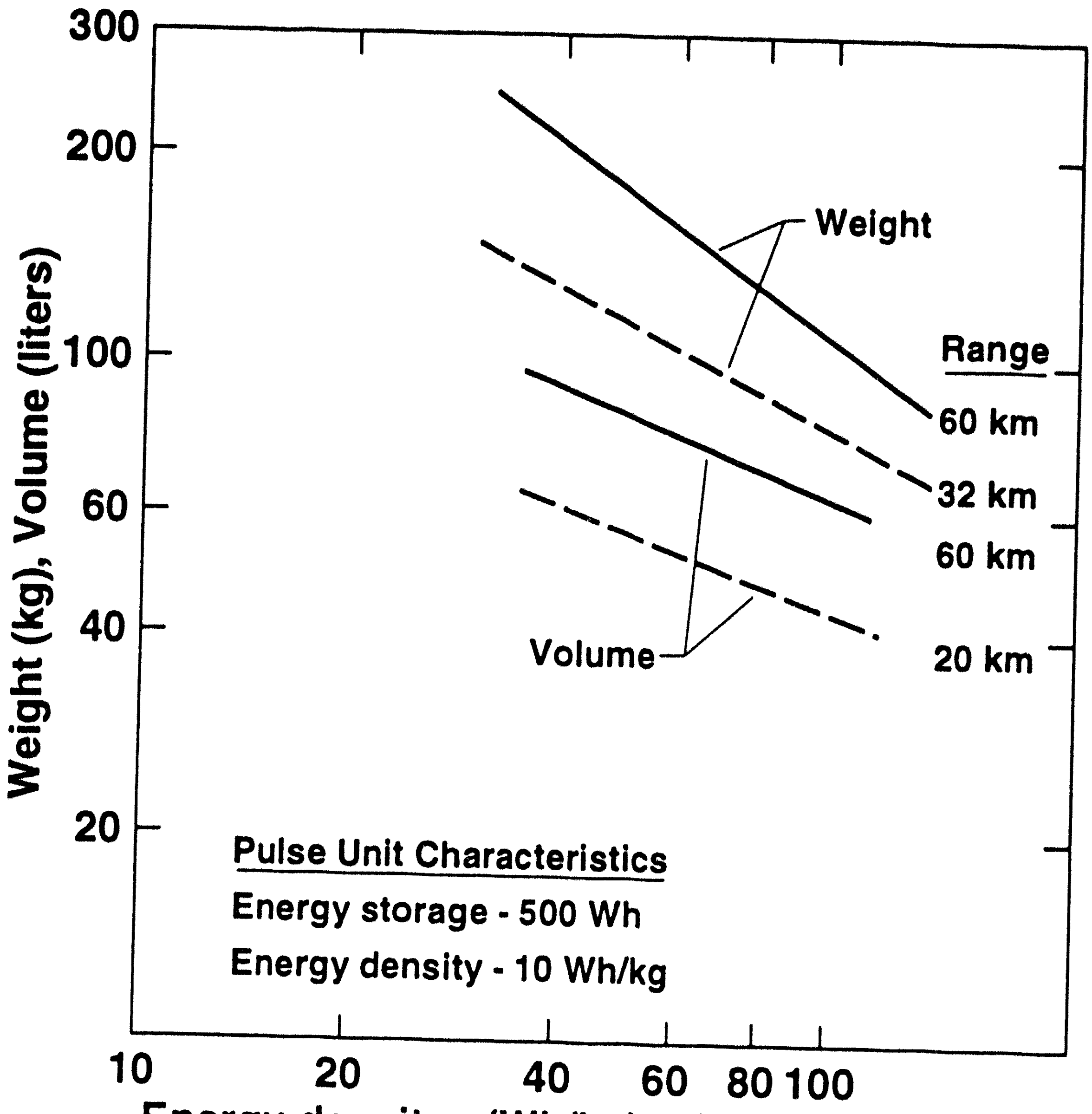
A93 0543

Weight and Volume of the Pulse Power Unit for Different Energy Storage Capacity (Wh) for a Compact Car



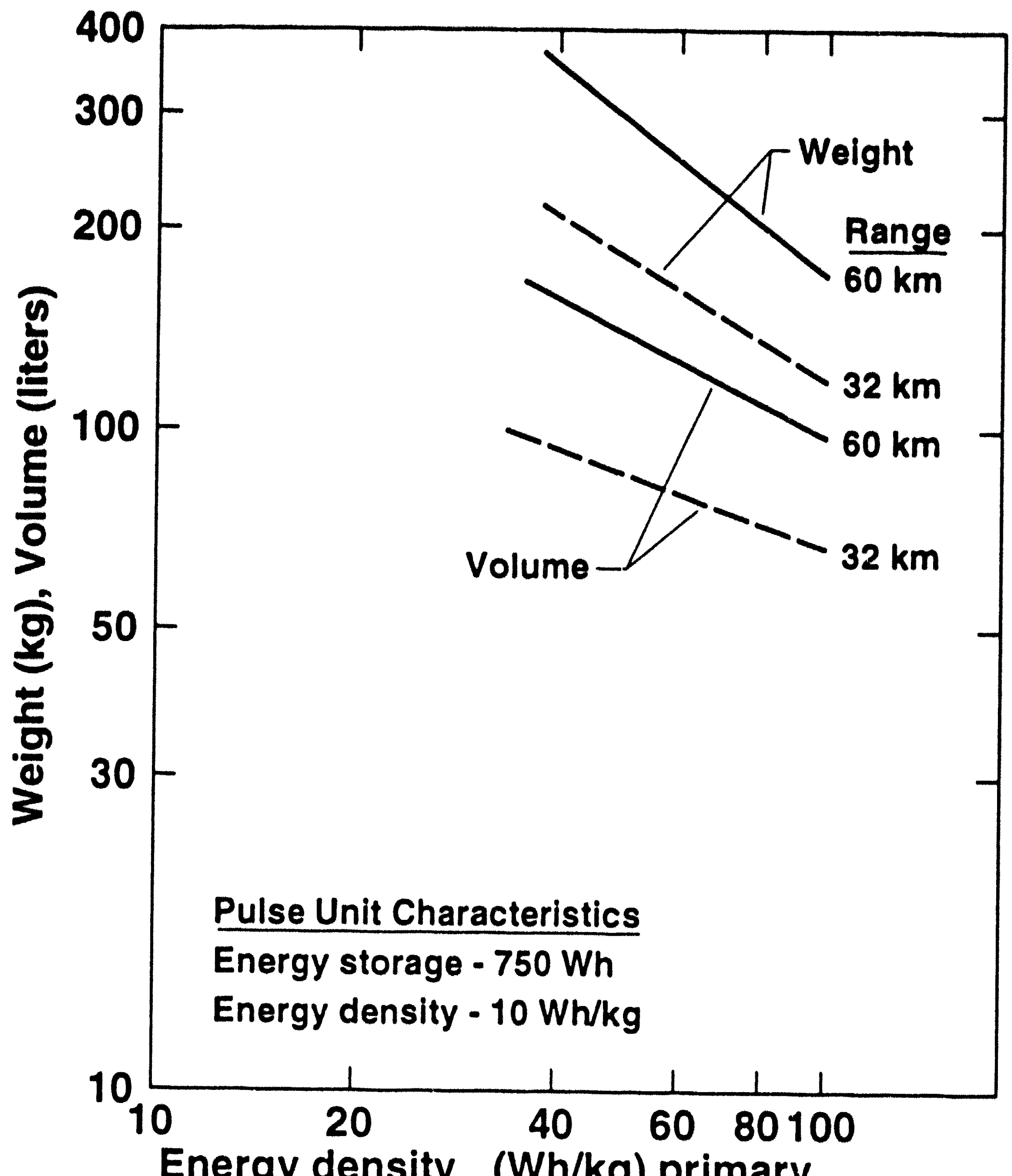
A93 0544

Energy Storage System Weight and Volume for a Compact Car



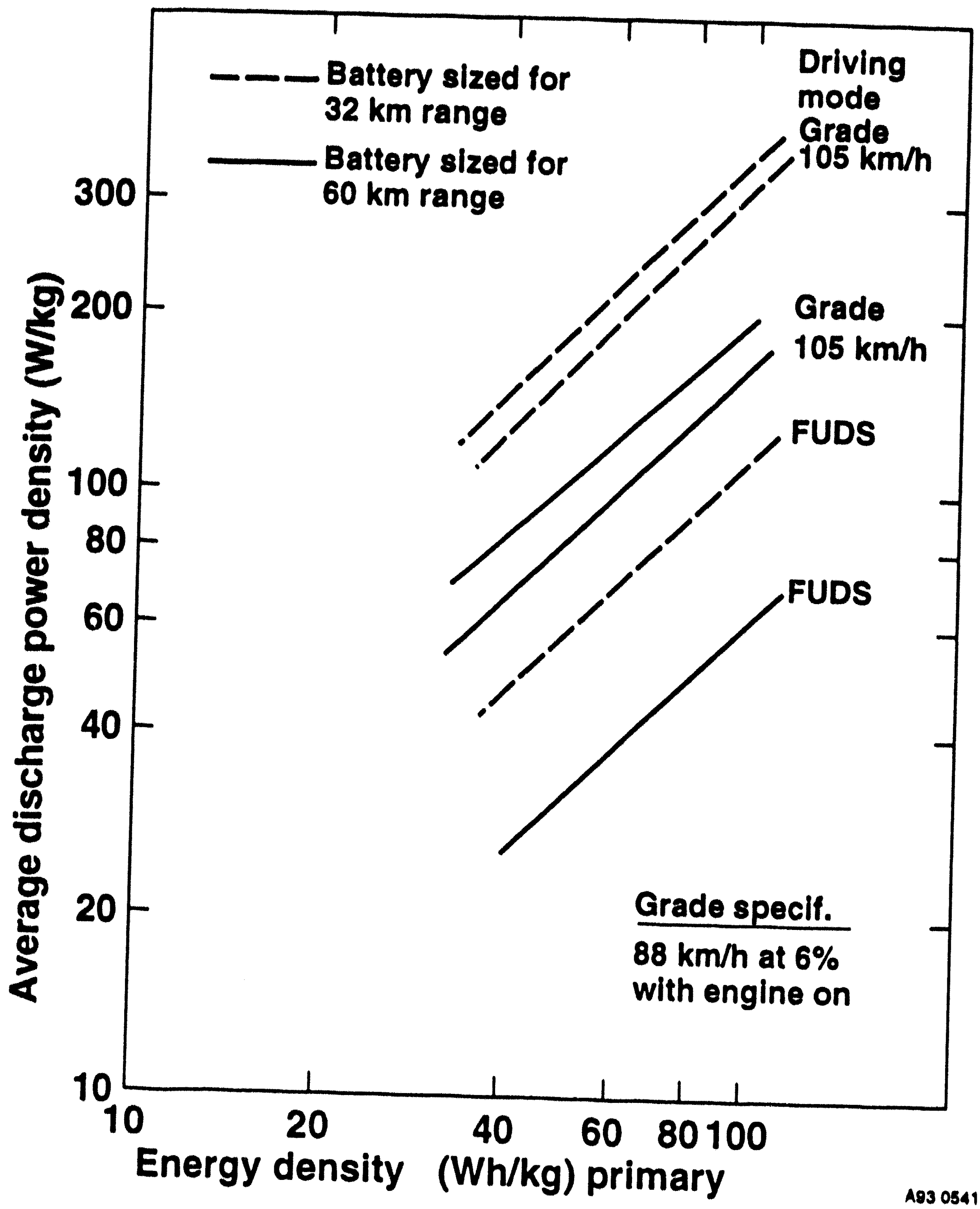
A93 0536

Energy Storage System Weight and Volume for a Minivan



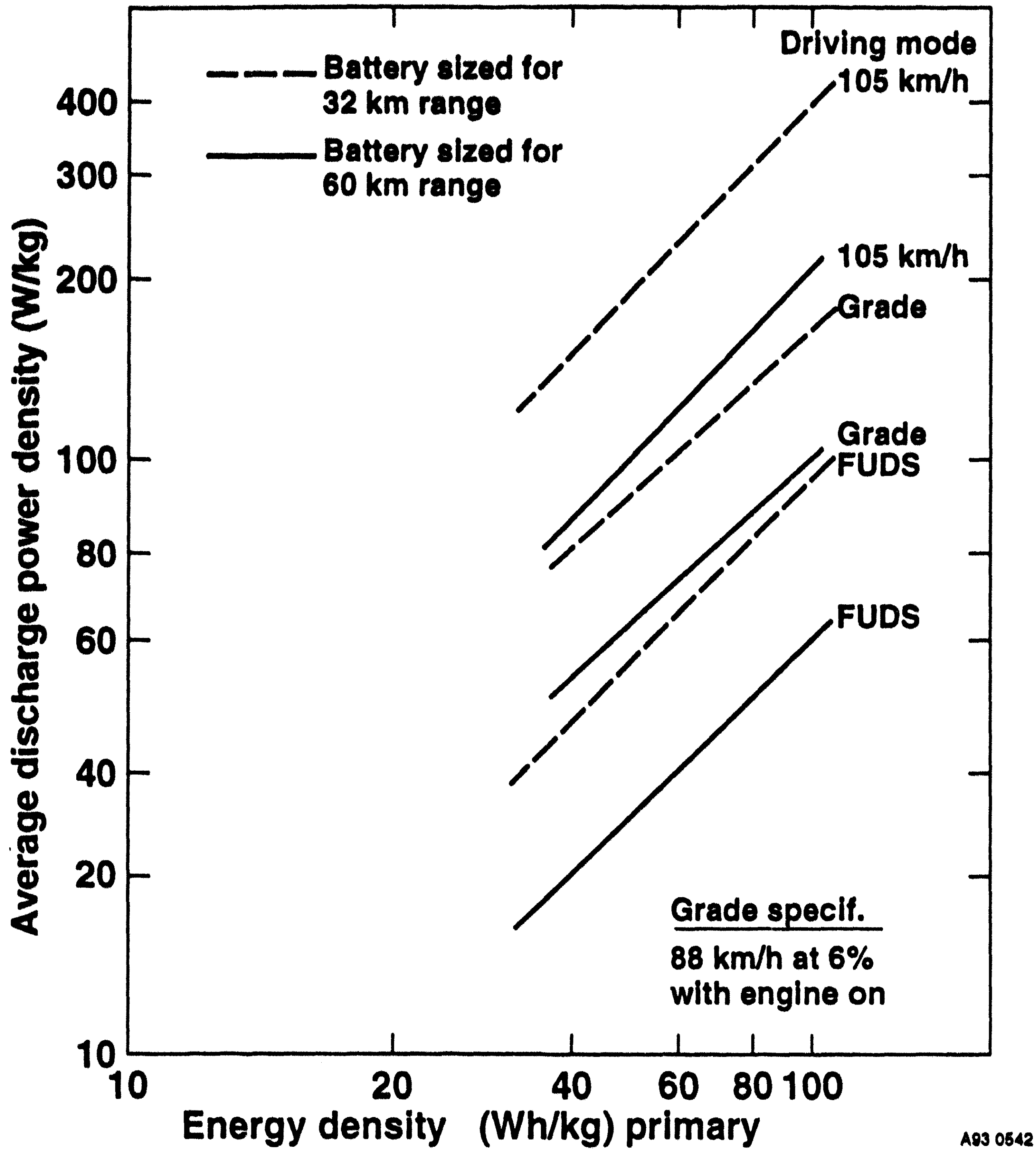
A93 0535

Average Discharge Power Density for Different Driving Modes for a Compact Car



A93 0541

Average Discharge Power Density for Different Driving Modes for a Minivan



The U.S. Department of Energy (DOE) Ultracapacitor Program

Technologies

- Carbon/metal fiber composites - Maxwell/Auburn
- Monolith foamed carbon - Livermore National Laboratory
- Foamed carbon with a binder - Sandia National Laboratory
- Doped polymer layers on carbon paper - Los Alamos National Laboratory
- Mixed metal oxides (ceramic) on metal foil - Pinnacle Research Institute

The U.S. Department of Energy Ultracapacitor Program (cont'd)

<u>Interface Electronics</u>

- General Electric Corporate Research and Development

Interface Electronics

- Needed to:
  - Control power split between main battery and pulse power device
  - Match voltage between power sources as capacitor voltage varies between Vo, 1/2 Vo
  - Use at least 75% of energy stored in the capacitors
- As a function of:
  - State-of-charge of power sources
  - Average power demand of vehicle
- Pulse power device is recharged during periods of low vehicle power demand
- Energy storage in pulse power device is small compared to that of main battery (50 kWh battery, 500 Wh capacitor)

A91 2944

Applications

Near-Term
(Used With Near-Term Batteries)

- Initial thinking
  A. Load-level the battery on the FUDS
  B. Power share during vehicle acceleration (0-50 mph in 20 sec)
  C. Discharge battery at P_{AV}
  D. Capacity 300-500 Wh

- Battery requirements without the ultracapacitors

Battery weight	Average	W/kg gradeability	Peak
500-600 kg	10	30-50	80

- Ultracapacitor unit
  500 Wh, 50 kW, 100 kg, 45 liter,
  5 Wh/kg, 11 Wh/ℓ, 500 W/kg
  > 90% round trip charge/discharge efficiency

- Capacitor energy for vehicle acceleration
  20 sec, 280 Wh

A92 0203

Applications

Advanced

(Used With Advanced Batteries and High Performance EVs)

- Advanced thinking
  A. Load-leveling battery during FUDS
  B. Power share during vehicle acceleration (0-60 mph in 10 sec)
  C. Capacity 750 Wh

- Battery requirements without the ultracapacitors

Battery weight	Average	W/kg gradeability	Peak
200-300 kg	20	110-160	375-550

- Ultracapacitor unit
  750 Wh, 80 kW, 50 kg, 20 liter,
  15 Wh/kg, 40 Wh/ℓ, 1600 W/kg
  > 90% round trip charge/discharge efficiency

- Capacitor energy for vehicle acceleration
  Acceleration: 10 sec, 230 Wh

A92 0204

Capacitor Specifications for Electric Vehicle Applications

Energy storage *(Wh, MJ)	500, 1.8
Power (kW)	50
Voltage (V)	200-300
Weight (kg)	< 100
Volume (ℓ)	< 45
Specific energy *(Wh/kg)	> 5
Vol. specific energy *(Wh/ℓ)	> 11
Capacitance (F/cm^2 1vcell)	> 1.5
Resistance (m-ohm cm^2/1vcell)	< 100
Discharge time (sec)	20-50
Charge time (sec)	60-120
Duty cycle	Continuous
Cycle life	> 100,000
Cost ($)	< 1,000

$$^{*}1\ \frac{\text{Wh}}{\text{kg}} = 3.6\ \frac{\text{kJ}}{\text{kg}}$$

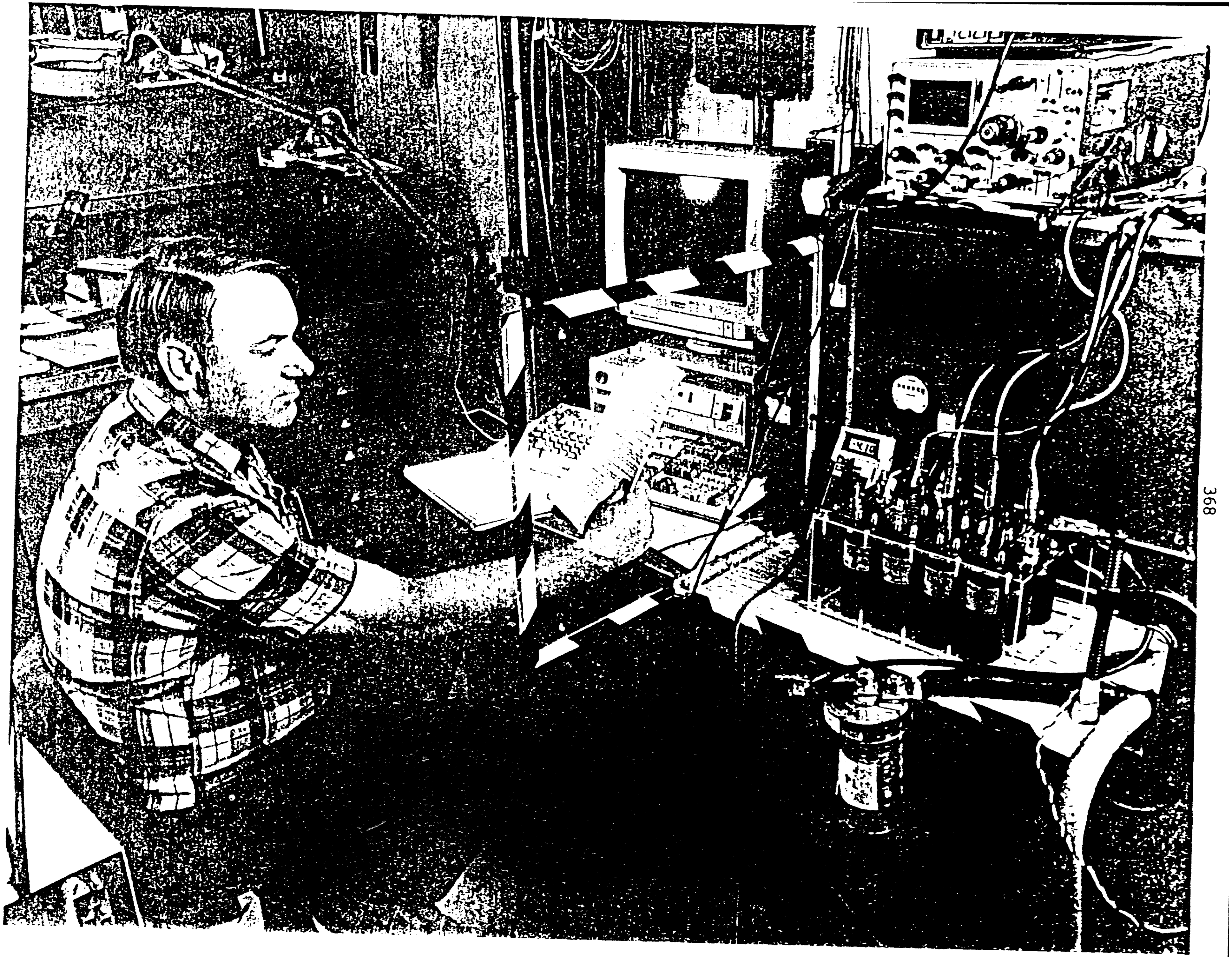
$$1\ \frac{\text{Wh}}{\ell} = 3.6\ \frac{\text{kJ}}{\ell}$$

A91 2945

Near-term and advanced goals for the DOE ultracapacitor development programs

Battery w/o Capacitor	Near-Term	Advanced
Weight (kg)	500-600	200-300
Power Density (W/kg)		
Average	10	20
Gradeability	30-50	110-160
Peak (accel)	80	375-550
Ultracapacitor Unit		
Energy stored (Wh)	500	750
Maximum Power (kW)	50	80
Weight (kg)	<100	<50
Volume (ℓ)	<40	<20
Energy density (Wh/kg)	>5	>15
Maximum useable power density (W/kg)	>500	>1600
Round trip efficiency (%)	>90	>90
Vehicle Acceleration		
0-88 km/h (sec)	<20	<8


SOLEQ P/N
470F 2.3V
70F



Panasonic 3 V, 1500 F Capacitors

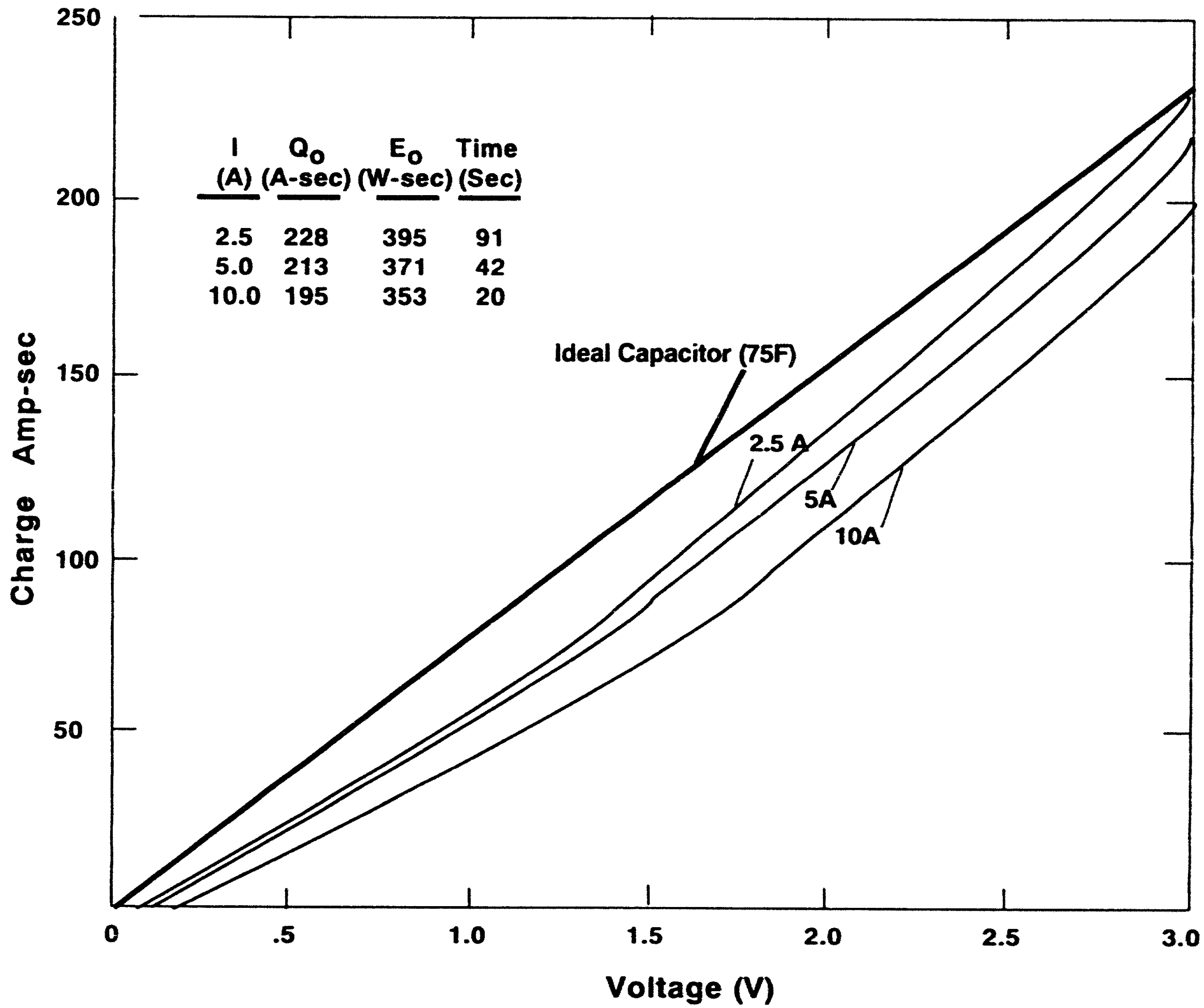
- **Technology** — Single cell, spiral wound, carbon-based, organic electrolyte
- **Size** — Diameter 7.7 cm
Length 14.9 cm
Volume 693 cm^3
- **Weight** — 887 gm

Panasonic Capacitors (cont'd)

- Energy stored (charging 100 A, 0 to 3 V)
  2.667 Wh (3.0 Wh/kg; 3.85 Wh/L)
- Energy Discharged (100 A, 3 V to 1 V)
  1.89 Wh (2.13 Wh/kg; 2.73 Wh/L)
- Resistance
  1.2 milliohms
- Maximum power* (3 V ---> 1.5 V)
  2.1 kW/kg

* to a matched load

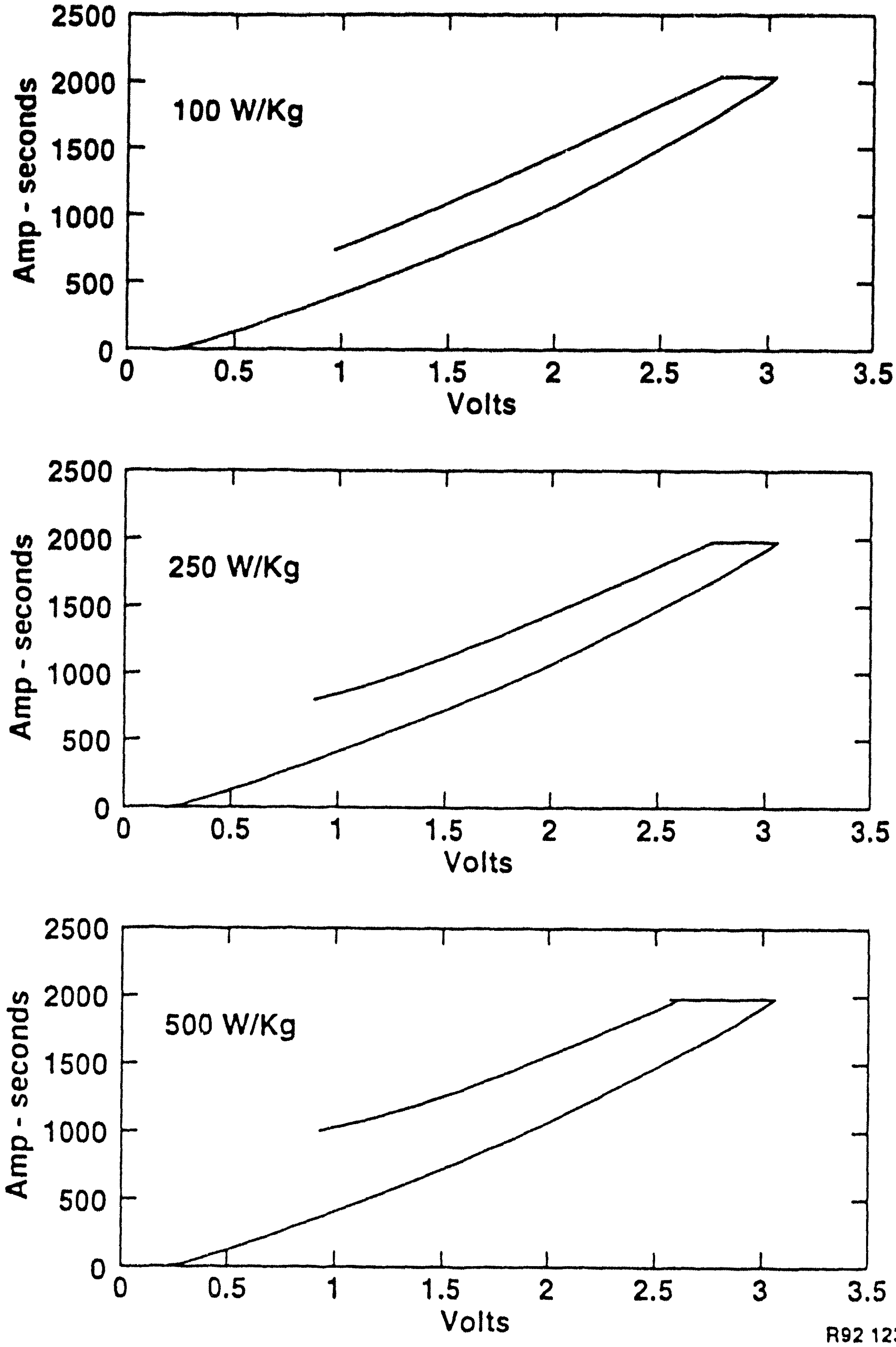
Charging Characteristic of the Japanese Capacitor at Several Charging Currents



I (A)	Q_o (A-sec)	E_o (W-sec)	Time (Sec)
2.5	228	395	91
5.0	213	371	42
10.0	195	353	20

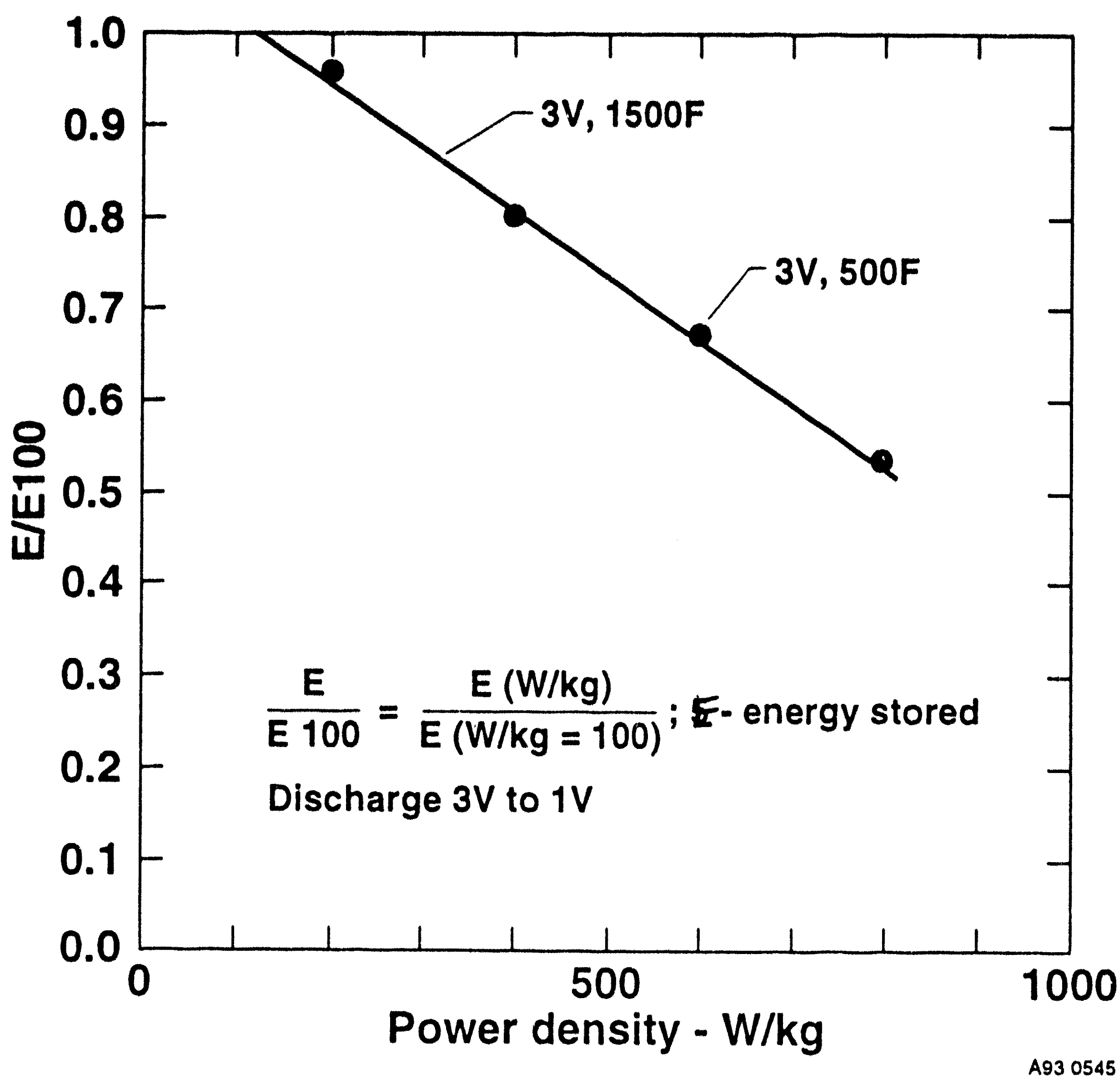
L91 0037

Discharge Characteristics of the 600 F Capacitors at Various Power Densities



R92 1232

Constant Power Discharge Characteristics of the Panasonic 3V, 500F and 1500F Capacitors



Life Cycle Test Results
Capacitor - 3 V, 600 F, Panasonic

- Cycle
  - 30 A charge in 15 sec (1.5-3 V)
  - 30 A discharge in 15 sec (3-1.5 V)
    Max power - 300 W/kg
    Average power - 225 W/kg
- Cycle life
  - 503,000 charge/discharge cycles
  - 7 months calendar time
  - 20% degradation in capacitance
  - V vs. time - Symmetric for all cycles

A92 2572

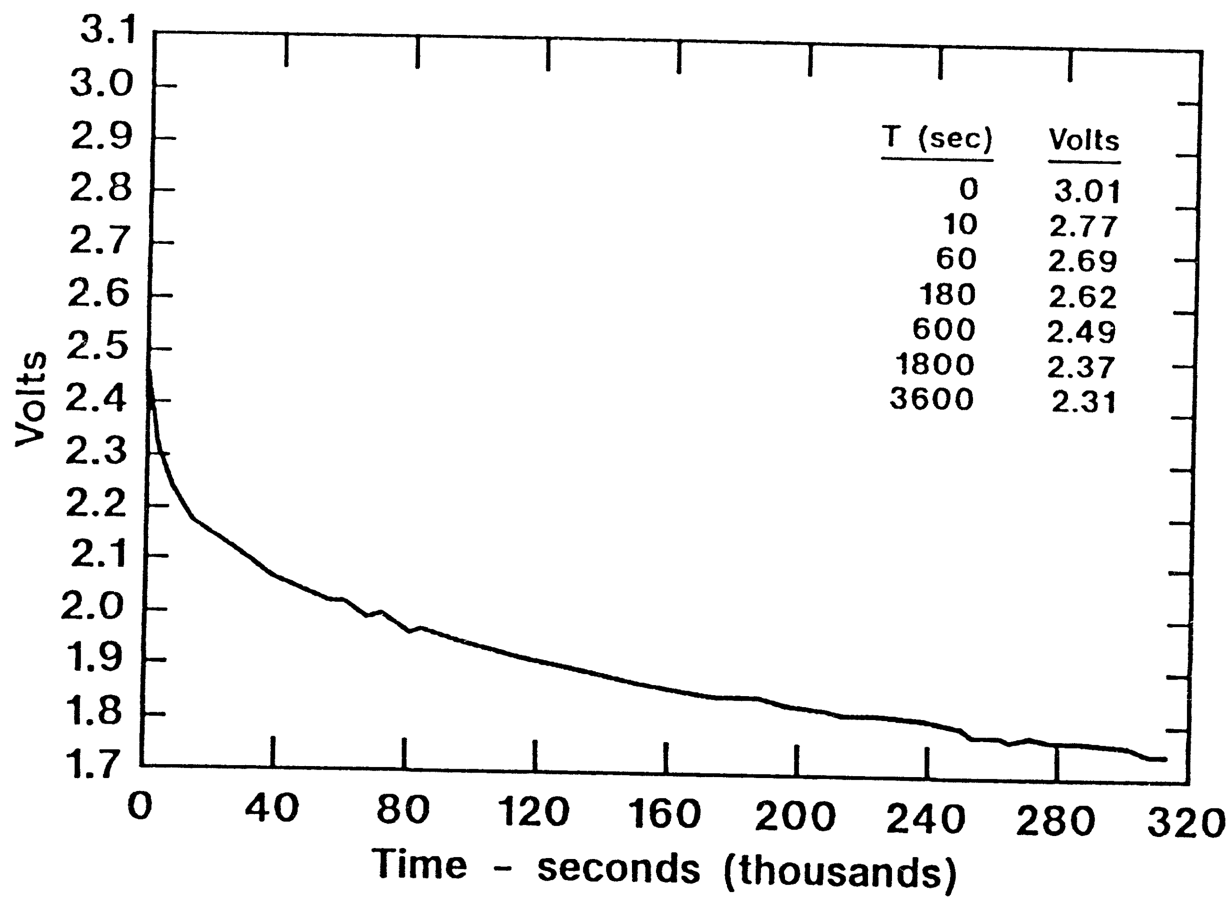
Summary of the 3V, 500 F Capacitor Life-cycle Test Data

DATE	CYCLES K	CHARGE/ DISCHARGE (1) CURRENT (A)	CHARGE TIME (SEC)	% CAPACITY	RESISTANCE (2) mOHM
01-16	10	20	29.1	100	6.25
02-11	48	20	28.5	98	6.25
02-28	71	20	28.35	97	6.7
04-01	124	20	27.1	93	6.7
04-01	124	30	15.6	93	6.7
04-17	165	30	15.4	92	6.7
04-22	180	30	15.2	91	6.7
04-30	200	30	14.8	88	6.7
05-18	256	30	14.5	86	6.7
05-26	280	30	14.4	85	6.7
06-08	320	30	14.2	84	6.7
06-15	341	30	14.0	83	6.7
06-29	384	30	13.9	83	6.7
07-06	405	30	13.9	83	6.7
07-13	424	30	13.8	82	6.7
07-27	468	30	13.7	81.7	6.7
08-07	503	30	13.5	80.5	6.7

(1) CHARGE/DISCHARGE BETWEEN 3.0V AND 1.5V

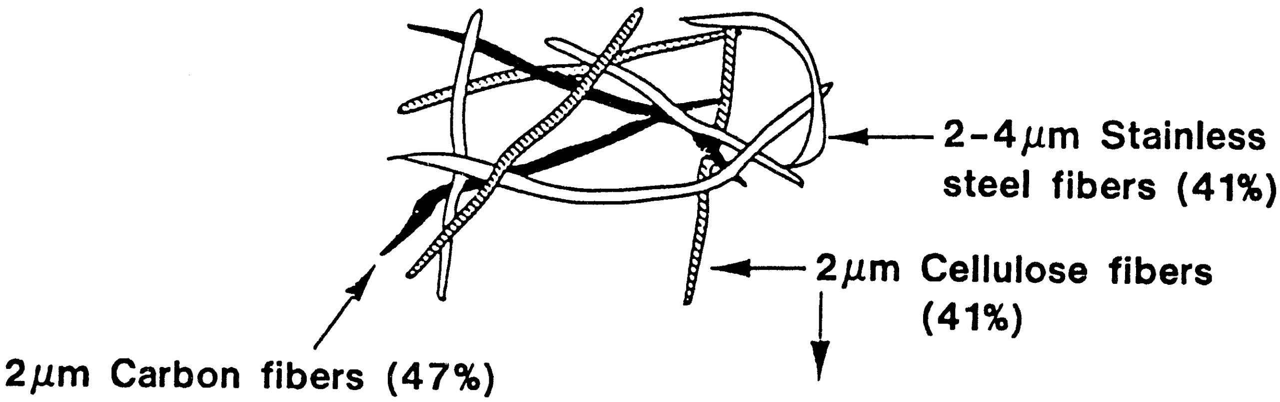
(2) BASED ON THE IR DROP AT BEGINNING OF CHARGE/DISCHARGE STEPS

Voltage Decay Characteristic of the Japanese Capacitor After Charging to 3V

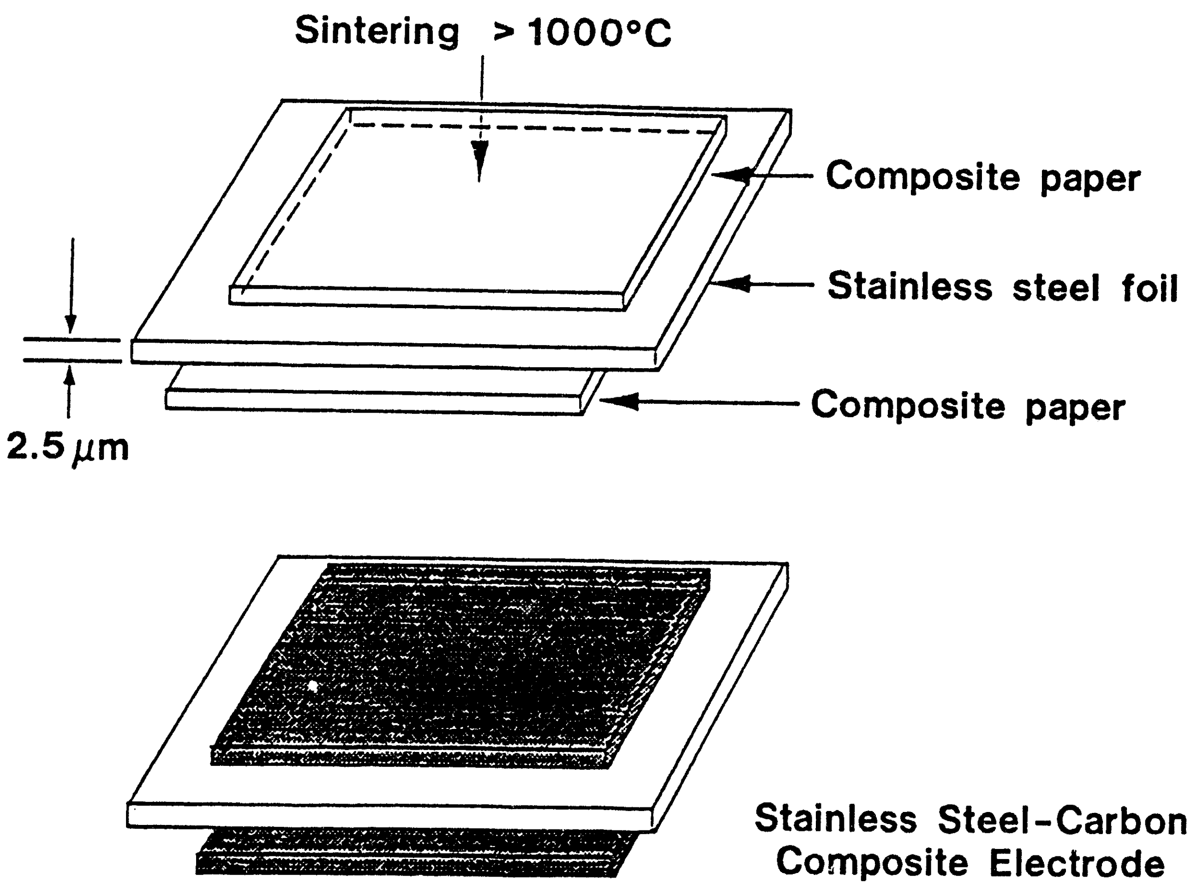


A91 2979

Carbon Metal Fiber Electrode Structure

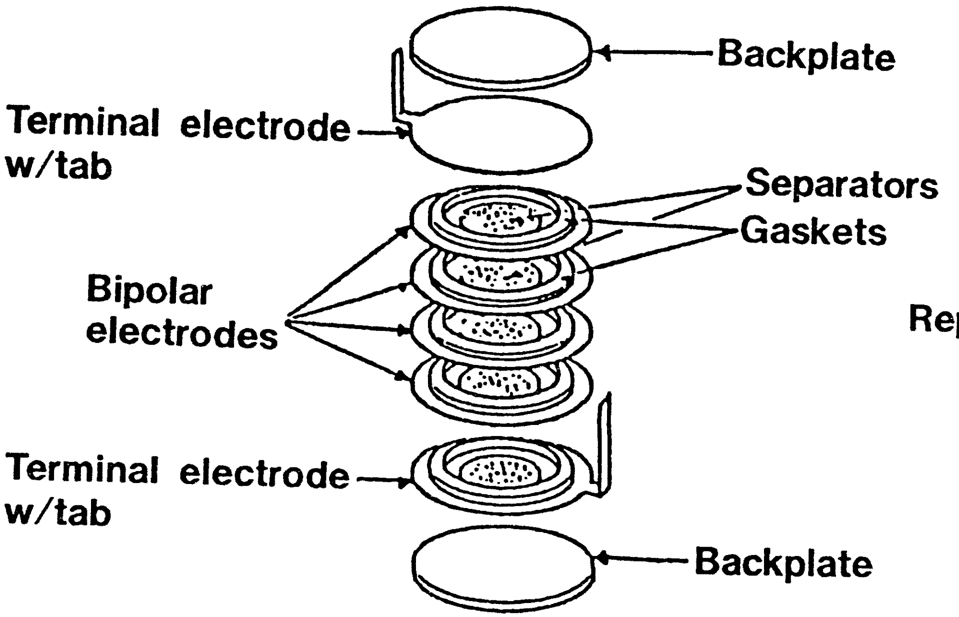


Intimately Mixed Metal-Carbon Composite Matrices from Paper Precursors

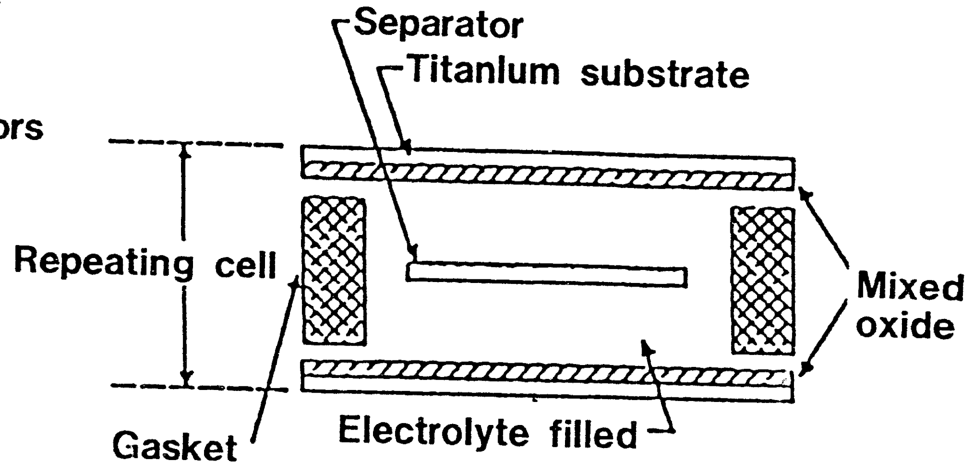


1-0356

Schematic of Ultracapacitor Construction



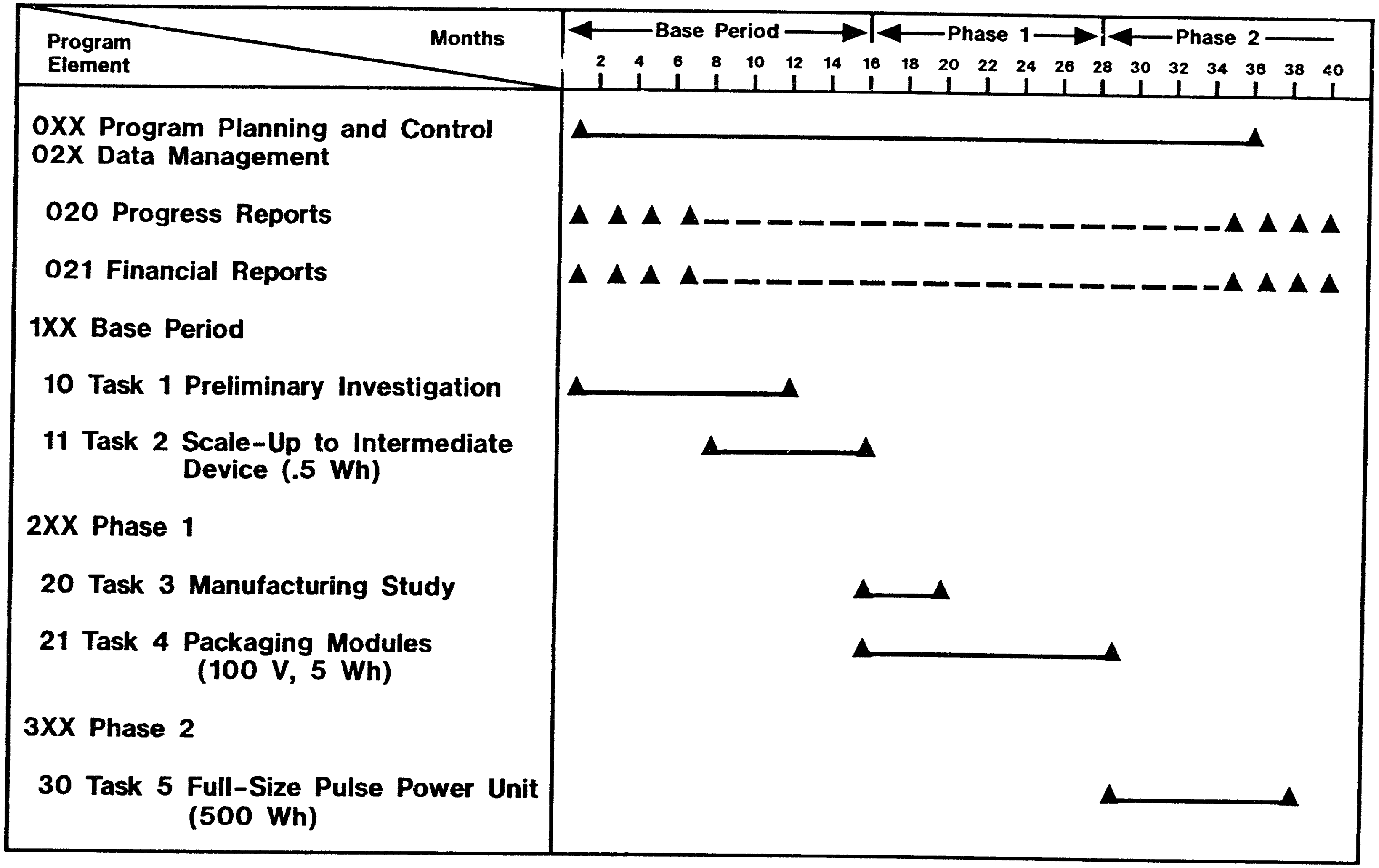
Exploded View of a Small Ultracapacitor



Unit Cell Construction of Ultracapacitor

1-0359

Milestone Chart for the Development of Ultracapacitor Technology Electric Vehicle Applications



A91 2948

Maxwell/Auburn 1 V, 75 F Capacitor (as of April 1993)

- **Technology** — Single cell, 20 cm^2 disk, composite carbon-metal fibers, aqueous (KOH) electrolyte
- **Size** — Diameter 5 cm; Thickness 0.187 cm; Volume 3.77 cm^3
- **Weight** — 6 gm

Maxwell/Auburn 1 V, 75 F Capacitors (cont'd)

Energy Stored/Discharged (1 A, 0 ---> 3 V)	39 W/sec (1.8 Wh/kg, 2.9 Wh/L)
Resistance	10 milliohmns
Maximum Power* (1 V to .5 V)	4.2 kW/kg

* to a matched load

Maxwell/Auburn 3 V, 27 F Capacitor (as of April 1993)

• Technology	Single cell, 20 cm^2 disk, composite carbon-metal fibers, organic electrolyte
• Size	Diameter 5 cm Thickness 0.15 cm Volume 3 cm^3
• Weight	4.5 gm

382

Maxwell/Auburn 3 V, 27 F Capacitors (cont'd)

Energy Stored/Discharged (1 A, 0 ---> 3 V)	121 W/sec (7.5 Wh/kg, 11.2 Wh/L)
Resistance	0.15 ohm
Maximum Power* (3 V to 1.5 V)	3.3 kW/kg

* to a matched load

Advantages of Ultracapacitors for Use in EV Drivelines

- Very high power > 3 kW/kg
- Very high recharge rates < 20 sec
- Long life > 100,000 cycles
- High efficiency > 95%
- Compatibility with electric drive system
  - Combine ultracapacitor unit with inverter electronics
  - Ease of microprocessor control

A92 0206

Conclusions

- Power capacitors are available commercially from Panasonic for laboratory tests.

- Good progress is being made in the U.S. DOE Program to develop capacitors with energy density of 5 to 10 Wh/kg.

- Ultracapacitors are likely to be key components in the drivelines of high performance hybrid-electric vehicles.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

DESIGN OPTIONS FOR HYBRID-ELECTRIC VEHICLES USING ULTRACAPACITORS
Andrew F. Burke, EG&G Idaho, Inc.

Q. Anonymous: Why is the ultracapacitor technology not used in Japan?

A. It is used in different applications. Isuzu uses it to extend life of batteries.

Q. Mehboob Sumar, ORTECH International: You mentioned an application with catalyst. How did this work?

A. We did an experiment with a 12-volt module to heat exhaust treatment catalyst to 700-800oC in 6-7 seconds. This use may be an ideal application for this type of device, where the capacitor could be charged off the vehicle battery. We will be studying costs for these devices over the next twelve months.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

FLEET USERS' EXPERIENCE WITH ALTERNATIVE FUELED VEHICLES PANEL DISCUSSION

Panel Moderator: Mike Jackson

(Presentations made during this Panel Discussion were unavailable at time of printing)

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

PANEL DISCUSSION: FLEET USER'S EXPERIENCE WITH ALTERNATIVE FUELED VEHICLES

Moderator: Mike Jackson, Acurex Environmental

Panel Members: (In order of presentations
David Ogilvie, National Association of Fleet Administrators
Michael Snodgrass, U.S. General Services Administration
Chris Burgeson, City of Glendale, California
Todd Krenelka, Batelle/Federal Express Fleet
Don Brunson, Xerox Corporation
Tom Finn, Avis Rent-A-Car

Each panel member made a short presentation. Then questions were directed at the panel. Some replies came from more than one panel member who are identified below by name.

Q. Matthew Bol, Sypher:Mueller International: Would you comment on resale value of the vehicles?

A. Tom Finn: Our contract required that the cars be returned to the vehicle manufacturer who then resold them in California. We have no information on dollar values.

A. Michael Snodgrass: We hope that there will be a market for alternative fuel vehicles in about three years. Also, that there will be fuel availability and other parts of the program in place to provide support to the vehicle owners.

Q. Norval Horner, Amoco Canada: The slides for Federal Express showed fuel economy data in gasoline equivalent. Was that volume equivalent or energy equivalent?

A. Todd Krenelka: It was energy equivalent based on lower heating value of the fuels compared with base gasoline from the Auto/Oil Industry Program.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

PANEL DISCUSSION: FLEET USER'S EXPERIENCE WITH ALTERNATIVE FUELED VEHICLES

Q. Paul Wuebben, SCAQMD: Could you explain the permitting problems for M85 methanol storage?

A. Todd Krenelka: Federal Express policy is not to install underground tanks on their property. However, the City of Santa Ana ordinance required extra use permits for the aboveground tanks that were used.

Q. Paul Wuebben, SCAQMD: In the discussion of CNG refueling, a back-up fueling system was mentioned. What was the experience with that?

A. Todd Krenelka: We have not had a compressor failure yet and did not need to use the second system.

Comment: John Christie, General Motors; Resale value is an important issue. Our experience so far in turning over our own staff vehicles at dealer auctions is that they offer slightly less on flexible fuel vehicles than conventional vehicles. I think that is a temporary situation.

SESSION 3: OVERCOMING BARRIERS TO ALTERNATIVE FUELS COMMERCIALIZATION

Chair: Ron Neville, ORTECH

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

PROPANE MOTOR FUEL MARKETING - CHANGING THE PERCEPTION

S. Vedlitz
Conoco Inc.

Propane Motor Fuel Marketing

Changing the Perception

392

With this experience, clean air a primary social goal, and propanes advantages over other fuels, it is surprising that it's benefits are often overlooked and in the case of the OEMS all but forgotten.

Why is this?

Propane is primairly supported by private initiative falling short of the backing of other fuels -- this makes it difficult to promote propanes advantages and dispel the misconceptions that have become barriers to propanes acceptance.

Propane
A Viable Alternative Motor Fuel

- First Used in the 1920s
- 3.8 Million Vehicles Operating Worldwide
- 500,000 Vehicles Operating in U.S.
- 140,000 Vehicles Operating in Canada
- Annual Vehicle Growth 25,000 U.S.; 15-25,000 Canada
- Ranks Third in Motor Fuel Sales
- 10,000 Public Fueling Locations
- Highest Volumetric Efficiency After Gasoline

What are these misconceptions and what needs to be done?
One perception is that the use of propane as a motor fuel will result in engine power loss -- reduced performance capability.

Changing the Perception

- Performance Capability
- Safety Characteristics
- Fuel Cost & Supply
- Fueling Locations & Availability

The facts are:
Propane has 104 octane
excellent cold weather starting (vaporizes at temp. as low as -44F)
greatest range of any alternative fuel and
clean burning


WE'RE DOING
OUR PART,
THIS VEHICLE
POWERED BY
CLEAN-BURNING
PROPANE
MOTOR FUEL
CONOCO
PROPANE
CLEAN AIR MOTOR FUEL
CLEAN AIR MOTOR FUEL
CONOCO

The facts are:
as a result of modern conversion technology,
electronicly monitored, fuel injected engines
and the quality standardization of HD5 propane for motor fuel -
Performance is no longer an issue


FUEL FOR OUR FUTURE
conoco
400

Power loss is no longer a problem

most vehicles experience less than a 4% power loss if that much

Propane has been tested under the most grueling conditions known in motor sports racing - Setting a world speed record for alternative fuels in 1991 at the Bonneville Salt Flats at 218.18MPH

and racing at Pipes Peak in 1991 and 1992. Coming in 2nd in 1992. Roger Mears, the driver, stated that he experienced no power loss at any point on the hill especially the upper third where other fuels always lose power. This year we will again be at Pipes Peak this time in a Dodge Dakota.

Performance is not the issue, education is

Establishing a network of certified conversion centers and promoting their existance is also the issue, not performance.

Safety is a concern with any fuel, but because propane is heavier than air it receives unwarranted notoriety

Changing the Perception

- Performance Capability
- Safety Characteristics
- Fuel Cost & Supply
- Fueling Locations & Availability

406

Propane has been in use as a motor fuel since the 1920's with an outstanding safety record

It is heavier than air, but it does not puddle and vaporizes quickly

It has a norrow flammability range (2.15% - 9.6%) air/fuel mixture

It has high ignition temperature 920F - 1120F (gasoline 450 -900F)

FLAMMABILITY RANGE OF ALTERNATIVE FUELS

Considered safe by independent school districts throughout the country
Fuel tanks are 20 times more puncture resistent than gasoline tanks
With many safety features designed into the carburation system (like safety relief valves)

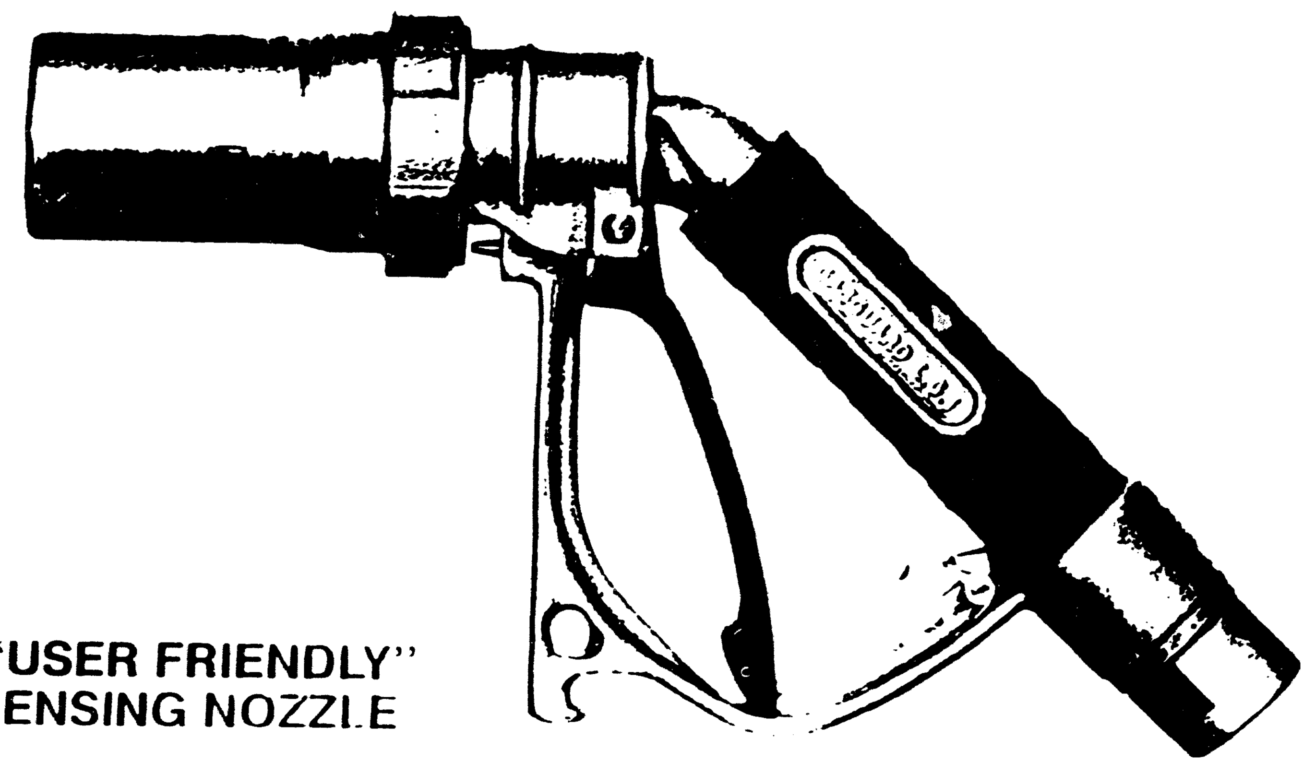

CONOCO
SCHOOL
410

It is the current refueling procedure that reinforces the negative safety perception.

The spit valve needs to be eliminated (modern tanks have built in 80% fill levels)

and modern nozzles that eliminate the white fog and the need to wear gloves at the disconnect need to become common place.

THE "GASGUARD" L.G.1E LIQUEFIED PETROLEUM GAS (PROPANE) NOZZLE



THE "USER FRIENDLY" DISPENSING NOZZLE

Test after test and years of use have proven propane a safe motor fuel to handle and to use.

It is interesting to note that propane is pronounced unsafe by its critics, not by those who use the fuel on a daily bases.


CONOCO
SCHOOL BUS
414

There have been stories and anti-propane publicity surrounding supply availability and unstable seasonal pricing, all designed to discredit propanes use and even its official consideration as an alternative motor fuel.

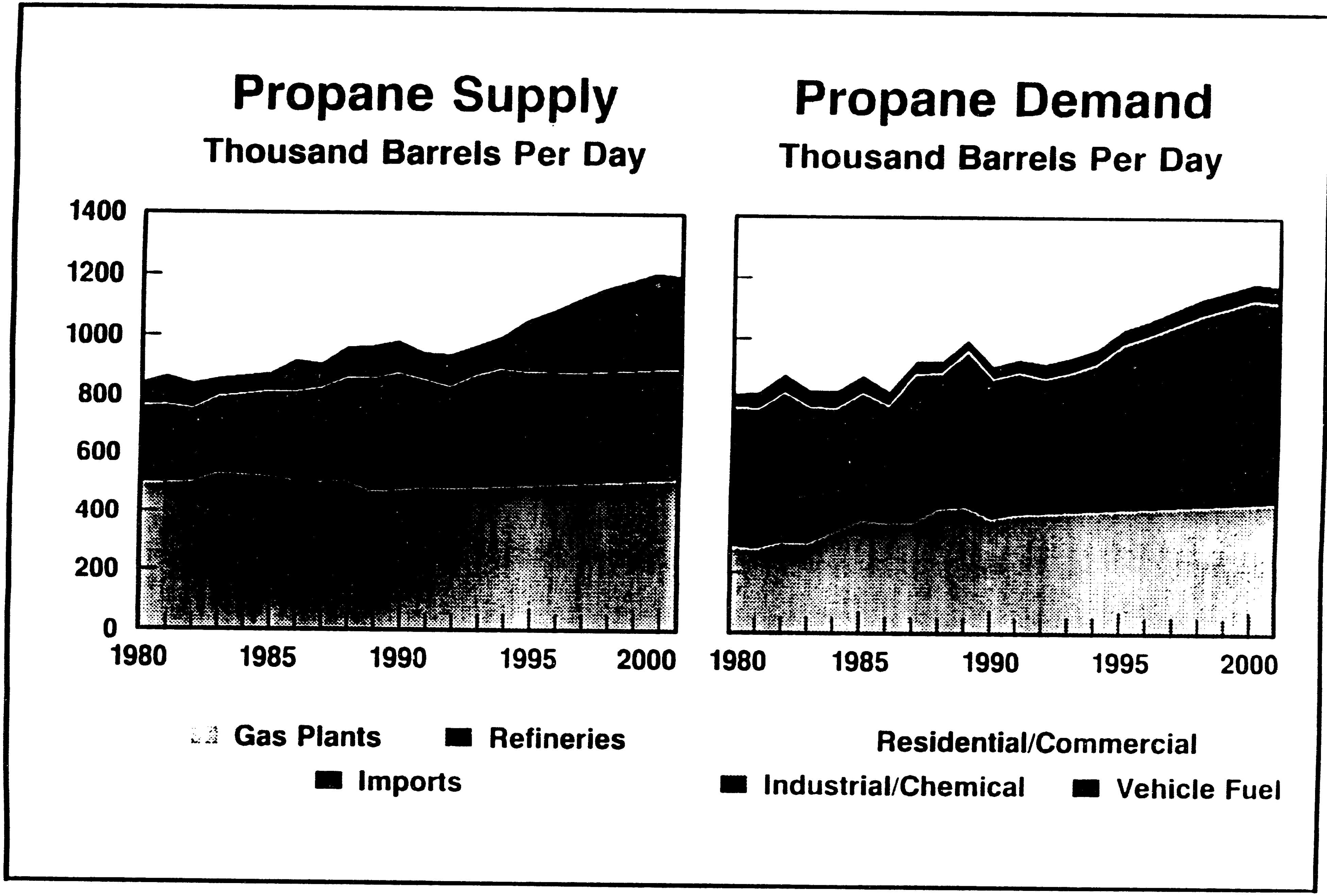
415

Changing the Perception

- Performance Capability
- Safety Characteristics
- Fuel Cost & Supply
- Fueling Locations & Availability

416

Recent supply analysis shows sufficient quantities of propane to extend its use as an alternative fuel - 6.5mm vehicles could be fueled with propane by the year 2004 without effecting domestic supply. According to the recent Webb Study 17mm vehicles could be fueled by propane by the year 2010 with moderate capital investment. There is also an adequate distribution system already in place which is under utilized today - it includes pipelines, storage & distribution terminals, railcars and tankers.


Propane Supply
Thousand Barrels Per Day
1400
1200
1000
800
600
400
200
0
1980
1985
1990
1995
2000
Gas Plants
Refineries
Imports
Propane Demand
Thousand Barrels Per Day
1980
1985
1990
1995
2000
Residential/Commercial
Industrial/Chemical
Vehicle Fuel

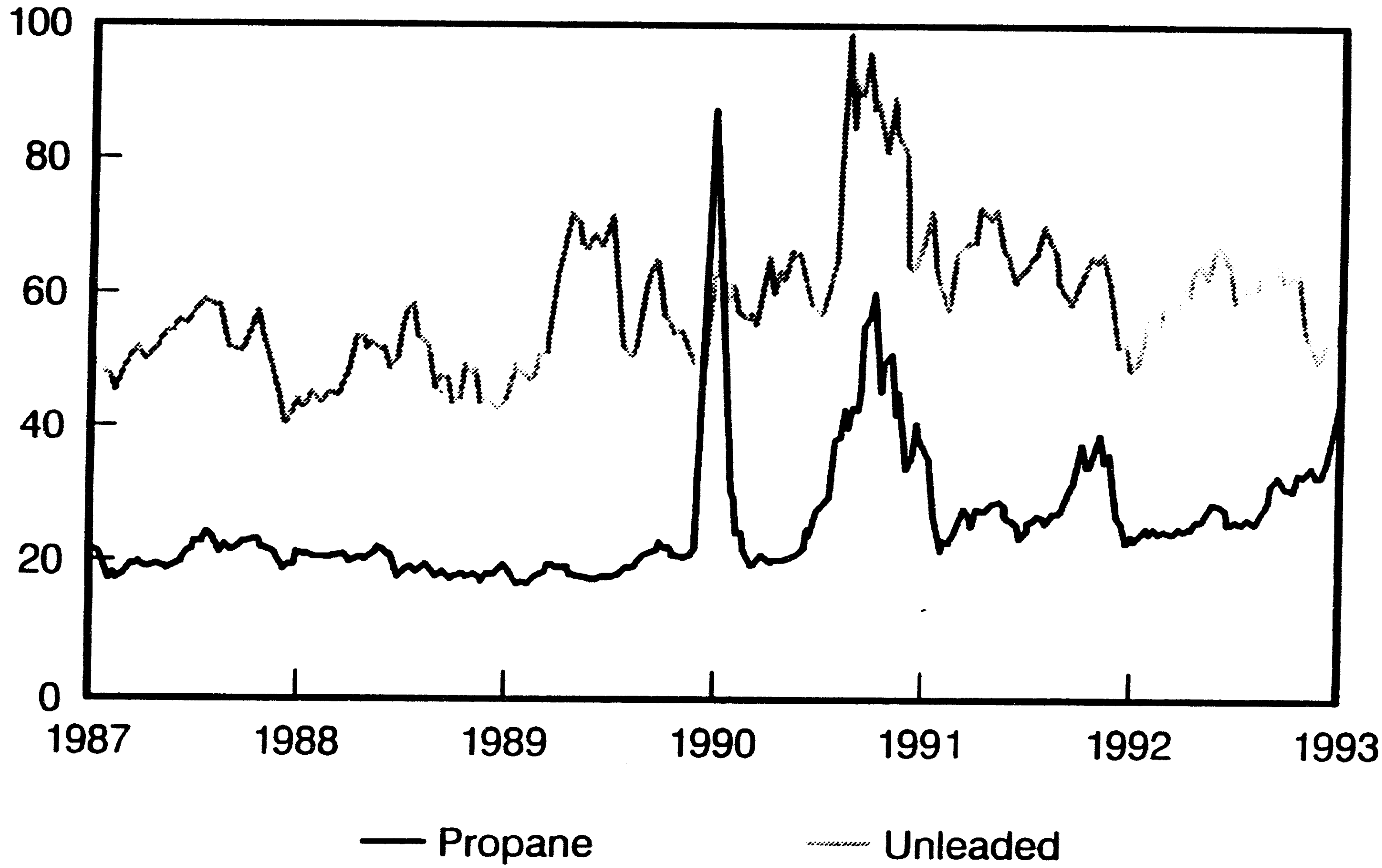
418

As for pricing instability and high winter prices, the perception is for the most part correct and the propane retailers need to change their pricing philosophy.

The wholesale price of propane only exceeded gasoline once in the past six (6) years - there is a sufficient delta between the two fuels to accomodate a pricing philosophy directly related to the retail price of gasoline.

B1114.06 300868 Vedlitz SR

Propane Vs. Gasoline Prices



Our pricing position is to price propane as a motor fuel below the retail price of gasoline, year round - we even post our price of propane at the street as we do gasoline for everyone to see.

Others need to and are following this example.


CONOCO
1.25⁹
1.33⁹
1.41⁹
1.21⁹
PROPANE MOTOR FUEL
.82⁹
CONOCO

Last but not least - we have to upgrade our refueling facilities and thus improve the image of propane motor fuel marketing.

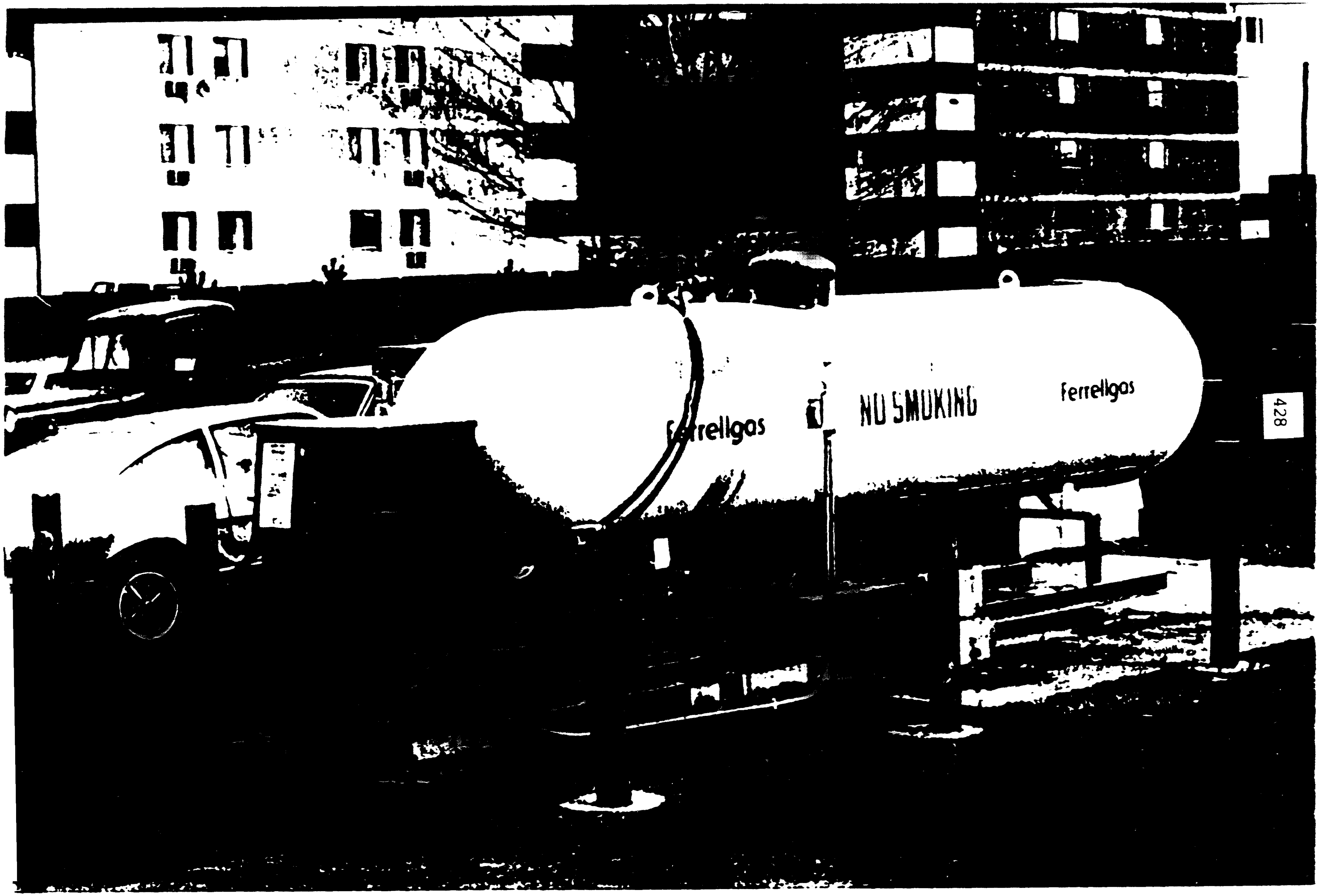
Changing the Perception

- Performance Capability
- Safety Characteristics
- Fuel Cost & Supply
- Fueling Locations & Availability

While there are 10,000 facilities open to the public, the overall image is poor. Set up for bottle fill or RV'S


PROPANE
426

Or in the back of some parking lot hard to find much less utilize.


Ferrellgas
NO SMOKING
Ferrellgas
428

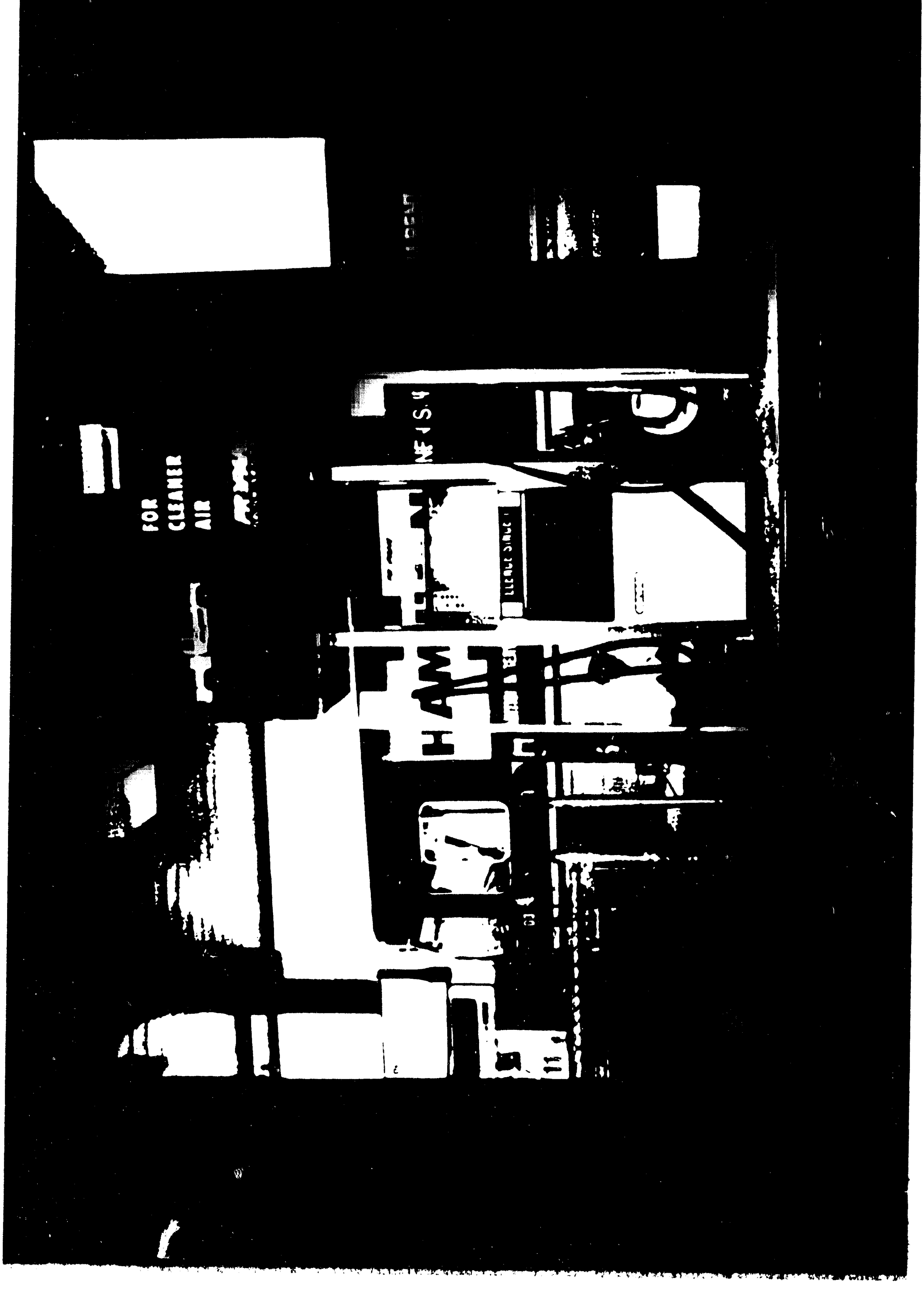
We must upgrade these units, taking advantage of the thousands of fueling permits that have already been issued to dispense propane motor fuel. Securing a permit is a major hurdle for offering any alternative fuel to the motoring public. We also need to expand the current Alt. Fuel refueling directories to include most if not all of the 10,000 units open to the public. In other words take advantage of propanes built refueling infrastructure.

430

We must bring propane marketing to main street USA (like this s/s) as it has been done in Canada and other countries. We must look operate and be as accessible and convenient as gasoline is today.


conoco

We must utilize modern, user friendly , self serve dispensing equipment - in other words, be inviting to the public like this unit in Denver, Co.


FOR
CLEANER
AIR

It is important for the industry
to work together
to work with government
to work with the OEMs
to educate and to create awareness
By working together, we can get more fleets to try propane, thus changing the perception of propane as a motor fuel - remember, those fleets that have tried propane as a motor fuel have a positive impression.

What's Needed

- OEM Support
- Fleet Demonstrations
- Education
- Advertising/Publicity

436

Those fleets, like myself and many others believe propane deserves to be recognized as the viable clean-burning alternative motor fuel that it truely is.

Thank you

Propane Motor Fuel

A Viable Clean-Burning Alternative Motor Fuel

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

PROPANE MOTOR FUEL MARKETING - CHANGING THE PERCEPTION
S. Vedlitz, Conoco Inc.

Q. Bernard James, Energy, Mines & Resources Canada: In the vehicle fuel tanks, will the stop-fill valve eliminate the need for the spit valve?

A. The stop-fill valve is required in all new tanks, so the spit valve is no longer needed. Its included because it is still required by regulations.

Q. Norman Brinkman, General Motors: What will happen with the price of propane relative to gasoline with an increase in demand for propane? Will it increase such as happened a few years ago with diesel fuel?

A. The same problem occurs with any alternative fuel today. We will have to change the pricing philosophy. Propane may reflect the gasoline fuel market in the future instead of being compared with heating oil or chemicals.

Q. Anonymous: Where does the excess propane go today?

A. It is used as a feedstock for ethylene or other chemicals. I would like to sell it as a preferred motor fuel.

Comment: Norval Horner, Amoco Canada: I agree. Ethylene can be made from ethane, butane, naphtha, or gas oil which would release a lot of propane for fuel at a modest price. A change of only a few cents per gallon would take propane out of the chemical market.

Q. Norval Horner, Amoco Canada: What is the price of M85 methanol?

A. Right now, M85 is about the same price as unleaded gasoline on a volumetric basis. That actually makes it about 50 percent more on an energy basis.

Q. Vinod Duggal, Cummins Engine Co.: Was your price chart comparison of propane and gasoline on a gallon basis or a BTU basis?

A. The chart was based on price per gallon in the sport market.

Q. How does the energy content of propane compare with gasoline?

A. Although the BTU content of propane is about 25 percent less, a propane-fueled vehicle will obtain about 15 percent less miles per gallon than gasoline.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

FUEL ISSUES FOR GAS ENGINES AND NGVs

W. Liss
Gas Research Institute

Fuel Issues For Gas Engines and NGVs

William E. Liss
Senior Project Manager
Engine Technology
Power Generation and Transportation Systems
Gas Research Institute
Chicago, IL 60631

(312/399-8352)

ABSTRACT

Interest has grown considerably in the U.S. and worldwide in using natural gas in stationary reciprocating engines (e.g., power generation and machinery drives) as well as in natural gas vehicles (NGVs). NGVs are seen in a compressed gas form (e.g., 3000 or 3600 psig) or in a liquefied form (LNG)--both which increase the storage density of the fuel (a critical factor in the vehicle market). In many gas uses, fuel properties are not of major concern. With reciprocating engines and NGVs, however, fuel composition and property changes can impact equipment (i.e., engine and refueling station) operation and performance. Particularly in NGVs, fuel issues come to the forefront because of the *sensitivity* of some engines (e.g., those running near knock-limited power), the extreme pressure and temperature regimes in which the gaseous or liquid fuel may be exposed (relative to ambient), and the low emission targets being sought. This paper will outline many of these areas and provide an update on knowledge of fuel property cause/effect relation on stationary engine, vehicle, and NGV station operation.

INTRODUCTION

There are often complex, elusive issues which arise in the operation of stationary gas engines, NGVs, and NGV refueling stations. One of the more controversial is fuel composition, properties or "quality." Often confusion exists as to the seriousness of some fuel-related issues. In part, this results from the complexity and variability of equipment in use and the number of dimensions along which fuel properties may change and influence equipment operation and performance. The objective of this paper is to provide background and insight on the interactive effect fuel has on performance of these equipment. This is intended to help foster awareness in the industry of some of the major fuel issues, debunk some misconceptions, and provide technology and information transfer. Some of these issues (e.g., fuel metering effects) will likely be familiar, while others may be new. References are cited for those readers who want to explore these issues in more detail.

GENERAL FUEL VARIABILITY

GRI began looking into fuel issues for this market segment in 1990. A program was started with AGA Laboratories, IGT and G. Steinmetz to document fuel property variations in twenty-six major U.S. cities. This included components routinely detected by a gas chromatograph <u>and</u> which have a meaningful influence on fuel properties. This means individual hydrocarbons through C_5, with hexane and heavier hydrocarbons being summed up as C_6+ and assumed to be n-hexane. Carbon dioxide, nitrogen, oxygen (if present) were included; some data were collected on water and sulfur. The resulting database(1) contains over 6800 analyses collected in cooperation with the U.S. gas industry. A companion SAE technical paper was written(2) which provides an overview of selected engine/fuel issues.

Figure 1 shows the weighted average non-methane hydrocarbon species for each city sampled and Table 1 shows summary data statistics. Figure 2 shows weighted frequency distributions for various natural gas species and properties. In general, these data show reasonable consistency throughout the U.S. Some areas have extremely stable fuel, while other regions have ongoing fluctuations within a given range. Two areas of exception were identified: (1) a Rocky Mountain region where a blend of ethane and air are added to natural gas and (2) use of propane/air peakshaving by some utilities. This survey established a baseline for understanding potential variations in fuel properties and have helped in assessing fuel effects related to specific equipment operational issues. A number of these issues will be discussed in the following text.

GAS ENGINE OPERATION

Addressing fuel issues for gas engines is not trivial. Though relatively small volumes of gas engines are produced annually (compared to gasoline and diesel engines), an amazing variety of gas engine *types* exist. These include stoichiometric open-chamber engines, lean-burn open-chamber engines, and lean-burn pre-combustion chamber engines. Many are four-stroke engines, but several thousand natural gas pipeline engines (collectively, millions of horsepower) are direct-injected, spark-ignited two-strokes that in several cases have been running for decades. Most gas engines are spark-ignited, but a small portion use diesel-pilot ignition ("dual fuel" engines). Some engines are being developed which are direct-injected, compression-ignited similar to diesel engines. On top of this complexity, such engines can have a variety of engine compression ratios, boost levels, and emission control strategies. From a technical viewpoint, such diversity makes it difficult to come up with standard answers to the question of how fuel changes impact engine operation.

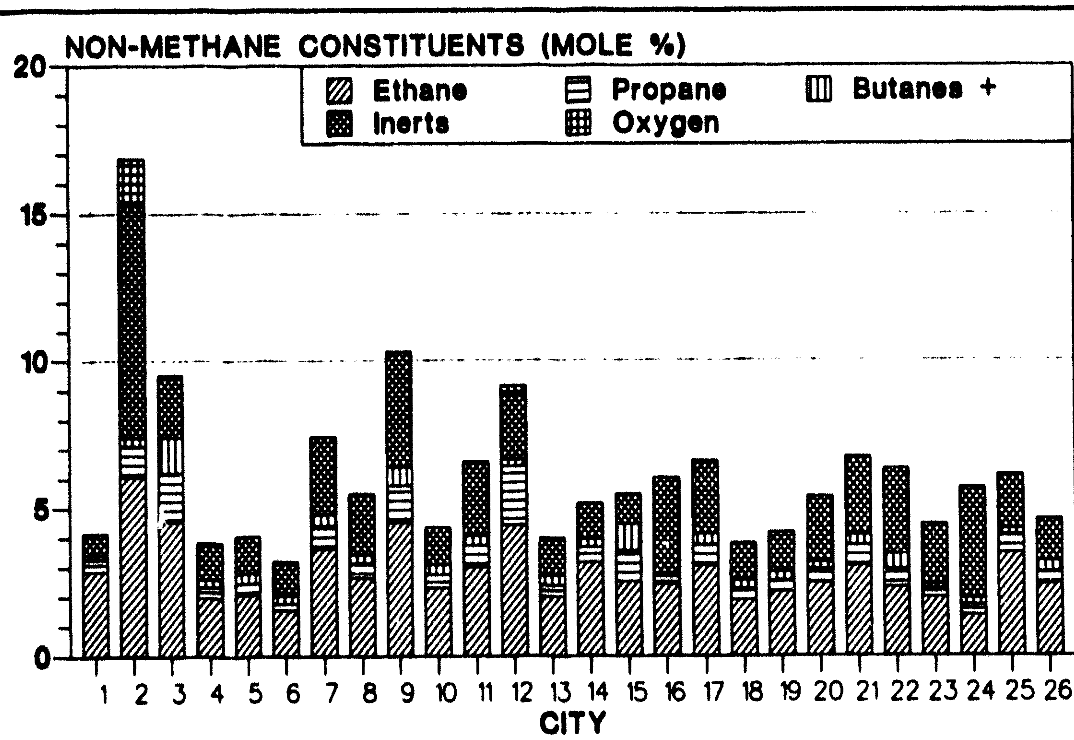


Figure 1: Weighted Average Non-Methane Hydrocarbons For 26 Cities

Figure 2: Weighted Frequency Distributions For Gas Constituents And Properties

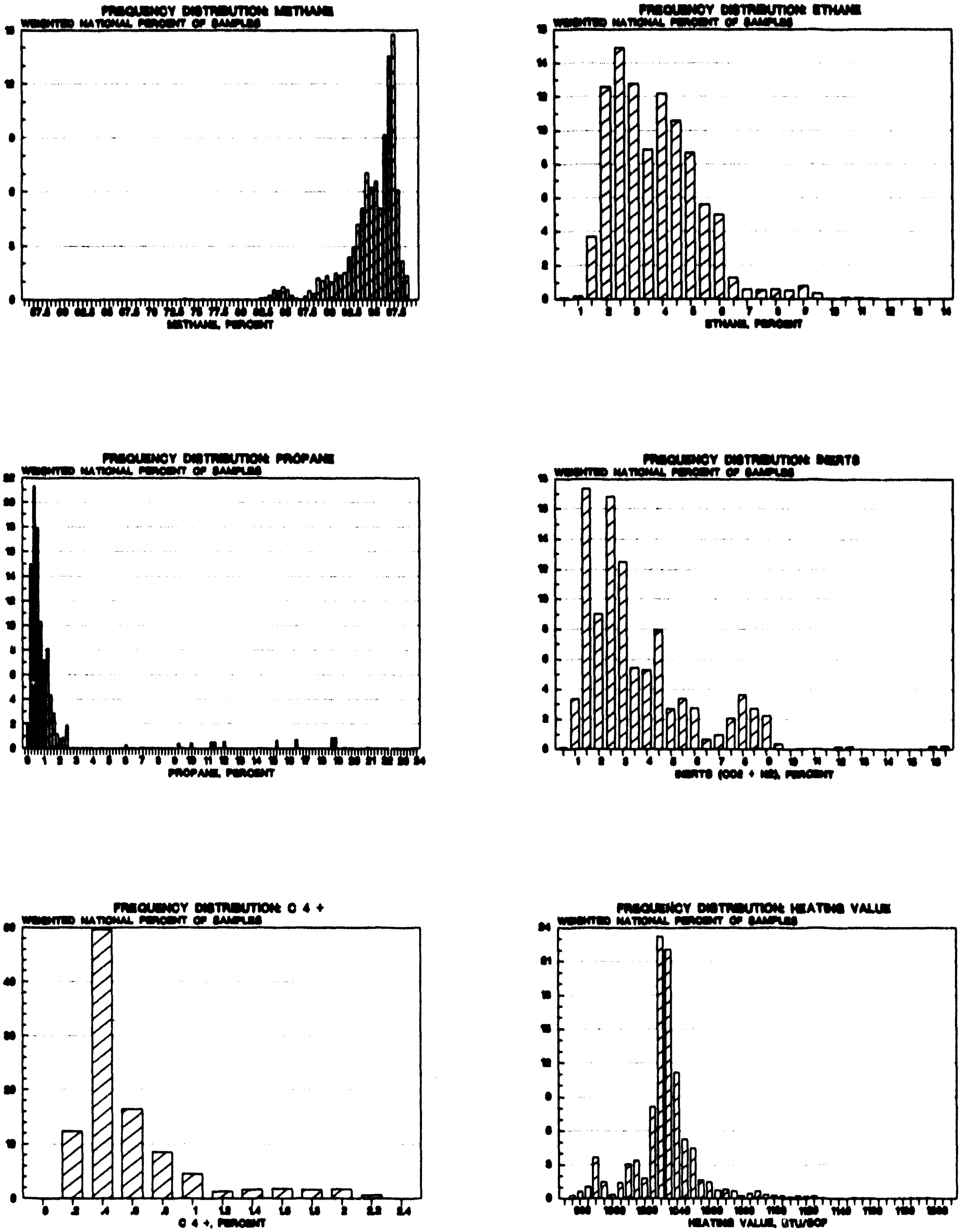


Figure 2: Weighted Frequency Distributions For Gas Constituents And Properties (cont.)

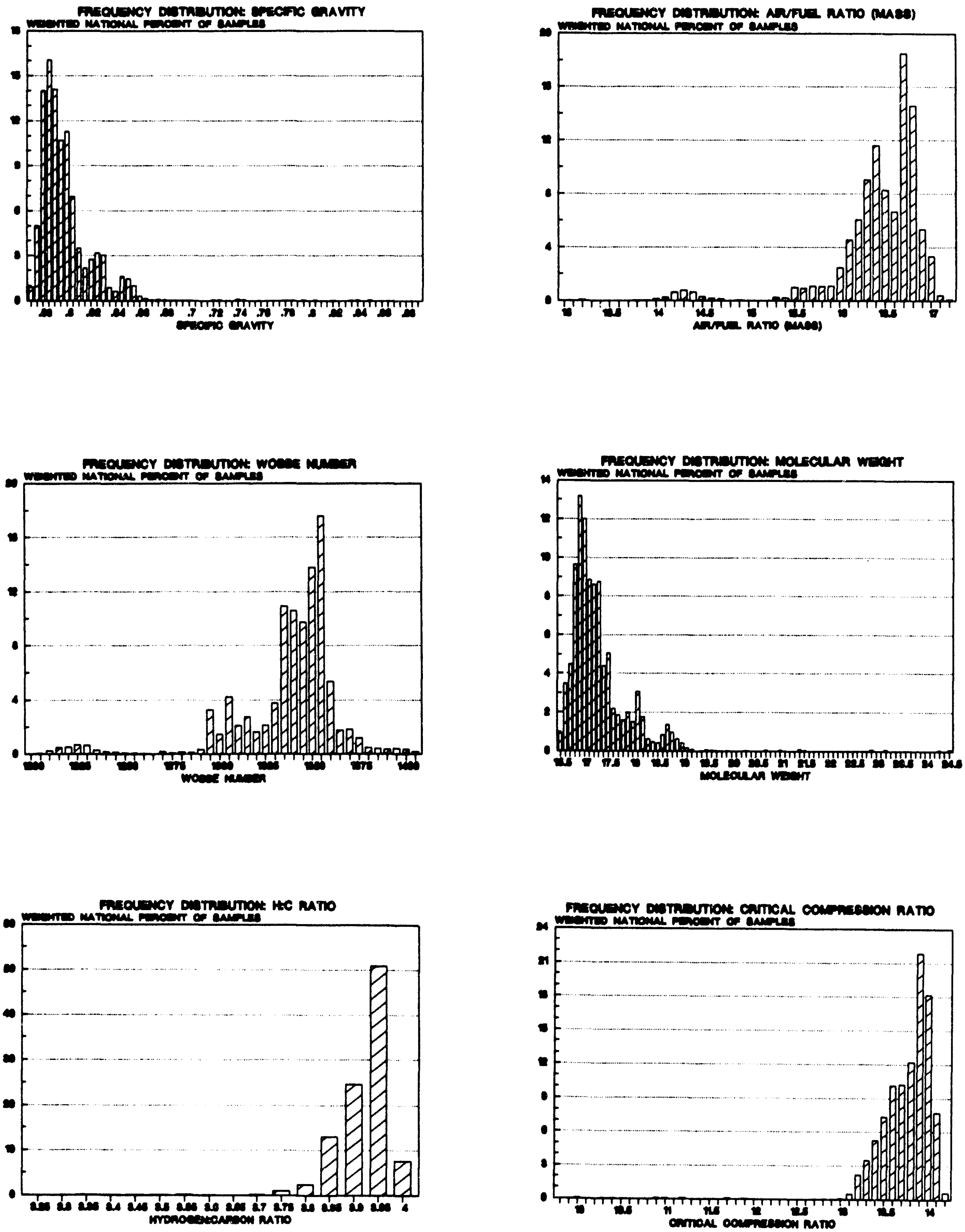


Table 1: Weighted Statistics For Natural Gas In 26 Major U.S. Cities

	Mean	Min. With P/A	Min. W/O P/A	Max. With P/A	Max W/O P/A	10th %-ile	90th %-ile
Methane (Mole %)	93.9	55.8	74.5	98.1	98.1	89.6	96.5
Ethane (Mole %)	3.2	0.5	0.5	13.3	13.3	1.5	4.8
Propane (Mole %)	0.7	0.0	0.0	23.7	2.6	0.2	1.2
C_{4+} (Mole%)	0.4	0.0	0.0	2.1	2.1	0.1	0.6
CO2, N2, O2 (Mole %)	2.6	0.0	0.0	15.1	10.0	1.0	4.3
Heating Value (BTU/scf, HHV)	1033	970	970	1208	1127	1006	1048
Heating Value (MJ/m^3, HHV)	38.46	36.14	36.14	45.00	41.97	37.48	39.03
Wobbe Number (BTU/scf)	1336	1201	1201	1418	1418	1331	1357
Wobbe Number (MJ/m^3)	49.79	44.76	44.76	52.85	52.85	49.59	50.55
Specific Gravity	0.598	0.563	0.563	0.883	0.698	0.576	0.623
Air/Fuel Ratio (Mass)	16.4	12.7	13.7	17.1	17.1	15.9	16.8
Air/Fuel Ratio (Volume)	9.7	9.1	9.1	11.4	10.6	9.4	9.9
Molecular Weight	17.3	16.4	16.4	25.5	20.2	16.7	18.0
Hydrogen/Carbon Ratio	3.92	3.24	3.68	3.97	3.97	3.82	3.95
Lower Flammability Limit, %	5.00	4.30	4.56	5.25	5.25	4.84	5.07

In the broadest sense, fuel changes impact engine operation in three key areas: (1) fuel metering, (2) emissions/power characteristics, and (3) knock potential. These parameters cannot be dealt with independent of each other--e.g., changes in metering accuracy can either increase or decrease emissions/power output as well as increase or decrease potential for engine knock. While recognizing this, these subtopics will be discussed as if each were independent.

Engine Fuel Metering

Like most gas appliances, fuel is delivered to gas engines via a fuel control strategy. This is done either by carburetion or through independent electronic or mechanically controlled valves (orifices). King's SAE paper(3), sponsored by GRI, illustrates basic equations describing natural gas flow through an orifice as well as an explanation of the magnitude of engine operating changes (i.e., effects) that would occur when switching between two different fuels (i.e., cause). An equation from this paper shows the following approximate relationship[1]:

1. Wobbe Number (WN) is a measure of energy flow rate through an orifice and is found by $WN = HV/\sqrt{S.G.}$. Equivalence ratio (phi, ϕ) is the actual fuel/air ratio divided by the stoichiometric fuel/air ratio (F_s). Q_c is heating value per pound and generally around 20,000-21,000 BTU/lb (LHV); HHV values are about 10% higher than LHVs.

$$\phi_2 = \phi_1 * (WN_2/WN_1) * [(Q_{c1}/Q_{c2}) * (F_{s1}/(F_{s2})]$$

In its most simplest approximation, this relation can be distilled by dropping the Q_c and F_s ratio terms because their product tends to be a constant (an interesting chemical phenomenon)[2]. This means that a first-order approximation of fuel metering cause/effect on equivalence ratio is obtained by ratioing the respective Wobbe Numbers of the two fuels as follows:

$$\phi_2 = \phi_1 * (WN_2/WN_1)$$

This relation is shown graphically in Figure 3, which includes a spectrum of fuels. The direct proportionality holds true over a broad range, though the presence of inerts and oxygen/air in the lower Wobbe Number range creates some non-linearity. This relation, while *seemingly* simplistic, goes far in describing the most pervasive manner in which fuel composition impacts gas engine combustion.

In general, Wobbe Number is held fairly constant in the gas industry. The 10-90th percentile span from the fuel survey is 1331-1357, with a mean value of 1336--nominally a ± 1.5% range for most fuels. The maximum and minimum were 1418 and 1201, indicating a broader spread at the fringe. The high-ethane region identified previously has a relatively low Wobbe Number--about 8% from the mean. While different from the norm, this region does tend to have a consistently different fuel--which can aid in recalibrating equipment to this specific region. Higher Wobbe Numbers tend to be encountered in regions located close to production sources. Gases in the 1350-1400 range typically have higher levels on non-methane hydrocarbons and low levels of inert gases.

The analysis linking ϕ and WN is specific to control of a combustion device--i.e., where the concern is the ratio of fuel and air relative to stoichiometry. It is not in principle a mass/volume/energy flow metering scenario. In a classic metering relation, the primary fuel-related issue is molecular weight or specific gravity. From this perspective, the fuel survey showed that the 10-90 percentile span for specific gravity was 0.576-0.623, with an average value of 0.598. This implies that fuel-related metering impacts would be about ±4 percent, whereas the engine/combustion Wobbe Number metering effect is about a factor of two lower in impact. The reason for this significant difference is largely due to the inverse correlation that exists between specific gravity and fuel stoichiometry. That is, there is a partial cancelling effect[3]. This is a perhaps a subtle issue requiring greater elaboration. The author encourages interested people to read King's paper and other sources on this subject.

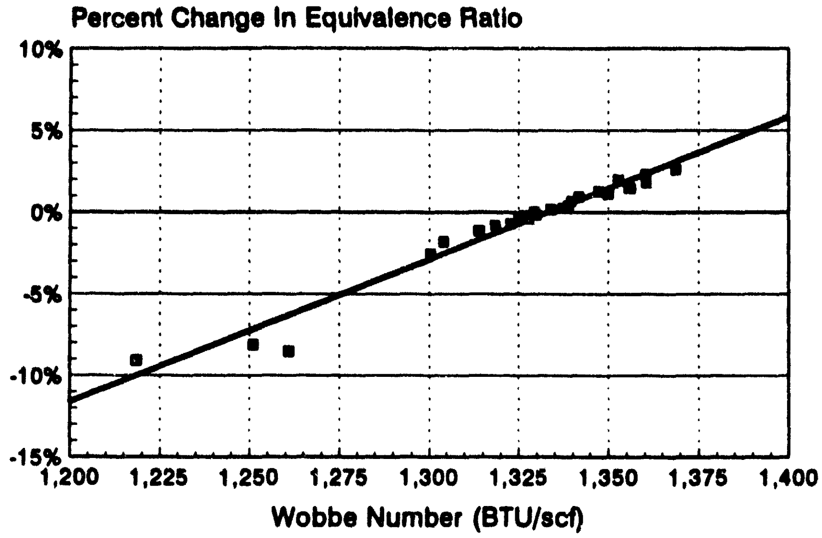
With regard to mass or volumetric metering, the amount of fuel that passes through an orifice under ideal conditions is related to fuel pressure, temperature and properties--basically, density of the fuel. For example, many light-duty NGVs operate with fuel injector pressures around 100 psig. At 90 psig, fuel density in the rail drops by 8.8%, yielding a sensitivity of about 0.9% per psig. Temperature-related density sensitivity is on the order of 0.2%/°F at temperatures around 70°F. Obviously, from a metering-only viewpoint, accurate temperature and pressure measurements are at least as important as having a handle on fuel properties.

In closing, it should be recognized that accurate mass or volumetric metering of fuel to an engine is really a means to an end point--it is not the ultimate goal. For this reason, the author refrains from mentioning mass air/fuel ratio and focuses exclusively on equivalence ratio--the ultimate goal. This will

---

2. A broad range of natural gas fuels have an amazingly narrow $Q_c * F_s$ value of 1378-1380 BTU (HHV) per pound of air consumed (under stoichiometric combustion conditions). This relates to molecular structure and H/C ratio of the fuel. Hydrogen has a value of 1393, gasoline is about 1371, and diesel fuel is about 1281. Note that the presence of oxygen in the fuel affects this value considerably.

3. The GRI fuel survey shows the following relation between specific gravity and stoichiometric A/F ratio (mass basis). $S.G. = -0.0252 * (A/F)_s + 1.007$ with an R^2 of 0.9.



Choked-Flow Conditions, Baseline U.S. Average

Figure 3: Impact Of Wobbe Number On Equivalence Ratio

be elaborated on in the next section. In general, Wobbe Number (a key determinant for engine metering) is kept fairly constant in the gas industry (though some excursions do exist).

Engine Emissions/Performance

Many factors influence the emissions and operating performance of reciprocating engines. For those interested in this topic, two resources are recommended(4)(5). Details of this area are beyond the scope of this paper, but a linkage will be drawn with the previous discussion of fuel metering accuracy.

As a quick primer, gas engines fall into two broad classes: (1) stoichiometric (or "rich" burn) and (2) lean burn. Stoichiometric engines operate near the chemically correct mixture of air and fuel (i.e., $\phi = 1.0$) and are often equipped with three-way catalysts for control of NOx, CO, and non-methane hydrocarbon emissions. Exhaust oxygen sensors are used for feedback correction. These concepts are broadly applied on today's automobiles. The exhaust oxygen sensor is critical in that it helps correct for changes in engine condition, ambient conditions, and fuel properties.

Lean-burn gas engines operate with a large excess of air--ϕ is generally on the order of 0.6-0.7 for low-emission open-chamber lean-burn engines, while prechamber and dual-fuel engines run even leaner ($\phi = 0.46$-0.6). With turbocharging, lean-burn engines can provide low NO_x emissions and excellent full-load fuel efficiency (on the order of 36-44%, LHV depending on size and combustion system). Due to the general lack of suitable oxygen sensors, however, most of these engines operate in an "open-loop" control mode. That is, there is no feedback correction to accommodate engine, ambient or fuel changes.

Engine engineers spend many hours in engine development using dynamometers to characterize (i.e., "map") an engine. In today's climate, most of this is in fine tuning trade-offs between efficiency, power, knock limit, and emissions. In some instances, this can be a delicate balance. While obtaining low emissions in the laboratory is generally possible, an even greater challenge is to devise sensors, controls and algorithms which are capable of ensuring that "in-use" emissions are on par with lab results. This is the primary purpose of On-Board Diagnostic requirements for vehicles.

The main overriding parameter for achieving emissions consistency is equivalence ratio (ϕ, phi)--especially for premixed combustion process (note that λ, lambda, is the inverse of ϕ and termed the excess air ratio). This is well established in the literature (see Heywood) and confirmed in single-cylinder engines tests conducted by Southwest Research Institute (SwRI) for GRI(6). These tests showed no statistically significant emission effects from widely different natural gas fuels when engine equivalence ratio was held constant (reinforcing the need for control of ϕ).[4]

For most engines, NO_x control is the most difficult challenge. NO_x vs ϕ trade-off sensitivity for stoichiometric and lean-burn engines are different. On stoichiometric engines, slight changes in ϕ (e.g., 1-2 percent) to the lean side can result in dramatic increases in NO_x due to the abrupt drop-off in catalyst NOx reduction efficiency when operating lean of the peak catalyst efficiency point (which generally exists around $\phi = 1.005\text{-}1.01$). Figure 4 shows this relation. This sensitivity virtually mandates a feedback oxygen sensor to correct for all factors which influence ϕ (which includes factors beyond just fuel). Running slightly richer has less severe impact--CO and HC emissions increase marginally, but NO_x removal stays high. For this reason, stoichiometric gas engine controls typically have a strong rich bias.

The challenge for stoichiometric fuel control systems is to devise adaptive learning strategies that can recognize and accommodate expected changes in fuels and other parameters. Discussions with control experts gives indications that some existing adaptive learning strategies can effectively accommodate a broad range of natural gas fuels. (However, not all control systems are as evolved.) Presuming such systems become commonplace in the future, it is the author's opinion that combustion/emissions fuel effects on stoichiometric, naturally aspirated gas engines will likely be of minimal concern on the vast majority of natural gas fuels.

Lean-burn engines also have sensitivity to fuel/air metering accuracy, though not as dramatic as stoichiometric engines. When operating richer--e.g., with a higher Wobbe Number fuel--engine power and NO_x levels increase and knock potential increases. When operating leaner--e.g, with a lower Wobbe Number fuel--the opposite effects will occur (up to a limit). If run too lean, the engine moves beyond the flammability limit of the fuel, resulting in misfires, hesitation and possibly stalling. In practice, the cause/effect relation between fuel changes on lean-burn engines depends on the "degree of lean-ness." In general, the margin for fuel metering is about ± 5 percent with open-chamber, low-emission lean-burn engines operating near $\phi = 0.675$ (though manufacturers will state that other factors "eat up" some of this margin). This is shown in Figure 5. Obviously, if the engine is running right at the "lean limit" decreases in Wobbe Number could shift the equivalence ratio beyond the flammability of the fuel[5]. As in stoichiometric engines, use of exhaust feedback control systems can be a solution to fuel shifts. Reliable, durable, and cost-effective feedback sensors (e.g., wide-range oxygen sensors) are needed for most low-emission lean-burn engines.

In closing, experience with engines has shown that accurate control of ϕ is the primary goal for repeatable engine emissions and performance (at least those using spark-ignited, homogeneous combustion). Closed-loop exhaust oxygen sensors and adaptive learning algorithms are seen as the most direct, pragmatic approach to achieving this end given the known or expected variability in engine condition, ambient conditions, and fuel properties. Reliance on equipment-based solutions is warranted

---

4. The importance of ϕ on engine operation cannot be overemphasized. Evaluation of engine operation or emissions based on air/fuel ratio is of questionable value. For example, an air/fuel ratio of 16.5:1 will be lean on some fuels while rich on others--air/fuel ratio must be referenced to stoichiometry to be put into proper context.

5. As discussed in King's paper, a shift in Wobbe Number may also result in a fuel with a slightly different flammability limit. This could alter the equivalence ratio at which the lean-limit exists.

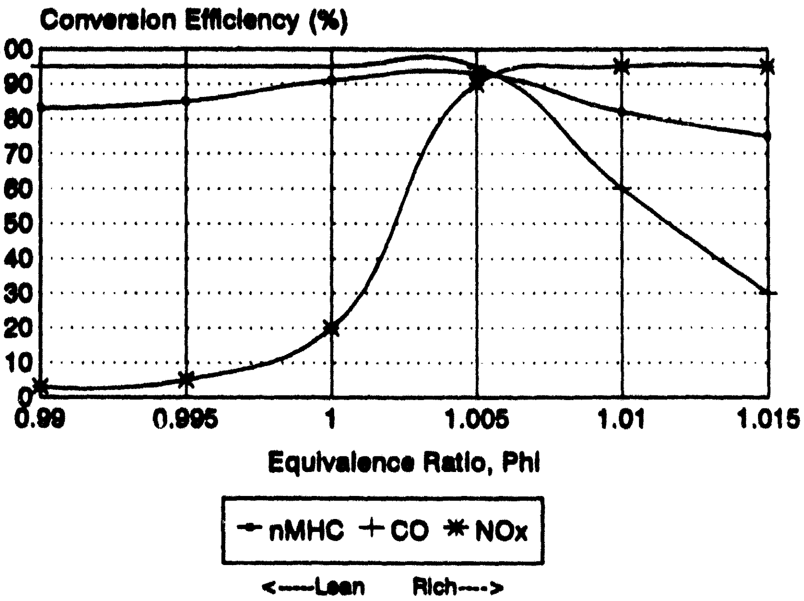


Figure 4: Influence Of Equivalence Ratio On Three-Way Catalyst Efficiency

given the low probability that wholesale changes in the operations of the natural gas industry will transpire over near-term (due to the low volumes of fuel used by engines compared to other natural gas markets).

Gas Engine "Octane Rating" and Knock Resistance

Gasoline users are familiar with the terms Octane and Octane Number. In essence, Octane Number is a non-dimensional value obtained by comparing a test fuels' resistance to knock relative to two reference fuels on a specific test engine. There are other less-common knock rating methods, such as Performance Number and Methane Number (for gaseous fuels), but Octane Number is the most widely known.

GRI-sponsored research performed at SwRI by Kubesh has applied ASTM Octane Rating methods to various natural gas fuels. These data are documented in a GRI report(7) and companion SAE paper(8). These tests show that pure methane has a Motor Octane Number (MON) index of approximately 140. Most natural gases have MONs in the range of 115-130, while peakshaving gases containing high levels of propane (e.g., 17-25%) have MON ratings of 105-110. Pure propane has a rating of about 96-97.

Kubesh developed two mathematical relations that can be used to estimate MON rating of natural gas fuels. The range of applicability of these relations cannot be stated with certainty, but it is believed to cover most conventional fuels containing saturated (i.e., paraffinic) hydrocarbons.

Linear Coefficient Relation

$$MON = 137.78*Methane + 29.948*Ethane + (-18.193)*Propane + (-167.062)*Butane + 181.233*CO_2 + 26.994*N_2$$

Where Methane is equal to methane mole fraction, Ethane equals ethane mole fraction, etc.

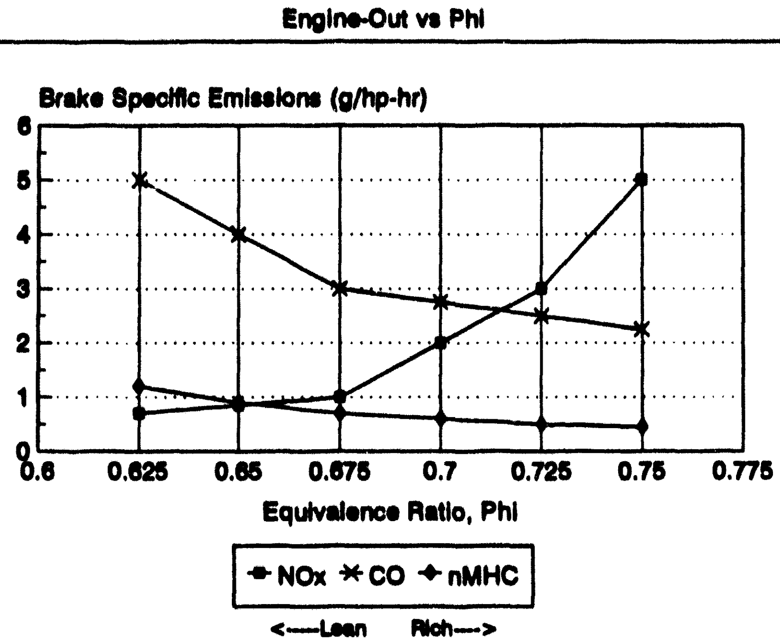


Figure 5: Influence Of Equivalence Ratio On Lean-Burn Engine Emissions

Hydrogen/Carbon Ratio Relation

$$MON = -406.14 + 508.04 * H/C - 173.55 * (H/C)^2 + 20.17 * (H/C)^3$$

Where H/C is the ratio of hydrogen atoms to carbon atoms.

These equations both provide an excellent fit to the experimental data points. Figure 6 is a graphical representation of the H/C vs MON relation.

To (possibly) help put the Octane Number scale into context, the author has modified an exhibit by Heywood[6] and incorporated data from Kubesh's work and Westbrook et al(9). Figure 7 shows the Research Octane Number[7] for a broad range of saturated (i.e., paraffinic or alkane) hydrocarbons containing up to eight carbon atoms. The basic trends are:

- Long, straight chains (i.e., "normal") hydrocarbons decrease in RON value significantly. For example, methane has a RON value of about 140 while n-heptane has an RON value of 0.
- Hydrocarbon branching generally increases RON value.

However, a simple mixing relationship cannot be used to predict the Octane Rating of a mixture of individual hydrocarbons. This is clear from the linear coefficient relationship--each hydrocarbon has a weighted impact on knock resistance. Thus, Figure 7 is mostly of academic interest--empirical

---

6. Ibid., p 472.

7. The author has shifted between Motor (MON) and Research (RON) values because Westbrook's data only showed RON values. MON values are lower than RON due the greater severity of the MON test. On gasoline pumps, consumers normally see the average of the two [(R+M)/2].

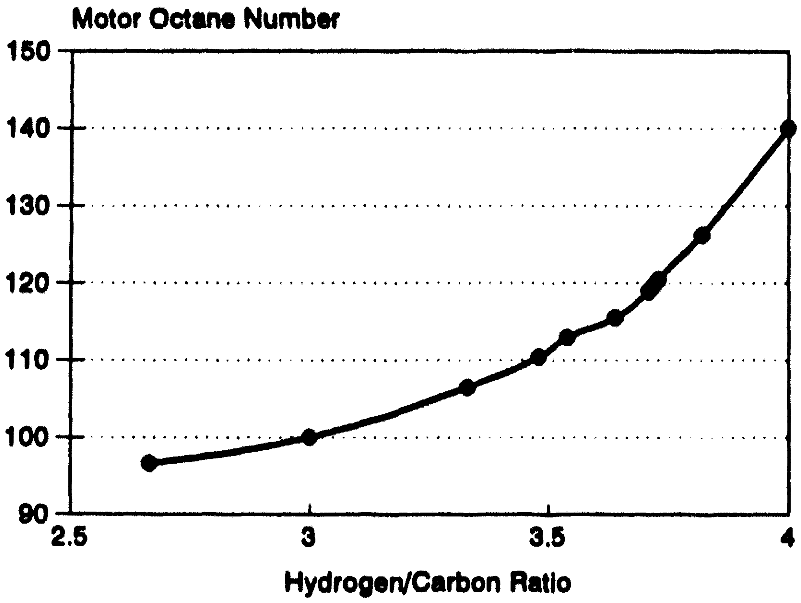


Figure 6: Correlation Of Motor Octane Number and H/C Ratio

testing is the best means of accurately determining the Octane Number of a fuel mixture.

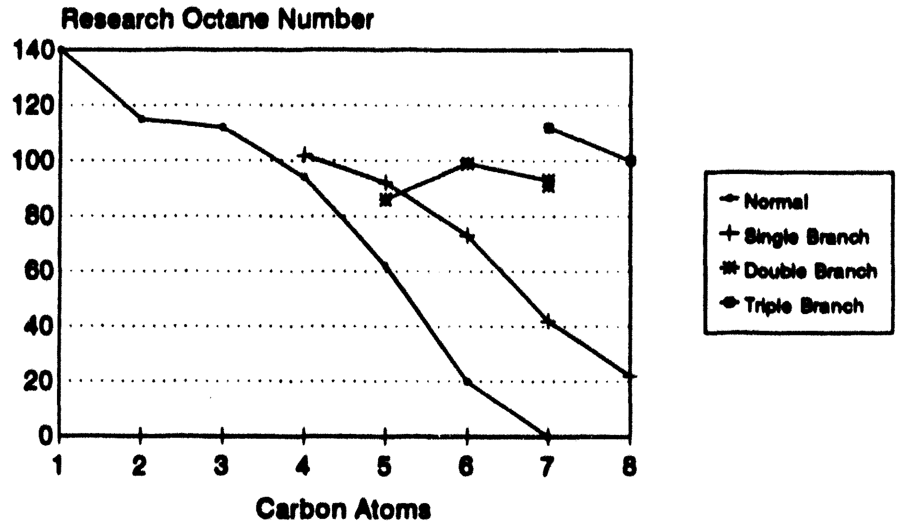
In closing, Kubesh's empirical data shows that the Octane Number of nearly all conventional natural gas fuels is extremely high on this scale. A mixture of 75% methane and 25% propane exhibited an estimated (R+M)/2 anti-knock rating of 112. From a knock resistance viewpoint, even the most outlandish gas blends have knock resistance much greater than commercial gasolines.

Gas Compression and NGV Refueling

Virtually all end-use delivered natural gas was once in a compressed state...interstate gas transportation normally occurs at 1000-1500 psig (or higher). The concept of compressing and handling high-pressure gas is not new to the gas industry. Despite this, NGVs go beyond typical transmission pressure levels (e.g., 3000-4000+ psig). What are some of the fuel issues associated with compressed gas at these levels? Examples include water content and water dewpoint, hydrocarbon dewpoint, compressibility factors, pressure-volume-temperature relations, compressed energy content, and others. These are all important factors influencing gas compression, refueling operations, retail metering, as well as vehicle operation and range. The following text will discuss some of these factors.

Heating Content, Gas Density and Vehicle Range

The most important aspect of NGVs is their fuel storage capability and driving range, which is dictated mainly by vehicle design (storage volume, tank pressure rating, and fuel economy) as well as the ability of the refueling station to *correctly* fill the tanks. Ultimately, the figure-of-merit is the amount of energy in the on-board storage tanks--which takes into account fuel heat content and compressibility. How does fuel composition relate to this? Further, the industry appears to be heading towards a unit of retail measure termed the "gasoline gallon equivalent" (GGE)--what is this and how does fuel alter this index?



SAE 912314 (Westbrook, Pitz, Leppard)
SAE 922359 (Kubesh, King, Liss)

Figure 7: Relation Between Carbon Number, Branching, and Research Octane Number

The author believes that a nominal heating content for gasoline is 114,000 BTU/gallon (lower heating value--LHV). Using an average natural gas composition as shown in Table 2, it can be estimated that 123 scf of natural gas equal a gallon of gasoline [GGE = (114,000 BTU/gallon)/(926.2 BTU/scf)]. This is an apples-apples comparison of both fuels, using lower heating values.[8]

Ideally, NGV stations should operate in a fashion that provides a constant energy density (BTU/ft³) of compressed gas. However, much to the consternation of the gas industry, stations do not even always fill tanks to the proper pressure levels. To elaborate, compared to the ideal fill at 3000 psig @70°F, 2400 psig gives 18.2% less energy, 2600 psig gives 11.7% less energy, 2800 psig gives 5.6% less energy, and 3600 psig gives 14.3% more energy. Pressure fill inaccuracies result in a 1.4%/50 psig compressed energy sensitivity impact around the set point of 3000 psig and 70°F. Clearly, an accurate fill is an important goal for consistent vehicle range. Temperature compensation (or mass fill concepts) can lead to this ideal(10).

To see the impact of fuel on range, envision a vehicle storage system with a "water" volume capacity of 6.5 ft^3. Using our average fuel, we have 74.49 lbs of fuel at 3000 psig (6.5 ft^3*11.46 lb/ft^3) on board with a total energy content of 1,516,318 BTUs (74.49 lbs*20,356 BTU/lb = 1.516 MMBTU). Assuming a fuel economy of 15 mpg (about 7600 BTU/mile, using 114,000 BTU/gallon), this vehicle should go about 200 miles before running completely out of fuel.

With this baseline, what happens when other fuels are plugged into the calculations of GGE and energy density? Table 3 shows four fuels that are meaningfully different than the U.S. average. The 10th and 90th percentile fuels were taken directly from the fuel survey. The high-ethane was derived from the survey results of one region; the propane/air peakshaving gas is a 20% blend of propane and air (in equal proportions) mixed with 80% of the average fuel.

8. The standard temperature and pressure (STP) reference points are 60°F and 14.73 psia.

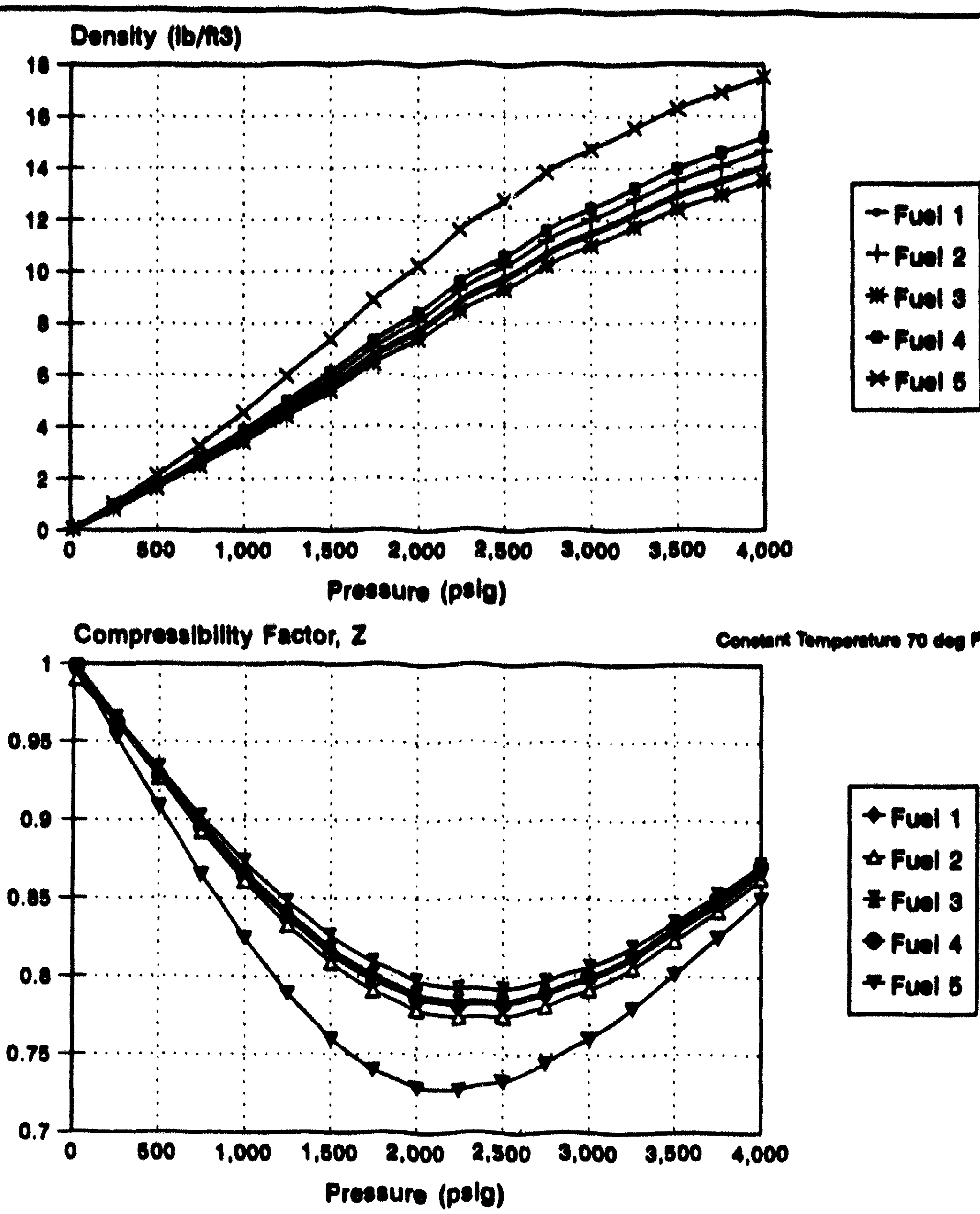


Figure 8a,b: Relationship Of Iso-Thermal Density And Compressibility Factor For Various Fuels

The differences in GGE (at STP) are shown. For the 10-90th percentile fuels, shifts in GGE value are minor--on the order of ± 0.5%. The other two atypical fuels have greater impacts (though the magnitude is not much more than "gasohol" blends have on gasoline).

With regard to <u>compressed</u> gas energy storage density, we see that the 10-90th percentile range for natural gas would have a nominal ±1.4% impact on vehicle driving range--about the equivalent of 50 psig underfill. The two atypical fuels--i.e., the high ethane and propane content--have larger impacts. Figures 8a,b illustrates the reason why compressed energy density is different than the GGE value (which is referenced to standard conditions). This shows how gas density and compressibility factor change with increasing pressure for each of the five fuels under constant temperature conditions. The 10-90 percentile and the average fuel fall within a fairly tight region. The density of the high ethane

Table 2: U.S. Average Composition and Properties

Species	U.S. Avg. (Mole %)	LHV (BTU/scf)	HHV (BTU/scf)	Relative Density	Spec. Volume (ft3/lb)
Methane	93.3	909.4	1010.0	.5539	23.654
Ethane	3.2	1618.7	1769.6	1.0382	12.620
Propane	0.7	2314.9	2516.1	1.5226	8.6059
n-Butane	0.08	3010.8	3262.3	2.0068	6.5291
i-Butane	0.10	3000.4	3251.9	2.0068	6.5291
n-Pentane	0.07	3706.9	4008.9	2.4912	5.2596
n-Hexane +	0.04	4403.8	4755.9	2.9755	4.4035
Carbon Dioxide	0.80	--	--	1.5196	8.6229
Nitrogen	1.71	--	--	0.9963	13.484

Calculated Values Of Average Gas Mixture

LHV (BTU/scf)	LHV (BTU/lb)	Density (lb/ft3, STP)	Density (lb/ft3 @ 3000 psig, 70oF)	Z-Factor(3000 psig, 70oF)	SCF/Gallon
926.2	20,356	0.0457	11.460	0.7988	123.1

Table 3: Comparison Of Five Diverse Fuels

Species (Mole %)	U.S. Avg.	10th %-tile	90th %-tile	Hi-Ethane	P/A Peaking
	Fuel 1	Fuel 2	Fuel 3	Fuel 4	Fuel 5
Methane	93.3	89.6	96.5	82.5	74.64
Ethane	3.2	4.6	1.8	6.9	2.59
Propane	0.7	1.15	0.4	1.0	10.56
n-Butane	0.08	0.10	0.04	0.10	0.06
i-Butane	0.10	0.12	0.06	0.11	0.08
n-Pentane	0.07	0.08	0.04	0.07	0.04
n-Hexane +	0.04	0.05	0.02	0.04	0.02
Carbon Dioxide	0.80	1.30	0.46	0.78	0.64
Nitrogen	1.71	3.00	0.68	7.1	9.18
Oxygen	0.0	0.0	0.0	1.4	2.19
Calculated Values Of Mixtures					
Heating Value (BTU/scf, LHV)	926.2	927.7	921.3	895.8	971.7
Heating Value (BTU/lb, LHV))	20,356	19,663	20,939	18,023	17,352
GGE (SCF/gallon)	123.1	122.9	123.7	127.3	117.3
GGE, % From Fuel 1	--	-0.2	0.5	3.4	-4.7
Density (lb/ft3, STP)	0.0457	0.0474	0.0442	0.0496	0.0559
Density (lb/ft3, compressed)	11.46	11.953	10.98	12.42	14.71
Compressed Energy In 6.5 ft3, (MMBTU)	1.516	1.528	1.495	1.455	1.660
Compressed Energy, % From Fuel 1	--	0.8	-1.4	-4.0	9.5

fuel is marginally higher, though Z-factor vs pressure relationship is virtually identical to the average fuel. Fuel 5, representing the propane/air blend, has a noticeably different density and compressibility relationship and yields a range increase of over 9%. This fuel is obviously different from typical fuels. Note that the values would be different at other temperature points.

In closing, understanding fuel-related range impacts requires more than evaluation of volumetric energy content--the overall determination must include analysis of gas compressibility and density at the final stored conditions. For most typical fuels encountered, there is a relatively minor fuel effect on energy storage density. Propane/air fuels tend to have a more dramatic impact on stored energy density due to their higher molecular weight and *more positive, non-ideal* behavior.[9] While fuels do have an impact on range, in practice the challenge of achieving an accurate temperature- and pressure-compensated fill tends to overwhelm the fuel issue for most conventional natural gases.

Water Content

One of the more contentious NGV fuel topics is water. This substance is found in natural gas due to natural absorption, similar to its presence in the air we breathe. Like rain and snow from the earth's atmosphere, water can condense from natural gas if the relative humidity exceeds 100%. Water becomes an issue in NGVs because of the extreme temperatures and pressures that the fuel can be exposed to, including station storage pressures from 3500-4500 psig and possible expansion-induced temperatures (at lower pressures) down to -25°F or lower. Water condensation from natural gas can be as a liquid, an ice or frost, or as a hydrate (a clathrate crystalline compound made up of water and trapped hydrocarbons).

Information on water/natural gas psychrometry is well-documented in the industry(11),(12),(13)(14). The water content of natural gas is typically quoted as a maximum of 7 lbs/MMSCF--in practice, values higher and lower do exist. Using a typical natural gas specific volume of about 21.9 ft^3/lb and a water content of 7 lbs/MMSCF, it can be found that water is about 153 ppm on a mass basis. This effectively is the absolute humidity. Using a water specific volume of 21 ft^3/lb, the volumetric concentration at STP is about 147 ppmv. Using the previous example of a 6.5 ft^3 storage system and 11.46 lbs/ft^3 compressed gas density, it can be found that the entire storage system contains about 0.011 pounds of water--or about 5 grams. Obviously, this is not a lot of mass[10].

While seemingly insignificant, problems can occur if water condenses in a concentrated fashion. Of course, the Joule-Thomson expansion--induced by pressure drop through a restriction--can cause significant gas cooling. The combination of gas cooling and tight piping, filters, or orifices can lead to possible freezing and plugging. In the author's viewpoint, herein lies the crux of the water issue in NGVs.[11]

Figure 9 shows the issue of water content in terms of 100% Relative Humidity (100% RH) as a function of gas temperature at 3000 psig. A condition (i.e., temperature and water content point)

9. Fluid density is inversely proportional to the compressibility factor ($\rho \propto 1/Z$). Lower Z-factors provide the opportunity for higher densities than expected by ideal gas-law calculations.

10. The author made a reference previously to air and condensation (rain and snow). It is important to note that natural gas has a water holding capacity (i.e., absolute humidity) that is two orders of magnitude (100 times) lower than air--these are really different fluids.

11. The issue of water-induced corrosion is often raised. While not meaning to trivialize an important safety issue,especially out of ignorance, the author is skeptical on this subject given the excellent track record of compressed gas cylinders for NGVs. Freezing is a more immediate, tangible issue. Further, most condensation is presumed to occur at low temperatures where condensate is a solid which is not an effective medium for corrosion processes.

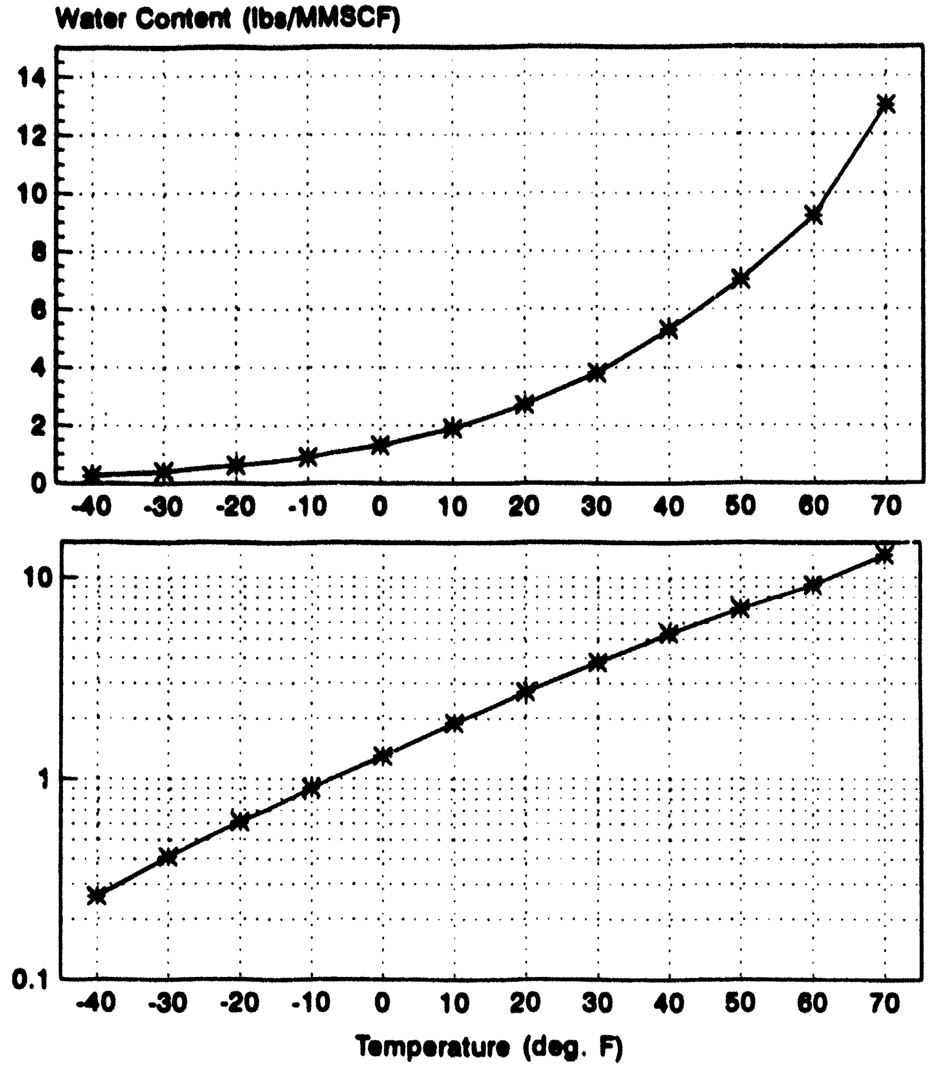


Figure 9: Natural Gas Relative Humidity

above the line represents an over-saturation condition--some form of condensation would occur to bring it down to the 100% RH line. Points below the line should be free of condensate. The amount of water that will condense is the difference between the specific condition and the 100% RH point for that temperature. At these elevated conditions, it becomes probable that water forms as a solid--certainly below 32°F. Even above this point, a solid water phase can form as a hydrate--even at temperatures up to 70°F.

To elaborate, take a gas with a water content of 7 lbs/MMSCF at 3000 psig, 70°F--just slightly below 100% RH. Assume further this gas was cooled by a drop in ambient temperature to 30°F. The saturated water content at this point is about 3.75 lbs/MMSCF at 3000 psig (in reality, tank pressure would drop to about 2500 psig, but this effect on water holding capacity is relatively small and will be ignored). Taking the difference, this implies about 3.25 lbs/MMSCF of water should condense--in this case, completely as a solid. Using the 6.5 ft^3 tank scenario, we have approximately 1630 *standard* cubic feet of compressed gas which implies about 2.4 grams of water should condense. Is there any wonder that water is such a controversial issue in the NGV industry? Can so little mass cause *real* problems? No doubt some areas have higher water content, but many areas of the country have even drier gas.

Presently, control of water content is predicated on preventing any form of condensation under the most extreme winter weather conditions. In the viewpoint of many, this is seen as an extreme requirement. Referring back to Figure 9, note the leveling off of this curve as temperature drops to about 10°F. As temperature decreases further, the absolute humidity appears to approach a horizontal asymptote----i.e., a point of diminishing return seems to exist. Yet, even at extremely cold temperatures a dewpoint exists (as shown in the bottom portion where the same data are displayed on a logarithmic scale). The water holding capacity continues to decrease, but the question is, so what? For example, between -10 and -20°F the water holding capacity of natural gas has drops about 0.3 lb/MMSCF. In our 6.5 ft^3 tank scenario, we're talking about possible condensation of about 0.2 grams. Is this worthy of concern? When does water become a *de minimis* concern and dewpoint become an essentially meaningless measure? These are difficult questions to quantitatively answer.

In closing, it is likely that water will continue to remain a controversial topic in the industry. Anecdotal evidence exists on both sides to substantiate either the need or ridiculousness of tight water control measures. One point is clear to the author: dewpoints, while a measure of dryness, become of questionable worth at temperatures below about 10°F. It appears there comes a point where the specter of water problems (operational or safety-related) becomes a matter more of academic debate rather than practical concern. Hopefully, at some point in the not too distant future an acceoptable and justified limit on NGV water content can be found.

Lubricating Oils

Lubricating oil is often present in natural gas either from oil carryover from gas transmission compressors or from NGV refueling compressors. For NGVs, refueling compressors tend to have the potential for being the larger source. The actual amount of oil carried over during compressor operation is dependent on the design of the compressor, the wear on rings and liners, and (if used) the removal efficiency of coalescing filters.

The potential negative or positive role of lube oils in NGVs is uncertain. Anecdotal evidence exists that high levels of lube oil can cause build-up of liquids in tanks and regulators, possibly influencing the performance of the latter. Conversely, one could speculate that trace levels of lubricating oil may have a beneficial effect by coating internal metal surfaces (i.e., acting as a corrosion inhibitor) and possibly lubricating moving parts in the system.

It appears that several NGV station operators are tending toward non-lubricated compressors, watching more closely the level of oil consumption on lubed compressors, or installing coalescing filters downstream of the unit. Recent unreported and draft data from Powertech Labs, in work sponsored by the Canadian Gas Association(15), revealed coalescing filter oil removal efficiency of about 75% on average, with a span of 60-97% (six different samples). More information and insight is needed on this subject.

Propane-Air Peakshaving

Propane-air (P/A) peakshaving is a method used by some gas utilities to meet peak fuel demand--generally during cold winter periods. P/A plants are owned by only a portion of the industry and many of these are used sparingly. P/A plants nominally prepare a mixture of 50% propane and 50% air, having a heating value of about 1258 BTU/scf (HHV). This mix is then capable of being blended with natural gas. In practice, when use, P/A levels typically are on the order of 10-30% send out, though higher levels may be used during extreme periods.

In gas distribution systems, P/A is an acceptable medium for transporting energy to the customer. At low pressures (e.g., up to a few hundred psig) and typical ambient temperatures, P/A has a high level of solubility in natural gas. However, for NGVs, high levels of propane, elevated pressures and low temperatures can cause liquids to form. The condensation behavior of these mixtures is mostly dependent on (1) the amount of propane present and (2) the fuel temperature. Pressure has an impact, but only up to the critical point. To elaborate, Figure 10 is a phase diagram (or "envelope") of a natural gas/propane mixture (about 10.5% propane). Within the envelope, a distinct two-phase region of liquid and gas exists. Outside of this region, only one phase exists. The interpretation of this single fluid phase can be rather subjective. To the left of the envelope and below Pt. C, (the critical point) it can be called a liquid; to the right and below C it can be called a gas. Those points above Pt. C (and outside the phase envelope) are best referred to as highly compressed fluids of varying denisty. To reinforce the point, when NGV storage pressure goes above the critical point (typically ranging from 900-1500 psig depending on composition), the *gas* should really be considered a critical, high-density, single-phase fluid.

Adding propane to natural gas has the effect of extending the phase envelop to the right--i.e., raising the temperature at which condensation can occur. This increases the potential for liquids to form at typical winter conditions. To document this area, GRI has been undertaking modeling analysis with SwRI using an established commercial software package(16). The model is constructed to simulate the depressurization of a compressed gas storage tank--i.e., simulating engine fueling and dropping of pressure from a condition where the fluid is in a critical state. Nominally, the model goes from about 1800 psig to about 100 psig in 20 finite steps. Fuel temperature is held constant.

Figure 11 shows typical results. These data are a 75 mole% blend of natural gas with a 25% blend of P/A--overall, the propane level was about 13.5%. The figure shows that initially there is no change in gas-phase concentrations because the fuel is above the critical point. However, at a pressure of 1500-1600 psig there is a change in the concentrations of the gas-phase methane and propane. Effectively, the fluid has entered the two-phase region and a liquid phase has formed. The liquid is comprised mostly of propane and other heavy hydrocarbons. The transfer of mass from the gas phase to the liquid phase increases the methane concentration in the gas phase. As pressure is further

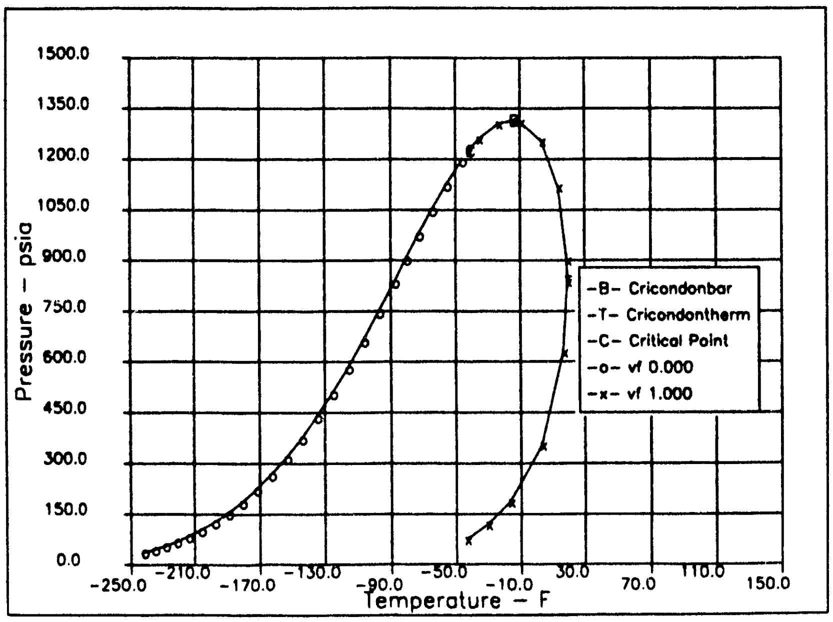


Figure 10: Pressure vs. Temperature Phase Envelope

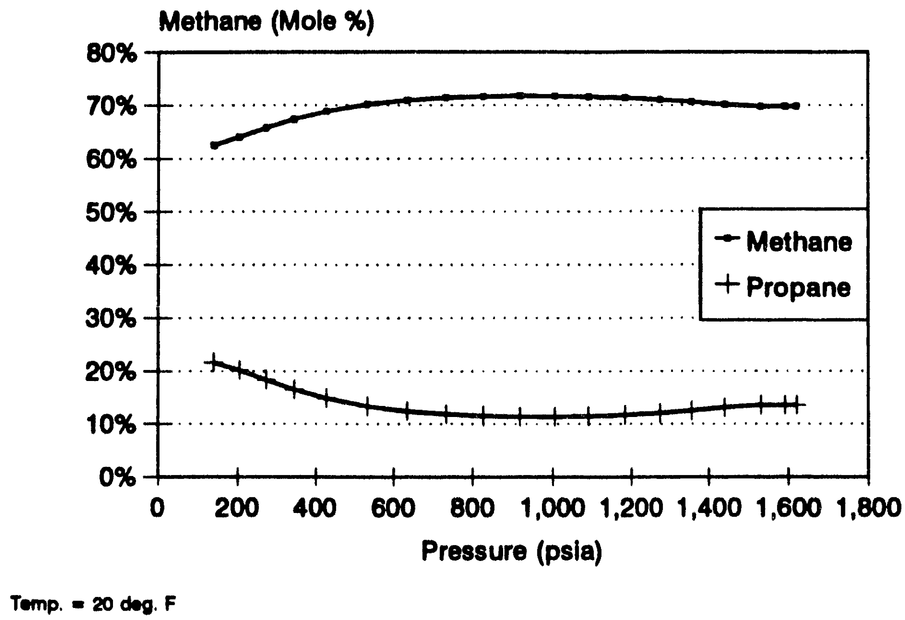


Figure 11: Depressurization Of A Natural Gas/Propane-Air Mixture

decreased, a minimum point is found at around 900 psig. Further drops in pressure are increasing the solubility of the liquid constituents in the gas as the mixture approachesw the right-most border of the envelope--i.e., the dewpoint curve. At low pressures, conditions exit the two-phase region and the revaporized liquid results in a final gas-phase propane concentration greater than the starting point. The greater the amount of liquid that forms initially, the greater the final propane concentration will be.

In closing, it should be recognized that P/A is not a widely used practice in the gas industry. However, for regions of the country where it is used, station operators and users should recognize that high levels of propane and low temperatures can result in liquid hydrocarbon condensation--which in turn can negatively impact station and vehicle operation.

Liquefied Natural Gas

Liquefied natural gas (LNG) is an attractive NGV fuel option because of its high energy density and lighter weight tanks (i.e., when compared to compressed gas). LNG seems to be especially attractive for use in heavy-duty engine and long-haul applications (e.g., locomotives, over-the-road trucks).

The primary fuel issue with LNG is its storability or *shelf life*. Testing and modeling work carried out by SwRI for GRI partially documented LNG NGV weathering and enrichment issues(17)(18). These data reveal that either limiting the flux of heat to LNG or quickly (e.g., within 4-7 days) using the fuel is of paramount importance. Either poorly insulated tanks (including those which loose their vacuum) or long storage periods can result in boil-off gas losses. The repeated withdrawal of these gases can result in a liquid which progressively becomes more concentrated with heavier hydrocarbons.

This phenomenon can become severe when the tank liquid level falls below ~1/4 full. This is shown if Figure 12, where the term "boil-off rate" refers to the proportion of system mass removed via the gas phase. At high liquid tank levels it is virtually impossible to alter the methane concentration (i.e., a high level of inertia exists). However, as the liquid level drops the amount of mass in the system

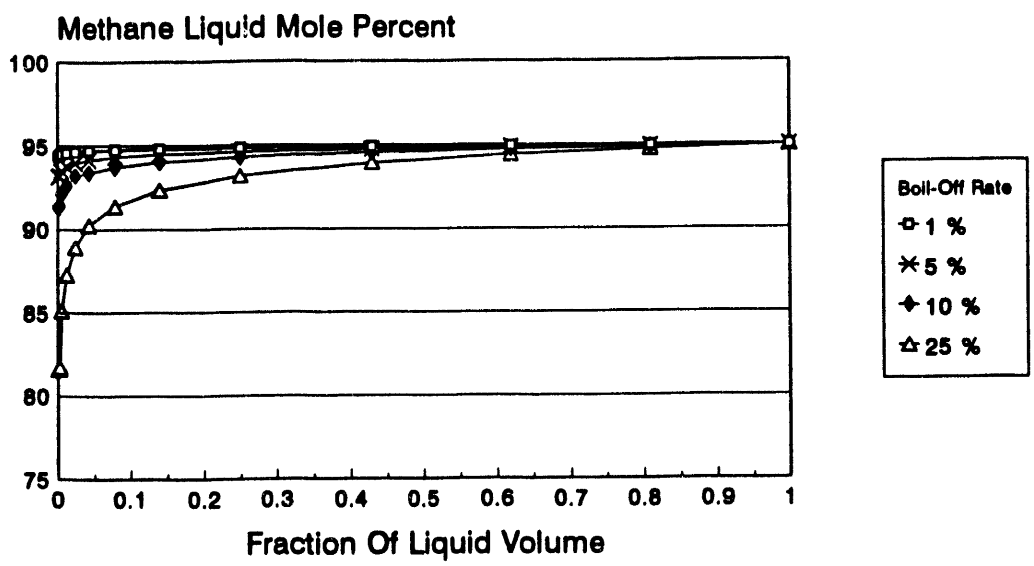


Figure 12: LNG Weathering Effects

decreases and the removal of boil-off gases can more meaningfully alter the liquid composition. For this reason, it is usually wise to keep LNG storage tanks filled. This helps increase the inertia (i.e., heat capacity) of the system. This latter point is believed to be important because the heat flux (or heat "leak") rate to the tank (BTU/hr) remains virtually constant regardless of the amount of liquid in the tank. That is, a tank containing small levels of liquids will have a higher specific rate of vaporization (i.e., moles vaporized/moles remaining) than a full tank--increasing the enrichment rate.. If LNG is left idle too long, it can effectively spoil (i.e., decrease in methane concentration). LNG has a finite shelf life.

SUMMARY

This discussion of fuel issues for NGVs goes into detail regarding potential cause/effect relations. An effort has been made to put these into context with other issues--such as sensitivities to measurement errors, requirement for advanced controls, etc. The reader should recognize that the practical reality is that NGVs are fully operational with the situation as it exists today. In most cases, equipment has a high level of tolerance to fuel changes. In fact, it should be a principal design challenge to incorporate such capabilities into refueling stations, vehicles, and engines.

By its nature, the discussion of issues and scientific phenomena on this subject tends to bring to light aspects of equipment operation for which even seasoned users are oblivious to and may appear as overly negative. In fact, many of these issues are more academic than practical. If minor effects occur, but are virtually undetectable by the user, do they really matter? From a practical standpoint, the answer is obviously no. However, as interested parties, it is in our collective interest to continue to expand our knowledge base on issues of various levels of importance--both minor or major. This is part of the evolutionary process that will make an already excellent vehicle fuel choice--natural gas--even better.

References

1. Thrasher, W. Liss, W., Steinmetz, G., Chowdiah, P, and Attari, A., "Variability Of Natural Gas Composition In Select Major Metropolitan Areas of the U.S.-Final Report," GRI Report-92/0123.

2. Liss, W. and Thrasher, W., "Natural Gas as a Stationary Engine and Vehicular Fuel," SAE Paper 912364.

3. King, S., "The Impact Of Natural Gas Composition On Fuel Metering And Engine Operational Characteristics," SAE Paper 920593.

4. Heywood, J., "Internal Combustion Engine Fundamentals," McGraw-Hill (1988).

5. Taylor, C.F., "The Internal-Combustion Engine In Theory and Practice," MIT Press (Two Volumes, 1985).

6. Ryan, T, Callahan, T., "Effect Of Gas Composition On Engine Performance and Emissions," Topical Report, GRI-92/0054.

7. Kubesh, J. "Effect Of Gas Composition On Octane Number Of Natural Gas Fuels," Topical Report, GRI-92/0150.

8. Kubesh, J, King, S., and Liss, W., "Effect of Gas Composition On Octane Number Of Fuels," SAE 922359.

9. Westbrook, C., Pitz, W. and Leppard, W., "The Autoignition Chemistry Of Paraffinic Fuels and Pro-Knock And Anti-Knock Additives: A Detailed Chemical Kinetic Study," SAE 912314.

10. Farkas, E., Microprocessor Control Of Natural Gas Vehicle Fast Fills," 1992 International Gas Research Conference Proceedings.

11. Gas Processors Suppliers Association, "Engineering Data Book, Tenth Edition" Tulsa, OK (1987).

12. Segeler, C., "Gas Engineering Handbook," American Gas Association, Industrial Press, New York (1965).

13. Katz, D. et al, "Handbook of Natural Gas Engineering," McGraw-Hill, New York (1959).

14. Sloan, E.D., "Clathrate Hydrates Of Natural Gases," Marcel Dekker, New York (1990).

15. Personal communication with N. White, CGA.

16. Hyprotech Ltd., Calgary, Canada. HYSIM computer software.

17. Liss, W., Okazaki, S., Acker, G., and Moulton, D.S., "Fuel Issues For Liquefied Natural Gas Vehicles," SAE 922360.

18. Acker, G, Moulton, D.S., "LNG Weathering Effects--Theoretical and Empirical," Topical Report, GRI-92/0464.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

FUEL ISSUES FOR GAS ENGINES AND NGV'S

W.E. Liss, Gas Research Institute

Q. Matthew Bol, Sypher:Mueller International: What advice do you have for a utility company that wants NGV business but uses propane-air for peak shaving?

A. It depends on the amount of propane-air used. In low proportions, the mixture would not affect vehicle performance. If high levels of propane-air are needed, it would be preferable to use liquefied natural gas instead of propane-air for periods of peak demand. The utility company could import the LNG or produce it locally in off-peak periods.

Q. Vinod Duggal, Cummins Engine Co.: Do I understand that CNG from pipeline gas does not require a specification for NGV fuel?

A. The NGV market is small proportion of the natural gas market. Having a specification for vehicle fuel is a good idea because it makes the gas industry aware of what is desired. However, it may not accomplish the changes to make such fuel available at all times. It would be more practical to provide closed loop control on vehicles to accommodate fuel variations.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

MAINTAINING FUEL QUALITY: CALIFORNIA'S METHANOL EXPERIENCE

A. Argentine, D. Fong, P. Ward
California Energy Commission

H.J. Modetz
Acurex Environmental Corporation

ACKNOWLEDGEMENTS

Principal Investigators

- Acurex Environmental Corporation
  Henry J. Modetz, Jesse L. Dorogusker
- California EnergyCommission
  Mike McCormack, Jose Palomo, Peter Ward

Technical Consultants

- Ford Motor Company
  Earle Cox
- General Motors Corporation
  Norm Brinkman, Bob Halsall
- Chrysler Corporation
  Mike Berube
- Mitsubishi Motors
  Debbie Bakker
- Nissan Research and Development
  Robert Cassidy

Oil Company Support

- ARCO
  James White
- Chevron
  Greg Lyman
- Exxon
  Dave Allen
- Ultramar
  Rich Meissner
- Mobil
  J.J. Novack
- Shell
  Nancy Curry
- Texaco
  Richard Laughton

SUMMARY AND PURPOSE

* California Energy Commission Demonstration Program involving methanol (M85) fuel flexible vehicles and fuel storage and dispensing facilities.

* Determination of M85 fuel quality.

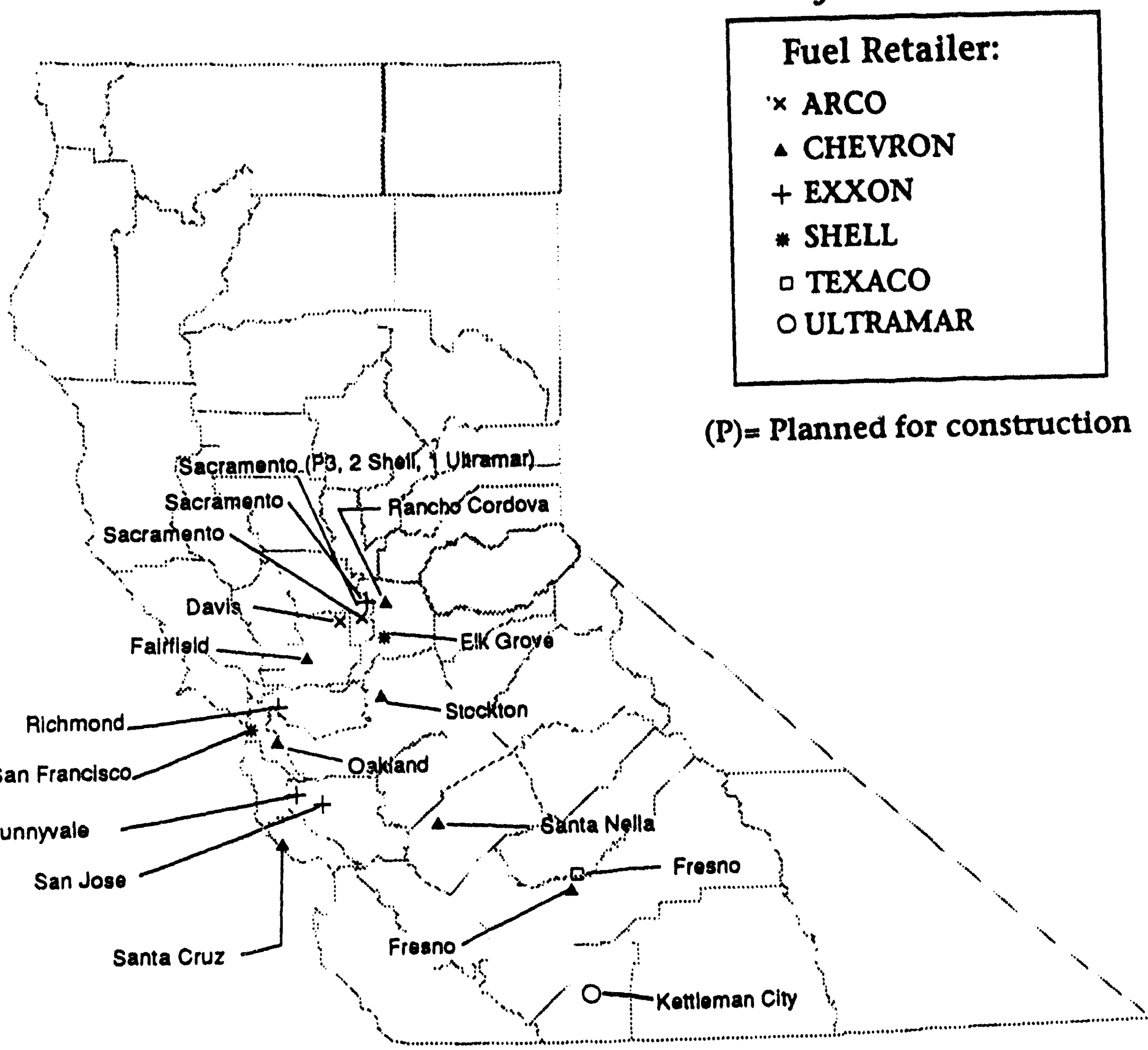
* Identify sources of possible fuel contamination.

* Suggestions for maintaining fuel quality.

CALIFORNIA M85 RETAIL NETWORK

Northern California

June 1993

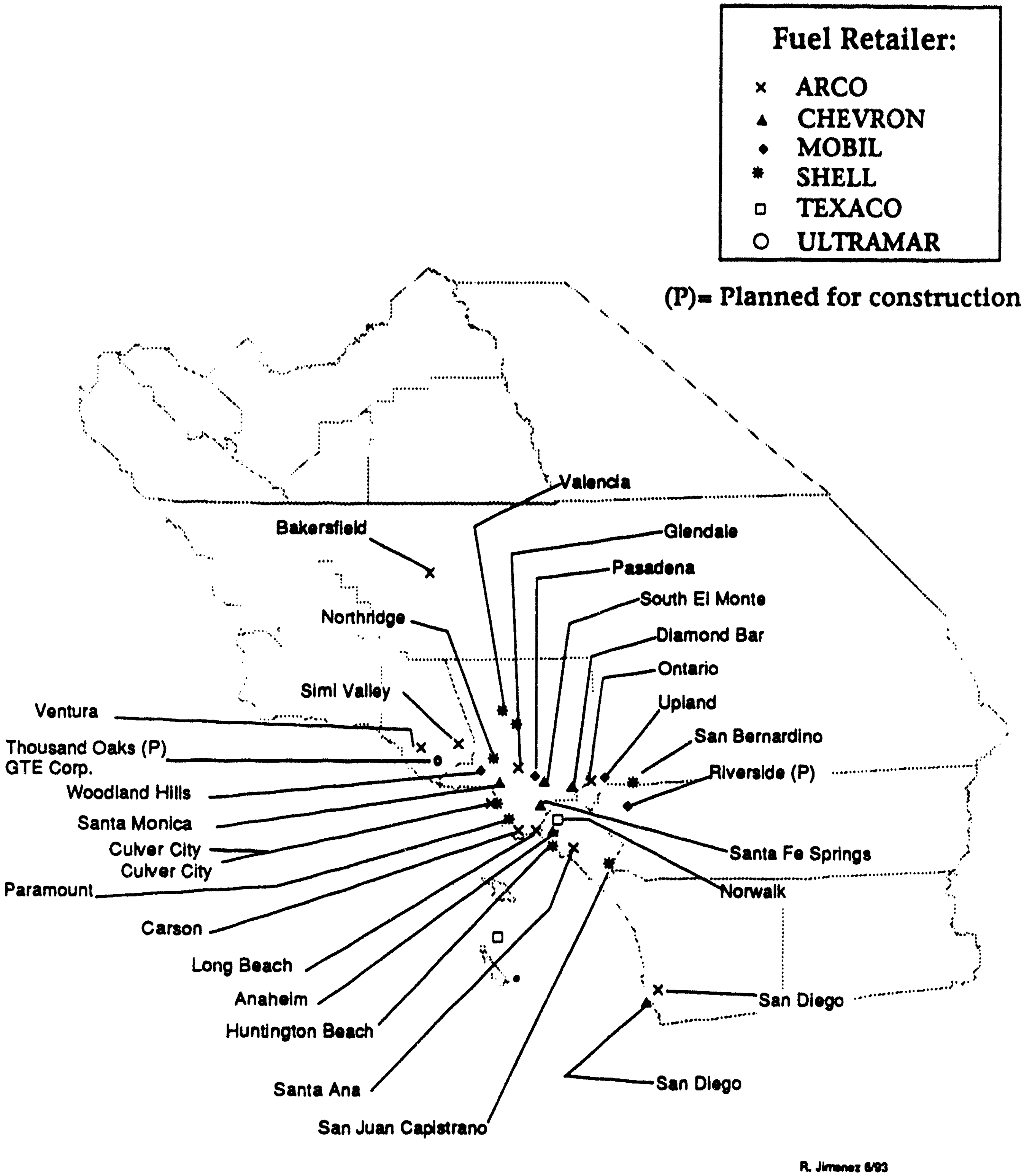


R. Jimenez 6/93

CALIFORNIA M85 RETAIL NETWORK

Southern California

June 1993



THROUGHPUT IN SAMPLED STATIONS, GALLONS

	June 1992	May 1993
Northern California M85 Retail Total	20,595	23,909
High Sacramento	6,778	6,906
Average	1471	1708

	June 1992	May 1993
Southern California M85 Retail Total	26,322	39,461
High Ventura	5,455	7,461
Average	2025	3035

Air Resources Board M85 Specifications

Test Parameter	Test Method	Specification
Particulates, max.	ASTM D 2276-89	0.6 mg/l
Gum, washed, max.	ASTM D 381-86	5mg/100ml
Water, max.	ASTM E 203-75	0.5% by mass
Lead, max.	ASTM D 3329-88	2 mg/l
Vapor Pressure	Methods in Title 13, sec. 2262	7.0 - 13.1 psi (dependent upon geographic area)
Methanol, min.	ASTM D2 Proposal P-232, Draft 8-9-91 (Annex A-1)	84% by volume
Higher alcohols, max.	ASTM D 4815-89	2% by volume
Acidity as acetic acid, max.	ASTM D1613-85	0.005% by mass
Total chlorides, max.	ASTM D 3120-87	0.0002% by mass
Phosphorus max.	ASTM D 3231-89	0.2mg/l
Sulfur, max.	ASTM D 2622-87	0.004% by mass
Hydrocorbons + aliphatic ethers	ASTM D 4815-89	16% by volume
Luminosity	NA	Luminous flame
Appearance	ASTM D 4176-86	Free of turbidity, suspended matter and sedimant

Comparison of M85 Specifications

Test Parameter	ARB	Chrysler	Ford	GM	MVMA
Particulates, max.	●	●	●	○	●
Gum, washed, max.	●			●	
Water, max.	●	●	●	●	○
Lead, max.	●		●	●	○
Vapor pressure	●	●	○	●	●
Methanol, min.	○	●	○	○	●
Higher alcohols, max.	●			●	
Acidity as acetic acid, max.	●		○	●	○
Total chlorides, max.	●		●	○	○
Phosphorus, max.	●		●	●	○
Sulfur, max.	○		●	●	●
Hydrocarbons + aliphatic ethers	●	○		●	○
Luminosity	●				
Appearance	●				
Aromatics	●				
Gasoline (unleaded)			●		
Distillation residue, max.			●		●
Conductivity, max.				●	
Gum, unwashed, max.				●	

○ = Most stringent specification

● = Specification exists

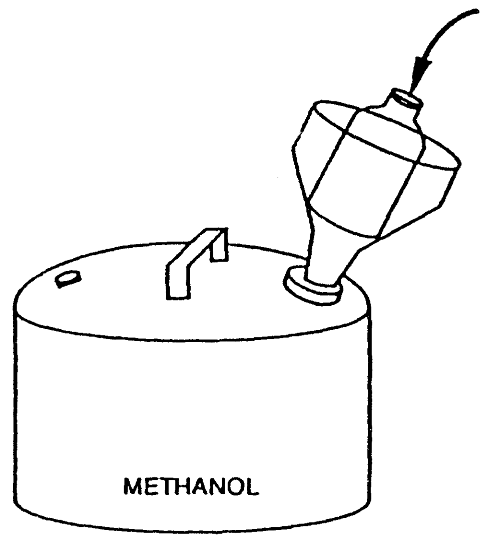
M85 ANALYSIS PROTOCOL

Property	Test Method
Electrical Conductivity	ASTM D 1125
Particulate contaminants, residue solids, and sediments	Modified EPA 160-2
Gum	ASTM 381
Water	ASTM D 1744
Lead content	ASTM D 3237
Sulfates	Ion Chromatography
Dry vapor pressure	ASTM D 4953
Aluminum	Atomic Absorption
Sodium content	Atomic Absorption
Calcium	Atomic Absorption
Iron content	Atomic Absorption
Aromatic content (vol. %)	Capillary Gas Chromatography
Methanol content	Modified ASTM D 4815
Other alcohols	Modified ASTM D 4815
Ethers	Modified ASTM D 4815
Specific gravity at 60 deg. F	ASTM D 1298
Acidity	ASTM D 1613
Total chlorides	Microcoulometry
Phosphorus content	ASTM D 3231
Sulfur content	ASTM D 3120
Refractive index	ASTM D 1218
Chlorinated hydrocarbons*	EPA 8010

*To be performed if total chlorides greater than 1ppm

FUEL SAMPLING METHOD

1. **SAMPLING EQUIPMENT**
   Amber Glass Sample Bottles with Teflon Caps, and Pre-cleaned to EPA Specifications, 5-Gallon Container, Funnel, Conductivity Meter (VWR Model 604, Serial No. 9109139), and Distilled Water



2. RINSE SAMPLE BOTTLES WITH REAGENT GRADE METHANOL

3. WITH 8 OZ BOTTLE IN THE FUNNEL IN THE 5-GALLON CONTAINER, ATTEMPT TO OBTAIN 4 OZ SAMPLE.

   -observe and record visual appearance
   -measure and record conductivity
   -seal and label bottle
   -rinse the conductivity meter cell with distilled water twice

4. OBTAIN A 1 LITER SAMP IN AN AMBER GLASS BOTTLE

FUEL SAMPLING METHOD CONT'D

5. PUMP 4 TO 5 GALLONS INTO THE FFV (OR THE 5 GALLON CAN)

   *Record the time
   *Record the amount of fuel

6. OBTAIN FOUR 1 LITER SAMPLES IN AMBER GLASS BOTTLES

   *Rinse the bottles
   *Discard the rinse into the 5 gallon can
   *Obtain four 1 liter samples
   *Seal and label the bottles

7. STORE THE BOTTLES IN A COOLER WITH ICE

8. TRANSFER CONTENTS OF 5 GALLON CONTAINER TO FFV

Summary of Analytical Results - M85 Retail

Fuel Property	ARB SPEC	Low	High	Mean
Particulates, max. (mg/l)	0.6	0.1	0.8	0.5
Gum, washed, max. (mg/100ml)	5	0.1	4.6	0.9
Water, max. (mass%)	0.5	0.0029	0.1990	0.0204
Lead, max. (mg/l)	2	<1	<1	<1
Vapor pressure (psi)	7.0-13.1	7.0	9.3	7.8
Methanol, min. (vol%)	84	80	87.2	84.6
Acidity as acetic acid, max. (mass%)	0.005	0.002	0.005	0.004
Total chlorides, max. (mass%)	0.0002	<0.0001	0.0003	0.0001
Phosphorus, max. (mg/l)	0.2	<0.03	<0.2	<0.05
Sulfur, max. (mass%)	0.004	0.0004	0.0033	0.0017

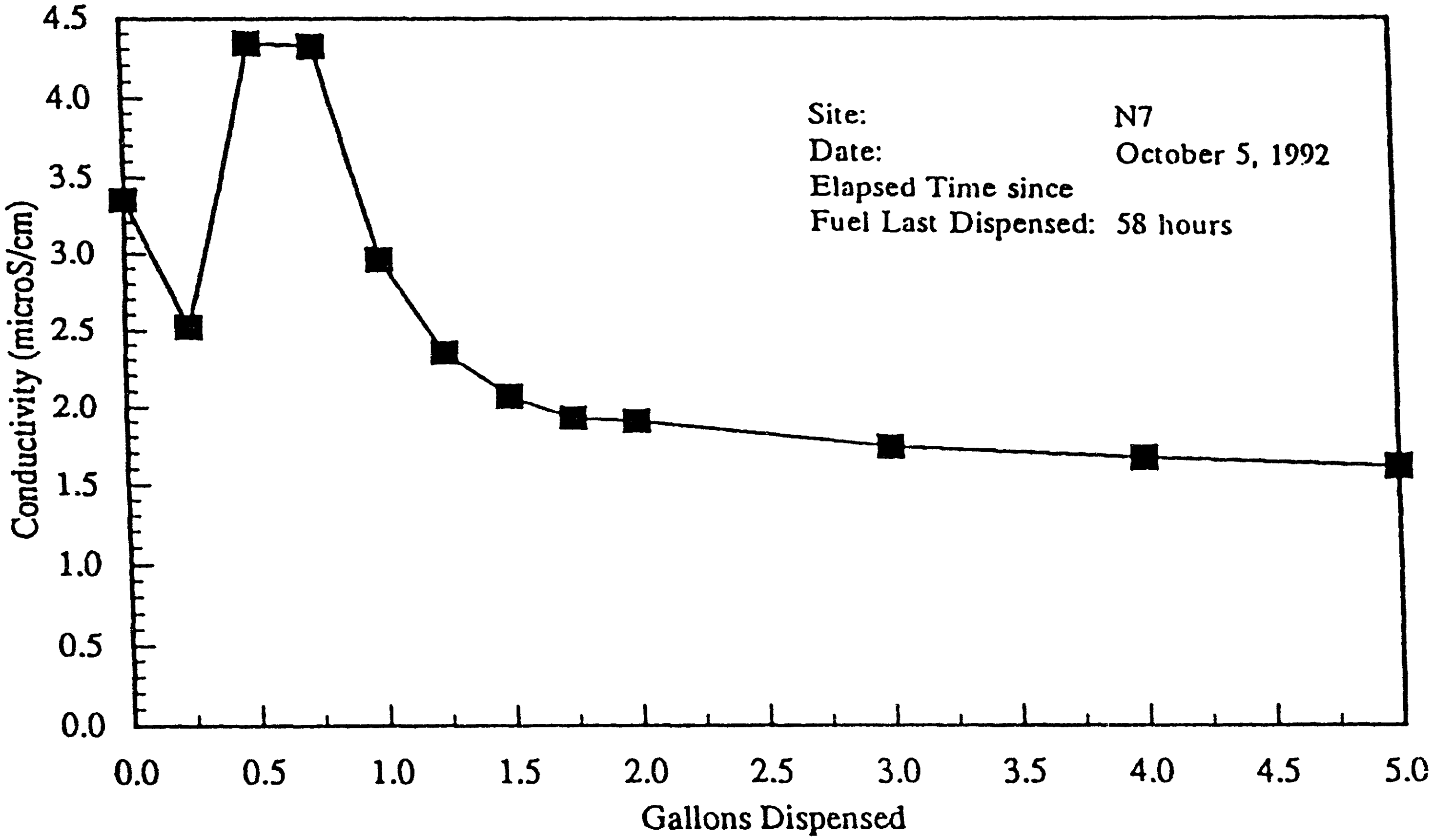
Summary of Analytical Results - M85 Non Retail

Fuel Property	ARB SPEC	Low	High	Mean
Particulates, max. (mg/l)	0.6	0.2	0.5	0.3
Gum, washed, max. (mg/100ml)	5	<0.1	0.6	0.2
Water, max. (mass%)	0.5	0.0022	0.61	0.097
Lead, max. (mg/l)	2	<1	<1	<1
Vapor pressure (psi)	7.0-13.1	7.3	9.3	7.7
Methanol, min. (vol%)	84	73.6	87.1	84.36
Acidity as acetic acid, max. (mass%)	0.005	0.003	0.010	0.004
Total chlorides, max. (mass%)	0.0002	<0.0001	<0.0001	<0.0001
Phosphorus, max. (mg/l)	0.2	<0.003	<0.2	<0.1
Sulfur, max. (mass%)	0.004	0.0004	0.0046	0.0023

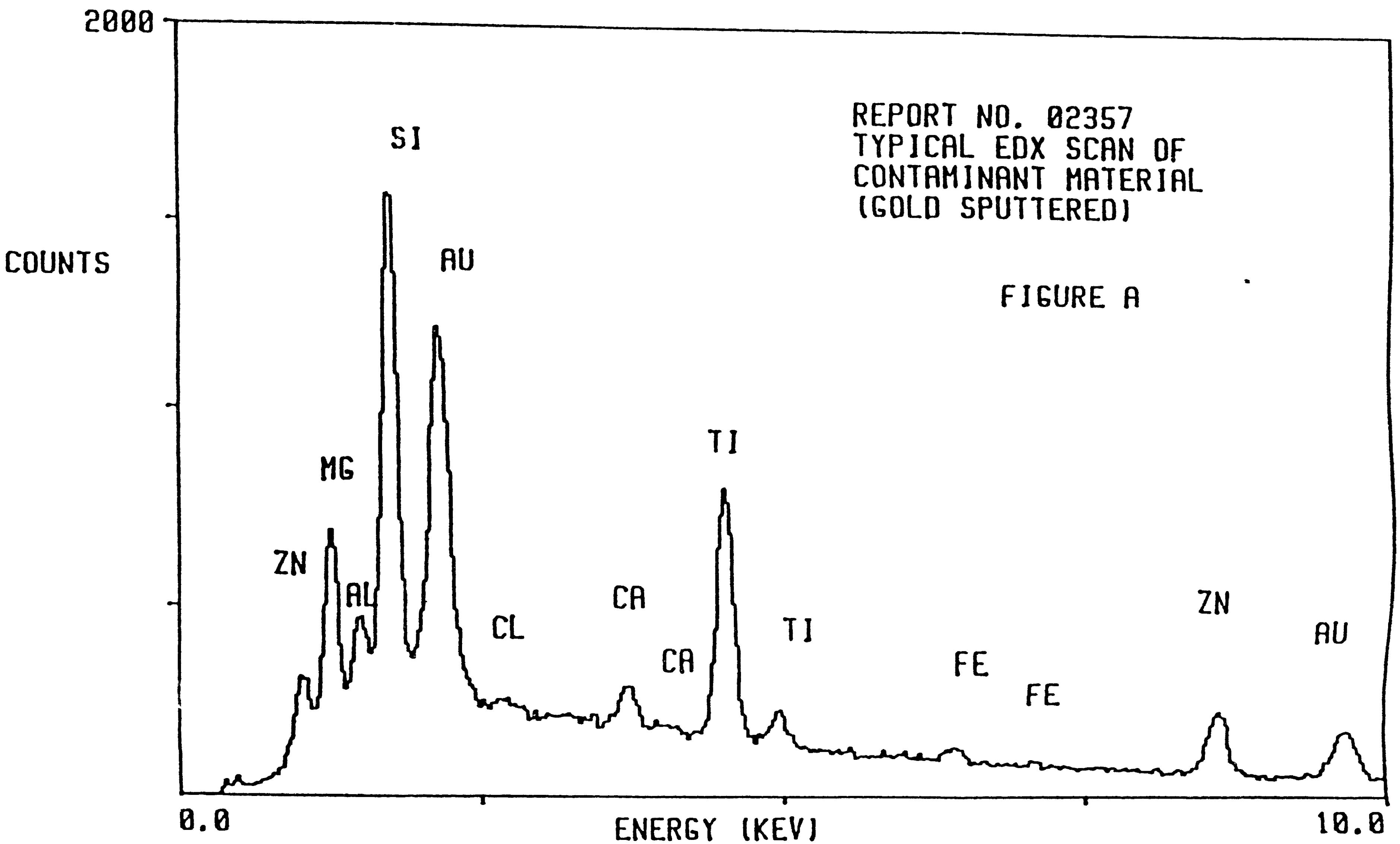
ARB Specification Exceedances

Test Parameter	ARB Std.	M85 Retail	M85 Non-Retail	Range to Exceedances M85 Retail	Range to Exceedances M85 Non-Retail
Particulates, max. (mg/l)	0.6	11	—	0.7-0.8	—
Water, max. (mass%)	0.5	—	1	—	0.61
Methanol, min. (vol%)	84	6	1	80.0-83.6	73.6
Acidity as acetic acid, max. (w%)	0.005	—	1	—	0.010
Chlorides (mass%)	0.0002	1	—	0.0003	—
Sulfur, max. (mass%)	0.004	—	1	—	0.0046

Fuel Conductivity

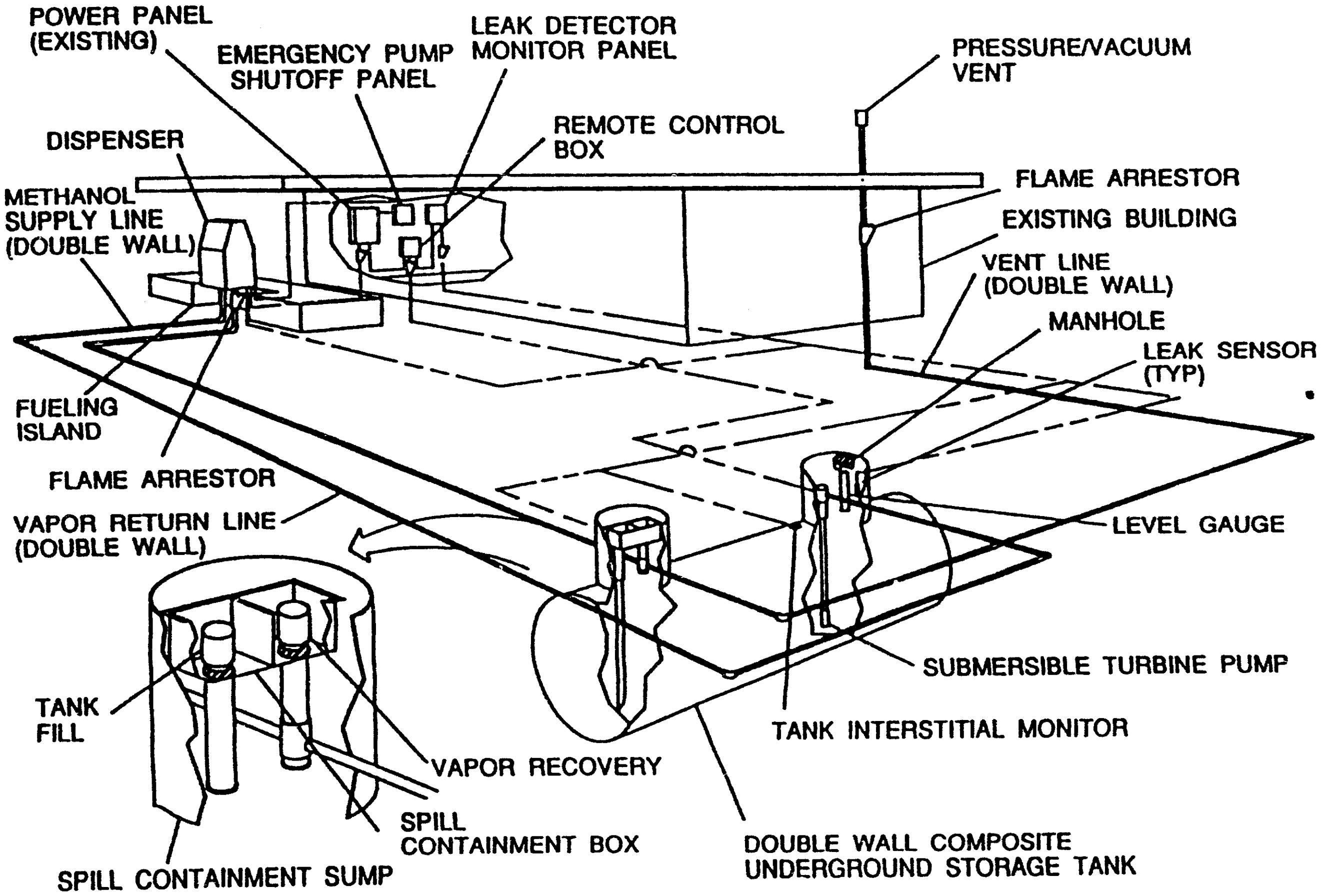


Fuel Precipitate



480

Generic M85 Fuel Station Design



Major Equipment Items

ITEM	MANUFACTURER	DESCRIPTION
UNDERGROUND STORAGE TANKS	OWENS-CORNING	Double-wall Fiberglass
	XERXES	Double-wall Fiberglass
	JOOR	Double-wall steel W/Fiberglass wrap
	MODERN WELDING	Double-wall Glass-steel
	TRUSCO	Double-wall steel
FILL TUBES	OPW	Model 61SOM with 1/500" annodizing
	EBW	Duratube Model No. 782-207-02
DISPENSERS	TOKHEIM	Models 1250 & 262RC Modified for M85 use
	GILBARCO	Salesmaker II modifed for M85 use
	DRESSER WAYNE	Modified for M85 use
SUBMERSIBLES	RED JACKET	Model A/G 75S1 3/4 HP
TURBINE PUMPS	TOKHEIM	Model 535-13
PIPING	AMERON	Dualloy fiberglass piping (UL listed for alcohol services)
	A.O. SMITH	Red Thread II
FLEX CONNECTORS	TITEFLEX	Stainless steel

482

MAJOR EQUIPMENT ITEMS CONT'D

ITEM	MANUFACTURER	DESCRIPTION
ENVIRONMENTAL MONITORING SYSTEM	API/RONAN POLLULERT CEI TIDEL	Miscellaneous Tank, sump, and image probes, line pressure sensors, etc.
IN-LINE FLAME ARRESTORS	PROTECTOSEAL	Models C4951F & C4952F
VAPOR RECOVERY NOZZLES	EMCO WHEATON	Electroless nickel plated A4001 & A4005
	OPW	Electroless nickel plated 11VF-4297
BREAK-A-WAY	EMCO WHEATON	Electroless nickel plated A4019-003
	OPW	66CL-0250
PRODUCT HOSE	GOODYEAR	Maxxim coaxial hose with RC58P602 tube compound
JUMPER HOSE	GOODYEAR	24" XLPE Fabchem hose with MxM roster fittings
FILTER HOUSING	AMF CUNO	Model 1B1 & 1B2 (Stainless or carbon steel)
FILTER MOUNTS	CIM-TEK	Models 50016, 50017 & 50018
FILTERS	CIM-TEK	1 Micron microglass inserts for 1B1 & 1B2 1 Micron microglass 70025-B
CARD READER	NBCS	GCII reader, dosc & pedestal

POTENTIAL SOURCES OF PROBLEMS

1. **ALUMINUM EQUIPMENT**

   * DISPENSER FITTINGS
   * NOZZLES
   * COAXIAL ADAPTERS/VAPOR VALVES
   * DROP FILL TUBE
   * FILTER HOUSING OR FITTINGS

2. **INCOMPATIBLE SUBMERSIBLE TURBINE PUMPS**

3. **GALVANIZED METAL PIPING**

4. **INCOMPATIBLE HOSES**

   * PRODUCT HOSE
   * JUMPER HOSE

5. **INCOMPATIBLE SEALANT/PIPE DOPE**

COMPONENT UPGRADES

NOZZLES

EMCO WHEATON A4001, A4005, AND OPW 11VF-4297 VAPOR RECOVERY NOZZLES TO BE REPLACED BY ELECTROLESS NICKEL PLATED VERSIONS OF THE SAME MODEL NOZZLES.

VAPOR VALVES/COAXIAL ADAPTERS

EMCO WHEATON A226 AND A227 VAPOR VALVES TO BE REPLACED WITH EITHER EMCO WHEATON A4041-003, A4041-004, OR A4042-002 ELECTROLESS NICKEL PLATED COAXIAL ADAPTERS.

OPW 38CS-0380 COAXIAL ADAPTER TO BE RELACED WITH ELECTROLESS NICKEL PLATED VERSIONS OF THE SAME MODEL ADAPTER.

BREAKAWAYS

EMCO WHEATON A4019-003 AND OPW 66CL-0250 BREAKAWAYS TO BE REPLACED WITH ELECTROLESS NICKEL PLATED VERSION OF THE SAME MODEL BREAKAWAYS.

DISPENSER FILTER HOUSINGS/MOUNTS

ENSURE THAT THE FOLLOWING FILTER HOUSINGS OR SPIN-ON MOUNTS ARE USED:

FILTER HOUSINGS
AMF CUNO 1B1
AMF CUNO 1B2

SPIN-ON FILTER MOUNTS
CIM-TEK 50016
CIM-TEK 50017
CIM-TEK 50018

DISPENSER FILTERS

CIM-TEK 70025B (SPIN-ON)
CIM-TEK (1B1 & 1B2 INSERTS)

PRODUCT HOSE

PRODUCT HOSES TO BE GOODYEAR MAXXIM M85 COMPATIBLE HOSE (W/RC58P602 TUBE COMPOUND)

JUMPER HOSE

HARD PIPE W/BLACK IRON OR USE GOODYEAR 24" XLPE FABCHEM HOSE WITH MxM ROSTER FITTINGS

CONSTRUCTION QUALITY ASSURANCE

* M85 FUELING EQUIPMENT LIST SHOULD BE REVIEWED BY THE CALIFORNIA ENERGY COMMISSION FOR APPROVAL PRIOR TO PROCUREMENT

* EQUIPMENT SHOULD BE INSPECTED UPON RECEIPT TO ENSURE THAT IT'S THE SPECIFIC EQUIPMENT THAT WAS ORDERED

* PRIOR TO ASSEMBLY OF THE SYSTEM THE SEALANT FOR THE FITTINGS SHOULD BE VERIFIED FOR M85 COMPATIBILITY

* AFTER INSTALLATION, FUELING EQUIPMENT SHOULD BE VISUALLY AND PRESSURE TESTED FOR POSSIBLE LINE LEAKS

* PRODUCT HOSE SHOULD BE SOAKED FOR A MINIMUM OF TWENTY-FOUR HOURS IN M85 TO LEACH OUT PLASTISIZERS PRIOR TO INSTALLATION

* FUEL SAMPLES SHOULD BE TAKEN FOR VISUAL INSPECTION OF POSSIBLE PARTICULATE MATTER

CONCLUSIONS

* BASED UPON AVERAGE TEST RESULTS, M85 FUEL QUALITY MEETS ARB SPECIFICATIONS.

* HOWEVER, PARTICULATE LEVELS NEED TO BE REDUCED.

* THERE MAY BE A CORROSION-TYPE PHENOMENA THAT MAY BE OCCURRING BOTH IN THE NOZZLE AND IN THE DISPENSER.

* CONDUCTIVITY MAY BE A USEFUL INDICATOR OF POTENTIAL CONTAMINATION.

* PROTECTING OR ISOLATING ALUMINUM PARTS THAT ARE IN CONTACT WITH M85 AND THE USE OF M85 COMPATIBLE HOSES ARE REQUIRED.

* RESEARCH NEEDS TO BE DONE ON THE SEALANT WHICH SHOULD BE USED ON THE DISPENSER AND PRODUCT LINE FITTINGS. THIS INFORMATION SHOULD BE DISTRIBUTED TO THE MAINTENANCE STAFF IN THE FIELD.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

MAINTAINING FUEL QUALITY CALIFORNIA METHANOL EXPERIENCE
D. Fong, California Energy Commission

Q. Norval Horner, Amoco Canada: What is the cost of a methanol filling station?

A. CEC contributes 35 to 40 thousand dollars for the equipment that goes into a station. The oil company adds another 30 to 40 thousand dollars in engineering, design, and construction, and they are committed to operate and maintain the facility for ten years.

Q. Anonymous: Could you comment on the plan to have 2,500 new methanol outlets across the U.S.?

A. I do not have all the details, but a major supplier is ready to make methanol available where needed, on their own or through other marketers. The fleet operators are asking for more M85 stations. The oil companies should be glad to hear this if there will be more vehicles to increase fuel demand and station throughput.

We believe that there could be 20,000 flexible fuel vehicles in California in the next 2 to 3 years. A regulation by CARB would require additional fueling sites in California with emphasis in the South Coast Air Basin.

SESSION 4: INFRASTRUCTURE ISSUES

Chair: Paul Wuebben, SCAQMD

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

MICROPROCESSOR CONTROL OF NATURAL GAS VEHICLE FAST FILLS

J.Y. Guttman
Canadian Gas Research Institute

Objective of CGRI Work

- To provide fast fills to NGVs
  - Refueling in two minutes or less
  - Operation analogous to gasoline refueling

G 9318

Conventional Technology

- **Mechanical dome load valve stops fill by creating zero pressure drop between dispenser and vehicle fuel tank toward end of fill**
  - Prolonged fills
  - Very large range of flow rates during the fill
  - Difficulty in accurate metering

G 9319

Fundamentals of CGRI Approach

- Mechanical dome load valve replaced using microprocessor technology
- Utilizes a mathematical algorithm developed by CGRI
- Sensors are placed entirely in the dispenser cabinet
- No sensors are attached to the vehicle since no vehicle information is required
- Automatic compensation for different flow path properties and different vehicle storage volumes

G 9320

How Does It Work?

- Microprocessor receives sensor inputs and utilizes algorithm to estimate current vehicle fuel tank pressure 60 times per second
  - Flow of gas monitored by micro motion meter
  - Gas pressure in dispenser
  - Gas and ambient temperatures
- Microprocessor contains pre-programmed information on maximum allowable vehicle fuel pressure
- Microprocessor instantaneously closes main valve to stop fill when estimated vehicle pressure reaches allowable maximum

G 9321

Test Conditions

- All mechanical dome load valves must be removed from the system in order to observe and evaluate the CGRI technology
- Ten fills correctly stopped out of twelve documented test fills
- Mathematical algorithm confirmed since random stopping of fill would unlikely be correct ten time out of twelve
- Failures related to human error

G 9322

Field Use

- Field tested by CGRI for one year, filling gas utility company vehicles at a company depot
- Extensive laboratory testing and field use by a second gas utility company in Canada
- Brief opportunity to test at a public filling station
- Installed at a public filling station in the U.S.
- Technology licensed to a manufacturer and is commercially available

G 9323

Benefits of CGRI Technology

- Better protection against overfills
- Eliminates restrictions to obtain faster fills
- More accurate fills for greater travel range
- Eliminates maintenance of mechanical valves

G 9324

Summary

- Based on the available data, the CGRI technology works well
- Mechanical dome load valves can be completely eliminated from the dispensing system
- The CGRI technology can provide control of all storage and dispenser functions

G 9325

MICROPROCESSOR CONTROL OF NATURAL GAS VEHICLE FAST FILLS

J.Y. Guttman and E.J. Farkas

Canadian Gas Research Institute
55 Scarsdale Road
Don Mills, Ontario
Canada M3B 2R3

Tel: (416) 447-6661
Fax: (416) 447-6757

Full consumer acceptance of natural gas as a motor vehicle fuel requires availability of a convenient and efficient "fast fill" procedure at public filling stations. Therefore, the natural gas fast fill time must be no greater than the gasoline refuelling time, i.e., less than two minutes for the typical passenger car or light truck. The natural gas vehicle must receive the maximum safe amount of fuel, for maximum range, without danger of overfilling.

The Fast Fill

Mass of fuel dispensed is not a direct indicator of the correct point at which to stop the fill. Mass of fuel is proportional to volume of on-board storage, which varies from vehicle to vehicle.

The maximum safe amount of fuel in the on-board storage is typically defined by regulatory agencies in terms of a maximum allowable pressure at a given temperature. In Canada, the maximum allowable pressure is 20.8 MPa absolute (3,000 psig) at 21.1°C (70°F). Over the year, outdoor temperatures in various parts of Canada range from -50°C to +40°C. The vehicle has been filled correctly if the pressure in the fuel tank would "settle" at 20.8 MPa if the vehicle were held indefinitely in a 21.1°C environment.

The primary factor in knowing when to stop the fill is vehicle fuel tank pressure. Temperature is less clear-cut; the temperature in the tank at the end of the fill is a function of initial and final tank pressures, as well as outdoor temperature, gas supply temperature, and fill time.

The requirement to fill in under two minutes means that flow rate must be high throughout the fill. For flow rate to be high, the driving force for flow must be high. Therefore, the pressure drop between the dispenser and the interior of the vehicle fuel tank must be significant throughout the fill. The pressure in the vehicle fuel tank during the fill is not known, complicating determination of when to stop the fill.

Drawbacks of Current Technology

Many dispensers utilize the dome load valve with a reference cylinder in order to stop fills at approximately the correct point. The dome load valve is located in the dispenser and can only sense the dispenser pressure rather than the vehicle fuel tank pressure. With the dome load valve, the correct final vehicle pressure is achieved essentially by equalization between the dispenser and the vehicle fuel tank. The result is very low flow rates toward the end of the fill.

The dome load valve is generally restrictive and, as a result, flow rates are lower than necessary throughout the fill. The dome load system is not readily able to account for the temperature increase in the vehicle tank during the fill. To ensure safety, most vehicles are, therefore, underfilled and driving range is reduced.

CGRI Microprocessor System

Canadian Gas Research Institute (CGRI) has developed a microprocessor-based system which resolves these problems. The CGRI system has been field-tested with excellent results and is available commercially.

The main points concerning the CGRI technology are the following:

- The system utilizes a proprietary mathematical algorithm developed by CGRI. The mathematical model is programmed into the microprocessor which is installed within the dispenser cabinet.

- The microprocessor receives inputs from the flow meter, from flowing gas pressure, and temperature sensors installed within the dispenser cabinet. There is also an input related to outdoor temperature.

- The CGRI system can be installed in new dispensers during manufacture or can be retrofitted to existing dispensers after removal of the dome load valve.

- The CGRI system does not require knowledge of the total volume of on-board storage. The CGRI system automatically compensates for different values of flow resistance due to different types of fittings and different tubing sizes on different vehicles.

- There is no mechanical equipment in the flow path, other than the main on-off valve within the dispenser cabinet. On the basis of the mathematical model, and using initial and current flow information, the microprocessor, typically 60 times per minute during the fill, prepares an estimate of current vehicle fuel tank pressure. When the estimated pressure reaches a pre-programmed value, the microprocessor instantaneously closes the on-off valve to stop the fill. The preprogrammed pressure values take account of the temperature increase in the tank during the fill.

Test Results

Consider a vehicle tank which contains 10 kg of fuel when the fuel tank internal pressure and temperature are 20.8 MPa and 21.1°C. On a cold day the correct final vehicle fuel tank pressure may be only 18 MPa in order to have 10 kg of fuel in the tank at the end of the fill.

The most straightforward test of the CGRI system is carried out during cold weather, when the correct final vehicle fuel tank pressure is well below the supply pressure. Under these conditions, observers can readily satisfy themselves that fills are stopped by the action of the CGRI system, rather than by equalization.

Also, the dome load valve must be removed from a dispenser in which the CGRI system is installed for test purposes. Otherwise, it is impossible to determine whether the CGRI system is working properly or not.

Two typical tests were carried out on January 16, 1990. These tests were performed with the commercial version of the CGRI system, installed at a public filling station in Mississauga, Ontario. The outdoor temperature was 4°C and at this temperature the pre-programmed pressure at which the CGRI system is supposed to stop the fill is 19.50 MPa (2815 psig).

In both fills, vehicle fuel tank pressure immediately after cessation of flow was 19.40 MPa (2800 psig). The dispenser pressure was observed continuously during the fills. The dispenser pressure toward the end of the fill was 21.47 MPa (3100 psig). in the first case and 20.78 MPa (3000 psig) in the second. Therefore the fills were correctly stopped by the CGRI microprocessor-based system, rather than by pressure equalization between the supply and the vehicle fuel tank. Flow rate was also observed to be substantial right up to the instant of the closing of the ball valve.

A further twelve documented fills resulted in ten correct fills and two underfills due most likely to human error. The mathematical algorithm is therefore confirmed since random stopping of fill would unlikely be correct ten times out of twelve.

The CGRI fast fill technology was field tested for one year at a gas utility company fuelling station for company vehicles. Extensive laboratory testing and field use of the system was carried out by a second gas utility company in Canada. There was also a brief opportunity to test the technology at a public filling station in Canada and another is installed in the U.S. The technology is licensed to a Canadian manufacturer and is commercially available.

Summary

The CGRI fast fill technology can completely eliminate the mechanical dome load valves, provide better protection against overfills, and obtain significantly faster and more complete fills of natural gas vehicles.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

MICROPROCESSOR CONTROL OF NATURAL GAS VEHICLE FAST FILLS
J.Y. Guttman, Canadian Gas Research Institute

Q. Anonymous: Will the system overpressure a tank slightly to compensate for cooling to 70°F after the tank is filled?

A. The microprocessor is temperature compensated so that calculations will predict the final pressure and temperature.

Q. William Liss, Gas Research Institute: Do Canadian regulations allow electronic replacement for mechanical devices?

A. Yes, the microprocessor-based technology has been accepted and eliminated the need for dome load valves.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE - PANEL DISCUSSION

Panel Moderator: Paul Wuebben

ALTERNATIVE TRANSPORTATION FUEL IMPLEMENTATION ISSUES - CALIFORNIA PERSPECTIVE

D. Fong
California Energy Commission

TECHNOLOGY DEVELOPMENT

* ENGINE AND COMPONENT DURABILITY
    * Fuel Systems
    * Emission Control Systems
* FUEL STORAGE AND DISPENSING SYSTEMS
    * Materials Compatibility
    * Vehicle/Fueling System Interface
* LUBRICANTS/ADDITIVES
    * Oils
    * Fuel Additives

INFRASTRUCTURE DEVELOPMENT

- FUEL AVAILABILITY

  * Number of Fueling Sites
  * Location
  * Supply and Distribution

- FUEL TRANSACTIONS

  * Access Control
  * Payment

- REGULATORY CONSTRAINTS

  * Local Authorizations (Permits)
  * State Certifications for Equipment

- MAINTENANCE SUPPORT

  * Vehicles
  * Fuel Distribution Systems

- SPECIFICATIONS

  * Fuel
  * Equipment

MARKET DEVELOPMENT

* EDUCATION
    * Consumers
    * Retailers
    * Mass Media
* PRODUCT AVAILABILITY
    * Vehicle Types/Models
* MARKET PENETRATION
    * Consumer Targets
    * Timing

COST REDUCTION

* INCENTIVES
    * Technology Development
    * Regulatory
    * Marketing

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE - PANEL DISCUSSION

Panel Moderator: Paul Wuebben

METHONAL FUEL INFRASTRUCTURE OVERVIEW

J. Spacek
Canadian Oxygenated Fuels Association

Canadian Oxygenated Fuels Association

COFA is a Methanol Fuel Industry Association.

Formed in 1984 by:

- Celanese Canada Inc.;
- Methanex Corporation; and
- Novacor Chemicals Ltd.

COFA's Objective is to Promote the Responsible Use of Methanol as a Transportation Fuel.

Light Duty Vehicle Program
(to March 31, 1993)

Program initiated in February 1991

- 11 vehicles (pre-production)
- 4 service stations

Program amended in January 1992

- 136 vehicle (production)
- 11 pre-production LH vehicles
- 5 service stations
- 6 portable stations

Amendment No. 2 August 1992

- dedicated project manager
- additional marketing resources

Proposed MLDVP
(to March 31, 1994)

Program Activities

- continue dedicated project manager
- fuel quality monitoring program
- vehicle marketing and promotions program
- station program

Targets

# of stations

	Current	New	Total
Toronto	2	6	8
Vancouver	1	3	4
Calgary	1	2	3
Kitimat	-	1	1
Medicine Hat	-	1	1
Kamloops	1	-	1
TOTAL	5	13	18

Refuelling Infrastructure Summary

Transit Installations

- Medicine Hat Transit;
- Winnipeg Transit; and
- Transit Windsor.

Service Station Installations

- Toronto, Ontario (Sunoco)
- Calgary, Alberta (Robertson/Mohawk)
- Kamloops, B.C. (Mohawk)
- Burnaby, B.C. (Mohawk)

Portable Refuelling Stations

- Clemmer Steel Tank Assemblies

Transit Installations

Overview

- Typically a Red Jacket submersible pump;
- 10,000 gallon steel double-walled under-ground tank;
- GasBoy island dispenser rated at 40 gallon/minute;
- Emco-Wheaton dry-brake nozzle;
- RPCO 559N hose;
- 5 micron Micro-Wind cartridge filters; and
- vacuum monitoring with alarm system.

Transit Installations

Cost (Based on Transit Windsor 1991)

Equipment		
Tankage	$ 18,700	
Card Tool	$ 1,750	
Pump/Dispenser	$ 13,200	
	$ 33,750	$33,750
Installation		
Installation Contract*	$22,500	
Inspection	$ 1,000	
Insurance	$ 1,250	
Freight	$ 1,000	
Engineering Fees	$10,000	
	$35,750	$35,750
Other		
Engineering Mark-Up	$ 6,000	
Goods & Services Tax	$ 6,000	
	$12,000	$12,000
TOTAL		$81,500

* Includes contractor supplied materials

Service Station Installations

Two Approaches:
1. M85 Installation
2. M100 With Pump Blending

M85 Installations

- Various dispenser/pump brands used including:
  - Red Jacket
  - GasBoy; and
  - Bennett
- Both steel and fibreglass tankage used;
- Hoses now standardized to cross-linked polyethylene with nickel plated swivels;
- Nozzles are OPW nickel-plated aluminum;
- 1 micron Cim-tek spin-on filters; and
- Vacuum monitoring with alarm system.

M85 Installation

Cost (Based on Calgary 1992)

Equipment		
Tankage	$ 8,000	
Dispenser	$ 3,600	
Other	$ 7,000	
	$18,600	$18,600
Installation		
Contractor*	$17,300	$17,300
Permits/Engineering/ Signage**	$14,100	$14,100
TOTAL		$50,000

* Includes submersible pump, cardlock and contractor supplied materials.

** Estimate.

Service Station Installations

M85 Pump Blending

- Wayne/Dresser electronic blending dispenser;
- Red Jacket submersible pump;
- Cross-linked polythylene with nickel-plated swivels;
- OPW nickel-plated nozzle;
- 1 micron Cim-tek spin-on filters; and
- Vacuum monitoring with alarm system.

M85 Pump Blending Installation

Cost (Based on Toronto 1992)

Equipment

Tankage	$11,700	
Dispenser	$10,000	
Submersible Pump	$ 1,800	
Other	$ 6,850	
	$30,350	$30,350

Installation

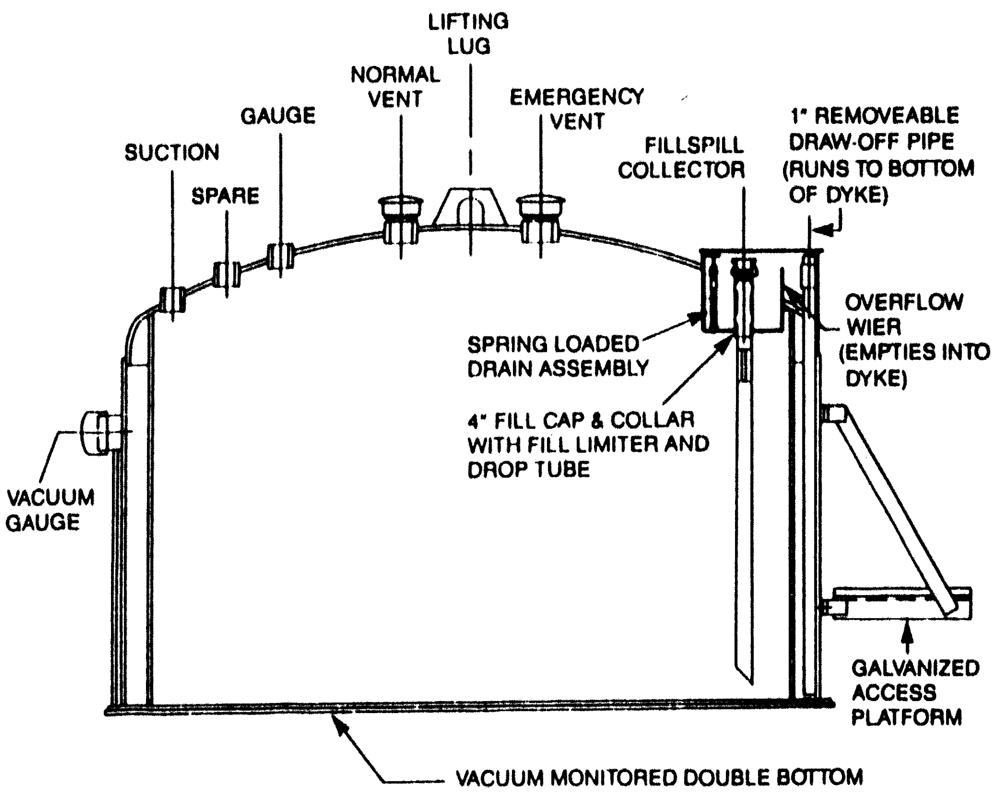
Contractor*	$23,150	$23,150
Permits/Engineering/Signage**		$16,500
		$70,000

* Includes contractor supplied materials.

** Estimate.

Fleet Installations

Clemmer Tank Diagram



- Methanol fuel portable station designed by Clemmer Industries;
- GasBoy commercial-use pump included; and
- Cost approximately $6,000.

Field Experience: Regulatory Environment

"The only thing worse than a regulation is no regulation"

Fuel Safety Organizations

- not familiar with methanol fuel;
- deviation approach typically used; and
- more stringent requirements than gasoline.

Fire Code/Practice Organizations

- not familiar with methanol fuel;
- methanol fuel not in fire codes; and
- substantial education required to obtain permits.

Weights and Measures Organizations

- not familiar with methanol fuel; and
- pumps installed under "demonstration" approval.

Field Experience: Fuel Quality

Early installations provided steep learning curve:

- "Methanol compatible" hoses were not M85 compatible;
- "Methanol compatible" nozzles were not M85 compatible; and
- "Methanol compatible" pumps/dispensers were not M85 compatible;

COFA published Methanol Fuelling Systems Guide:

- recommends installation procedures; and
- lists infrastructure manufacturers offering/claiming methanol compatible equipment.

Continued

Fuel retailers involvement critical in:

- "auditing" methanol installations to ensure methanol compatible components used; and
- Monitoring fuel Quality.

Other:

- Stations with low fuel through-put exhibit higher levels of fuel contamination;
- Aluminum contamination highest priority.

Transit:

- Fuel quality not a concern
- Vehicle fuel system design pro-active

Lessons Learned

Be Pro-active

- methanol fuel education of regulatory bodies a must;
- network to ensure access to latest fuel infrastructure knowledge.

Be Specific

- identify specific methanol compatible components and manufacturers.

Be Patient

- allow for long regulatory approval period;
- be prepared to educate fuel retailers.

Be Watchful

- ensure aggressive fuel quality monitoring;
- ensure fuel installation is "audited" for methanol compatible materials.

Recommendations

Infrastructure

- Immediate Requirements For:
  - dispensing nozzle;
  - dispenser; and
  - hose.

- Investigate Temporary Refuelling Infrastructure:
  - above ground tankage with island pump
  - estimate $15,000 - $20,000

- Investigate Station Retrofit
  - clean steel tank;
  - replace components with methanol compatible; and
  - replace dispensing pump.
  - estimate $15,000-$20,00.

Continued

Government:Regulatory

- Accelerated Methanol Fuel Education of Regulatory Officials

- High Priority Needed on Placing Methanol Fuel into Regulatory Regime:

    - fuel specification
    - fire code
    - fuel safety

Government:Policy

- Government Leadership to Encourage Flexible Fuel Infrastructure;

    - development of service station infrastructure compatible with all liquid fuels;

    - encourage all tankage to be methanol compatible; and

    - encourage competition in market place.

Continued

- M85 Service Station Financial Assistance:

    - should be provided after evidence of quality fuel performance; and

    - should reward pump blending approach on strategic and cost effectiveness objectives.

Other Stakeholders:

- Vehicle Manufacturers Address Accessible and Enhanced Fuel Filtering on Vehicles.

1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS

INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE - PANEL DISCUSSION

Panel Moderator: Paul Wuebben

PROPANE - INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE

N. Horner
Amoco Canada

(Other presentations made during this Panel Discussion were unavailable at time of printing)

PROPANE - INFRASTRUCTURE ISSUES FROM THE RETAILERS PERSPECTIVE

PRESENTED TO THE
1993 WINDSOR WORKSHOP ON ALTERNATIVE FUELS
TORONTO, JUNE 15, 1993

NORVAL HORNER - MGR. OF ENGINEERING, AMOCO CANADA

ASSISTANCE FROM ICG & SUPERIOR
2 LARGE CDN. DISTRIBUTORS.

1. INTRODUCTION AND HISTORY
2. TYPICAL AUTO PROPANE FILL STATION
3. DESIGN AND PERMITS
4. CONSTRUCTION AND OPERATION
5. MAINTENANCE AND PRODUCT QUALITY
6. OEM PRESENCE IN VEHICLES
7. SUPPLY
8. TRANSPORTATION/WHOLESALE INFRASTRUCTURE
9. PRICE AND CONCLUSIONS

NOTATIONS BASED ON ACTUAL DELIVERED VERSION NWH

1. INTRODUCTION AND HISTORY

. CINDERELLA FUEL - MOST POPULAR ALTERNATIVE FUEL IN CANADA AND U.S.

. RAPID GROWTH IN CANADA IN THE 1980 TO 1993 PERIOD.
- INCENTIVES ON CONVERSIONS (TO '84)
- INCENTIVES ON ROAD TAXES (DECLINING)

. IN 13 YEARS WE HAVE ACHIEVED:
- 5000 AUTO PROPANE STATIONS IN CANADA (MORE STATIONS THAN DIESEL)
- 170,000 PROPANE POWERED VEHICLES
- 1.3 BILLION LITRES/YR SALES TO VEHICLES
- ABOUT 4% OF GASOLINE'S SALES:
  - o NOTE HOLLAND HAS PROPANE AT 13.5% OF TOTAL TRANSPORT FUEL

. GROWTH DUE TO PROPANES ADVANTAGES
- ENERGY DENSITY 3/4 OF GASOLINE
- OCTANE RATING OF 100+
- NATIONAL PRODUCTION & PIPELINE INFRASTRUCTURE

NOTE: CANADA IS A SIMILAR SIZE MARKET TO CALIFORNIA.

2. TYPICAL PROPANE AUTO FILL STATION

. ADD-ON TO A GASOLINE STATION

. USUALLY FULL SERVICE
  - SELF SERVE REQUIRES TRAINING
  - CARD LOCK OR KEY LOCK ALSO USED

. TYPICAL TANK VOLUME, 2000 GAL.

. SKID MOUNTED SELF CONTAINED DISPENSER

. PROPANE IS STORED AND DISPENSED AS A LIQUID

. SAFETY SYSTEMS AND TRAINED PERSONNEL

. COST $40,000 ALL-IN

. DISTRIBUTOR USUALLY PROVIDES THE FACILITY AND THE PRODUCT. THE STATION OWNER GETS A GALLONAGE FIGURE.

. CURRENT AVERAGE SALES = 200,000 LITRES/YR

. COULD SELL 5 TIMES AS MUCH PER STATION (1,000,000 LITRES/YR)

PROPANE COULD BE WORKING HARDER YET

3. DESIGN

- STANDARDIZED DESIGNS ← MODEST PRESSURE PROPANE STORED AT UNDER 200 PSIA.
- CGA B149 CODE
- PROPER TRAFFIC FLOW
- DECIDE ON ATTENDED VS CARDLOCK APPROACH
- USUAL LIGHTING/SIGNAGE ISSUES
- USUALLY SKID MOUNTED - SIMPLE EQUIPMENT STEEL TANK, STORAGE PUMP, CONTROLS AND POWER
  - 45 LPM DISPENSING RATE ← SAME FILLING TIME AS GASOLINE.
- SAFETY ASPECTS - COLLISION PROTECTION
  - INTERNAL SAFETY CONTROL VALVE
  - HIGH FLOW SHUT OFF
  - AUTOMATIC SHUT OFF ON HEAT

PERMITS

- TANK AND OTHER EQUIPMENT MUST MEET A VARIETY OF STANDARDS AND CODES
  - IE. ASME, ELECTRICAL
- VARIOUS APPROVALS REQUIRED (ZONING, BUILDING PERMIT, FIRE DEPARTMENT)
- IN ONTARIO - REQUIRE A PROVINCIAL PROPANE TRANSFER FACILITY LICENCE
- TYPICALLY REQUIRES 4 - 6 WEEKS OF TIME

4. CONSTRUCTION

- SIMPLIFIED DUE TO STANDARDIZATION - SKID MOUNTED - ABOVE GROUND
- REQUIRES ONLY POWER CONNECTIONS, FOUNDATIONS AND COLLISION PROTECTION
- CONSTRUCTION NORMALLY TAKES 2 WEEKS
- SITE INSPECTIONS - ELECTRICAL & FUEL SAFETY

OPERATION

- NORMALLY ATTENDED VEHICLE INSPECTION STICKER REQUIRED
- ALL ATTENDANTS RECEIVE PGAC 100-1 TRAINING
  - 900 CERTIFIED INSTRUCTORS IN CANADA
  - 14,000 PER YEAR ARE TRAINED
- UNATTENDED, IE. CARDLOCK OPERATION, WE REQUIRE VEHICLE OPERATOR TO BE TRAINED
- FILL TO 80% OF TANK TO ALLOW EXPANSION
  - HISTORICALLY USED A LIQUID LEVEL VALVE
  - NOW HAVE AN APPROVED AUTOMATIC "STOP FILL"
- VAPOURS MINIMIZED DUE TO CLOSED SYSTEM
- MINIMAL OPERATING COSTS - LOW POWER REQUIREMENTS

5. MAINTENANCE

- PROPANE IS DELIVERED BY BULK VEHICLES
- DISPENSING NOZZLES AND HOSE NEED THE MOST MAINTENANCE
- PREVENTATIVE MAINTENANCE SCHEDULES ON BREAKAWAY COUPLERS, FILTERS, METERS AND PUMPS - SEMI ANNUAL OR ANNUAL

PRODUCT QUALITY

- AUTO PROPANE, HD5 - NATIONAL STD OF CANADA
- ALL PROPANE IN CANADA MADE TO THIS (SO IS ALL RETAIL PROPANE IN THE U.S.)
- LIMITS ETHANE, BUTANE, SULPHUR, WATER AND OIL STAIN
- POLYPROPYLENE LIMITED TO 5% (HURTS OCTANE RATING)
- ODORANT ADDED
- NO OXYGEN, INHERENTLY NON-CORROSIVE
- CONSISTENT ACROSS NORTH AMERICA

SLIDES ON PROPANE LINE HAUL CARRIERS
DISTRIBUTION CENTRES, DELIVERY TRUCKS
RETAIL AND WHOLESALE STATIONS.

6. OEM PRESENCE

- BUSINESS HISTORICALLY BASED ON CONVERSION FROM GASOLINE TO PROPANE.
- DOING BETWEEN 15-20,000 CONVERSIONS/YR IN CANADA.
- COST $1800 BASIC PLUS $400 TO ADAPT TO A CURRENT ENGINE FEEDBACK CONTROL.
- GM AND FORD MAKE FACTORY PREPARED ENGINES DESIGNED FOR AFTERMARKET CONVERSION TO PROPANE.
- FORD MEDIUM DUTY TRUCKS AVAILABLE FOR PROPANE FROM MANUFACTURER.
- CHRYSLER $4.25 MM JOINT INDUSTRY/GOV'T PROJECT TO BUILD A PROPANE AFV. GOAL IS VANS AND/OR LIGHT TRUCKS AVAILABLE IN 1995.

7. SUPPLY

- PROPANE IS IN SURPLUS IN CANADA
  - CDN PRODUCTION IS 190,000 BBL/DAY
  - EXPORTS ARE APPROXIMATELY 50%

- PROPANE IS IN BALANCE IN NORTH AMERICA
  - U.S. PRODUCTION OVER 900,000 BBL/DAY
  - PETCHEM DEMAND

- FOR COMPARISON (U.S. PRODUCTION):

METHANOL - 78,000 BBL/DAY (8.5%)
ETHANOL - 52,000 BBL/DAY (6%)

WORLD METHANOL PRODUCTION = 460,000 BBL/DAY.

IE: THE U.S. PRODUCES 12 TIMES AS MUCH PROPANE AS IT DOES METHANOL!

THE U.S. ALONE PRODUCES 2 TIMES AS MUCH PROPANE AS THE ENTIRE WORLD PRODUCTION OF METHANOL!

PROPANE IS NOT THE WHOLE SOLUTION SEE A LARGER ROLE FOR NATURAL GAS AS WELL.

8. TRANSPORTATION & WHOLESALE INFRASTRUCTURE

- THERE IS A NORTH AMERICAN WIDE PROPANE STORAGE AND DELIVERY STRUCTURE ALREADY IN PLACE.

- IN CANADA:
  - MAJOR TRANSCONTINENTAL PIPELINES IN PLACE FROM THE WEST TO ONTARIO. TARIFFS OF 1 - 2.4 CENTS/LITRE.
  - PRODUCTION AT REFINERIES
  - THE STORAGE, DISTRIBUTION TERMINALS, THE BULK TRUCKS ARE ALL IN PLACE.

- IN THE U.S.A.:
  - OVER 800 GAS PLANTS PRODUCE PROPANE
  - THERE ARE 31 FRACTIONATORS
  - 150 MILLION BARRELS OF STORAGE (C3)
  - TWENTY FIVE STATES SERVED BY PIPELINE
  - OTHERS SERVED BY INTERNAL REFINERY OR GAS PLANT PRODUCTION

OTHER LIQUID FUELS WOULD HAVE TO SPEND A STAGGERING SUM TO REPEAT THIS INFRASTRUCTURE

9. PRICE

- CURRENT SARNIA WHOLESALE PROPANE PRICE IS 11.6 CENTS/LITRE FOR PROPANE.

- CURRENT TORONTO PROPANE PUMP PRICE IS 29.9 CENTS/LITRE INCLUDING TAXES (APRIL 27, 1993).

- CURRENT TORONTO GASOLINE PUMP PRICE IS 53.6 CENTS/LITRE INCLUDING TAXES.

- CHECK FINANCIAL PAGES FOR PROPANE FUTURES AND UNLEADED GASOLINE FUTURES.

- ON A LEVEL PLAYING FIELD PROPANE CAN WIN ON ECONOMICS ALONE VS GASOLINE.

- ENERGY COMPARISON

$$\frac{\text{PROPANE LHV}}{\text{GASOLINE LHV}} = \frac{82,500}{114,000} - 72.4\%.$$

(PER GALLON)

- ADJUSTED PRICE COMPARISON.

$$\frac{1.38\ \ell\ \text{PROPANE}}{1.0\ \ell\ \text{GASOLINE}} = \frac{41.2¢}{53.6¢}.$$

- PROPANE ACTUALLY GETS BETTER MILEAGE THAN A STRAIGHT ENERGY CONVERSION WOULD IMPLY.

CONCLUSIONS

- PROPANE SUPPLY AND INFRASTRUCTURE WOULD ALLOW CANADA TO TRIPLE EXISTING AUTO PROPANE USE WITH VIRTUALLY NO INVESTMENT.
  - SAME IS TRUE IN THE U.S.
- OTHER LIQUID FUEL ALTERNATES REQUIRE:
  - MASSIVE INFRASTRUCTURE INVESTMENT
  - MASSIVE INVESTMENT TO EXPAND SUPPLY
- PROPANE IS INEXPENSIVELY RETAILED
- MORE OEM INVOLVEMENT COMING

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

PANEL DISCUSSION: INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE

Moderator: Paul Wuebben, SCAQMD

Panel Members:
Dan Fong, California Energy Commission
John Spacek, Canadian Oxygenated Fuels Association
Herbert Burnett, Southern California Gas Co.
Norval Horner, Amoco Canada

After short presentation by each panel member, questions were permitted. Panel member replies are identified by name below.

Q. Paul Weubben, SCAQMD: What materials are used for methanol dispensing nozzles?

A. John Spacek, We have been through several iterations with nozzle materials. Nickel plated aluminum has been used for M85. Another choice for M100 was nickel plated brass or stainless steel. An all-steel version will also be tested this year.

Q. Paul Weubben, SCAQMD: Is there a concern for moisture in natural gas, especially in cold weather?

A. Herbert Burnett: There have been problems with freezing where water content has been above 0.5 pound per million SCF. We recommend filter-coalescers and dryers on the suction side of compressors and non-lubricated compressors to avoid oil contamination of the gas. We also encourage a vigorous testing program for contaminants.

Q. Joe Wagner, NYSERDA: What is the largest transit bus fueling facility?

A. Herbert Burnett: We have two facilities for buses that have 80 gallon equivalent tanks on board. Fueling time allowed is 10 minutes per bus. We deliver about 10 gallons per minute per hose to a temperature-compensated fill point of 3000 psi and 70oF within plus or minus 2 percent. Building the facility is about a 12-month process. Market development may take 2 to 3 months minimum. Design, procurement, and construction require 8 to 9 months. Permits can add another 2 to 3 months.

SUMMARY OF VERBAL COMMENTS OR QUESTIONS AND SPEAKER RESPONSES

PANEL DISCUSSION: INFRASTRUCTURE ISSUES FROM THE RETAILERS' PERSPECTIVE

Q. Anonymous: What type of drivers are used on natural gas compressors? And what are compression costs?

A. Herbert Burnett: All of our compressors are electric-driven. Compression costs are about 30 cents per gallon, including power cost and other operating expenses.

Q. Anonymous: What type of card system is used for access to methanol dispensing stations? Will this change in the future?

A. Dan Fong: The oil companies each have their own cards. There may be a move to a single card for all seven companies. That would depend on increased demand to justify software development to use bank-type cards.

Q. Anonymous: What use is made of mobile natural gas dispensing equipment?

A. Herbert Burnett: We use mobile refueling systems as means to start a developing station. Customers typically start with a small portion of their fleet dedicated to natural gas. We can provide a cost effective systems with a portable trailer and a lower cost station without compression to provide up to 250 gallons per day.

Q. Lois Bennett, General Motors: What actions are in progress to adopt standard connectors for refueling natural gas vehicles?

A. Herbert Burnett: The American Gas Association committees are working on this subject. A draft document is expected by the end of 1993 that will incorporate overpressure protection for various type of fittings.

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

D.P. Gardiner, V.K. Rao, M.F. Bardon
Royal Military College of Canada

V. Battista
Transport Canada

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

D.P. Gardiner, V.K. Rao, M.F. Bardon
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

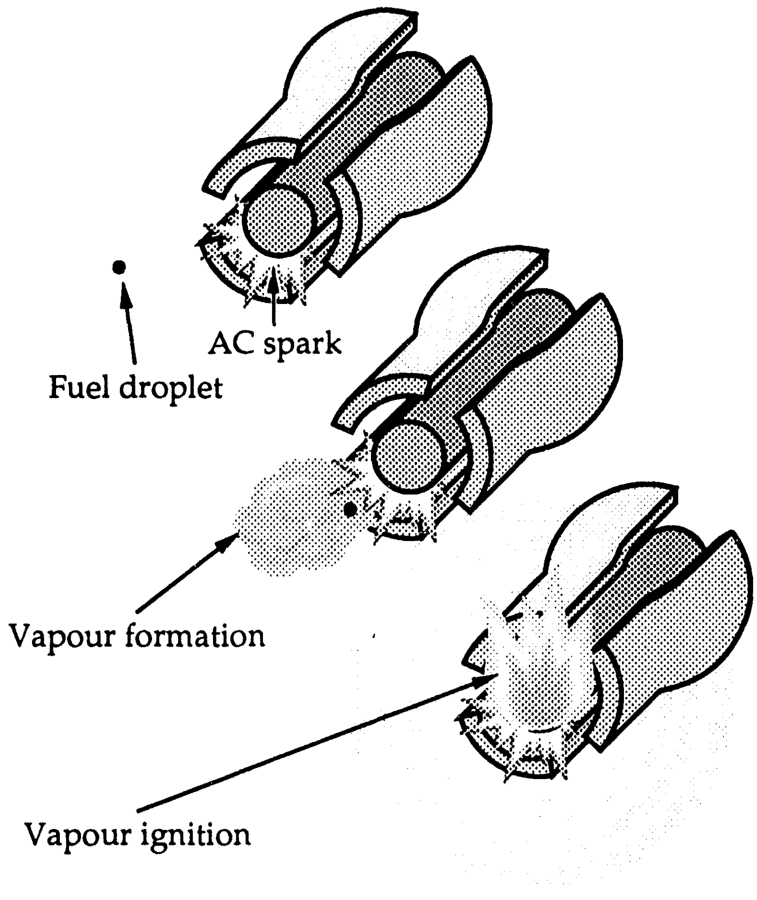
M85 EMISSIONS

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

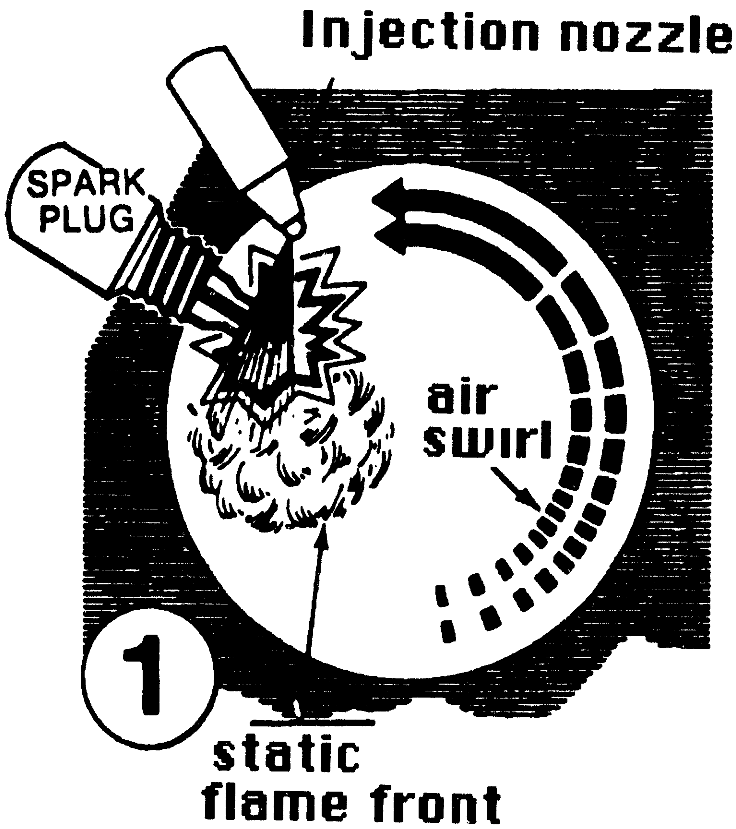
Iwachidou and Kawagoe, 1988

M100 COLD STARTING

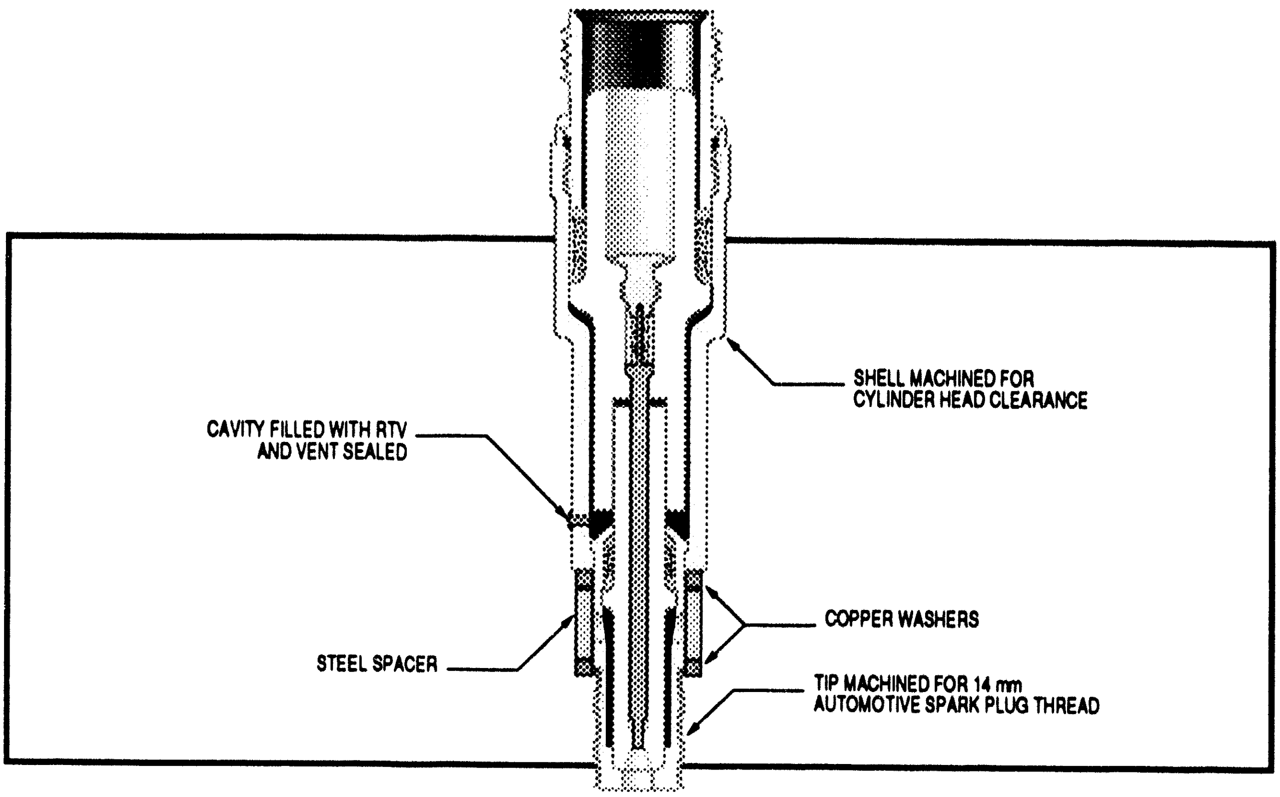
- M100 (neat methanol) contains no "light ends"
- Overfuelling is not effective for cold starting



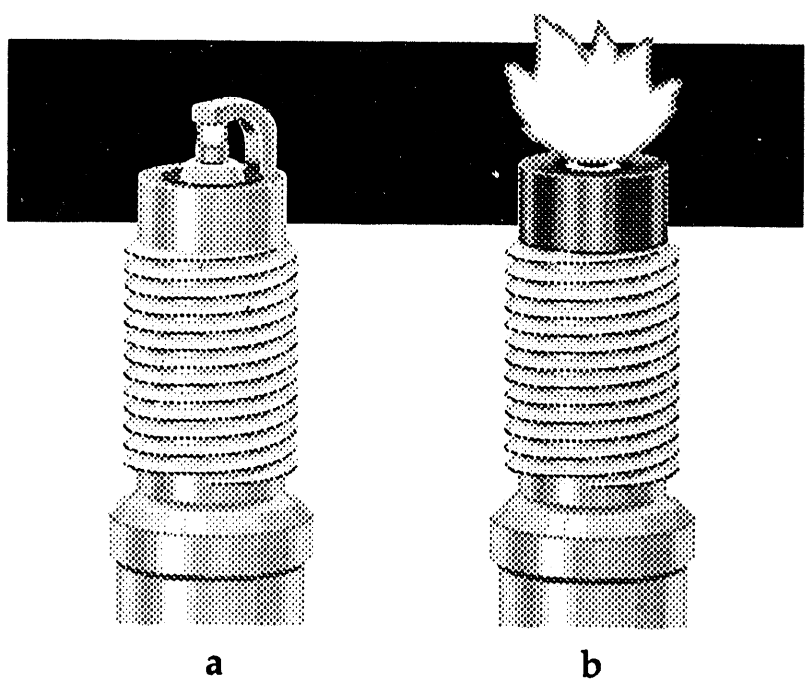
SPARK VAPORIZATION WITH THE DISC ENGINE (JORGENSEN, 1988)



SPRAY COMBUSTION IN THE DISC ENGINE (LEWIS, 1986)



HIGH VOLTAGE RECESSED GAP IGNITOR

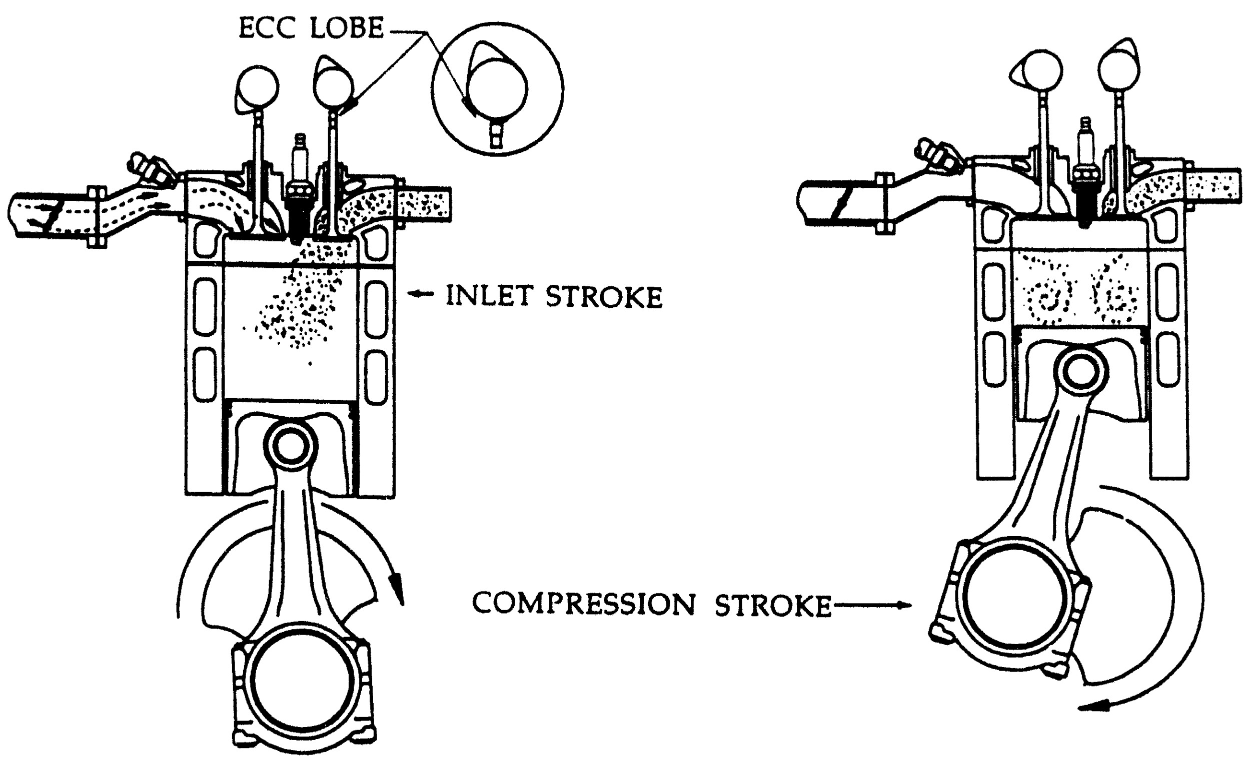


AIR-GAP SPARK PLUG (a) AND OPEN CAVITY
PLASMA JET IGNITOR (b)

1. Plasma Jet Ignition (PJI)

2. Prompt EGR Using Exhaust Charged Cycle (ECC)

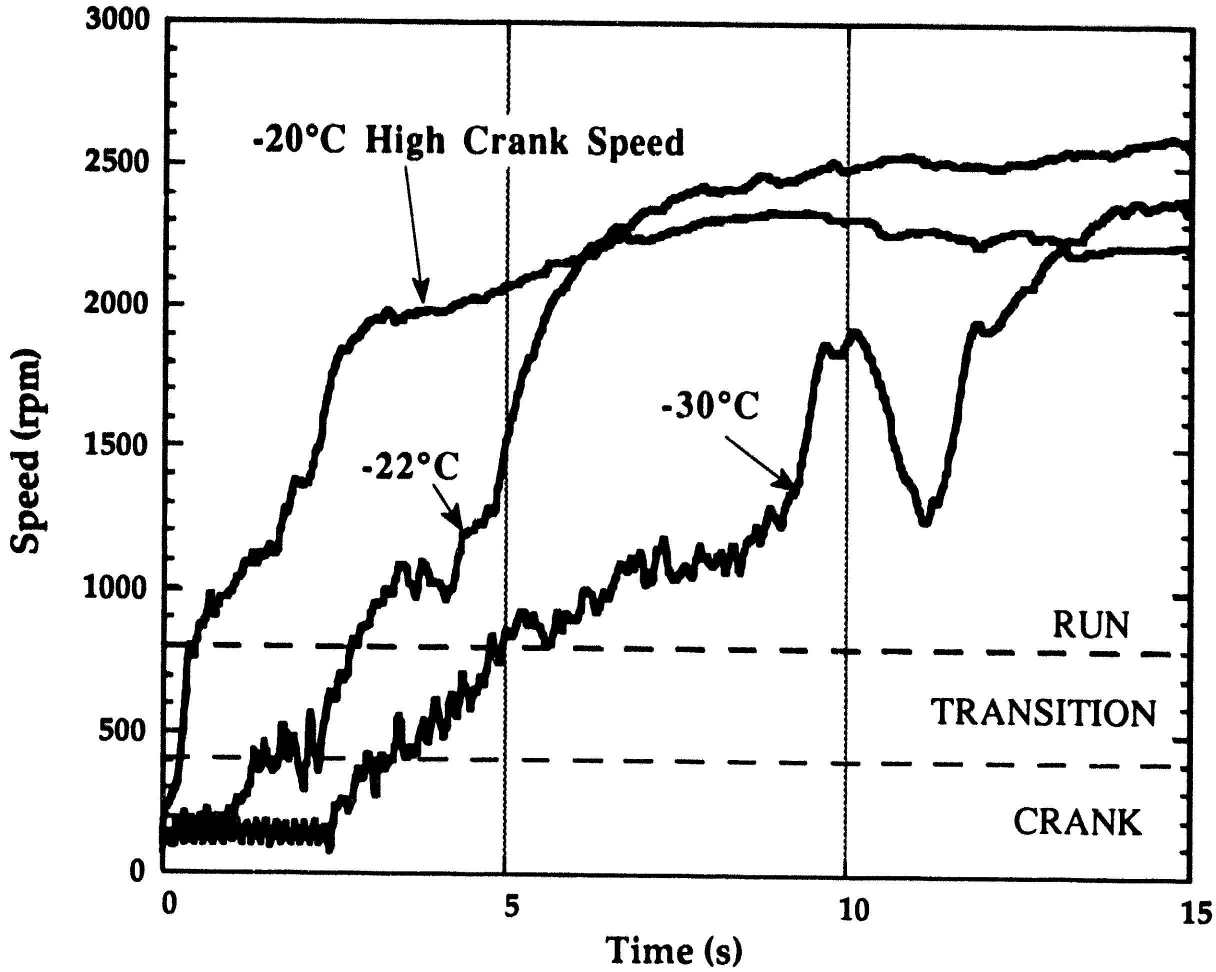
THE EXHAUST CHARGED CYCLE (ECC)



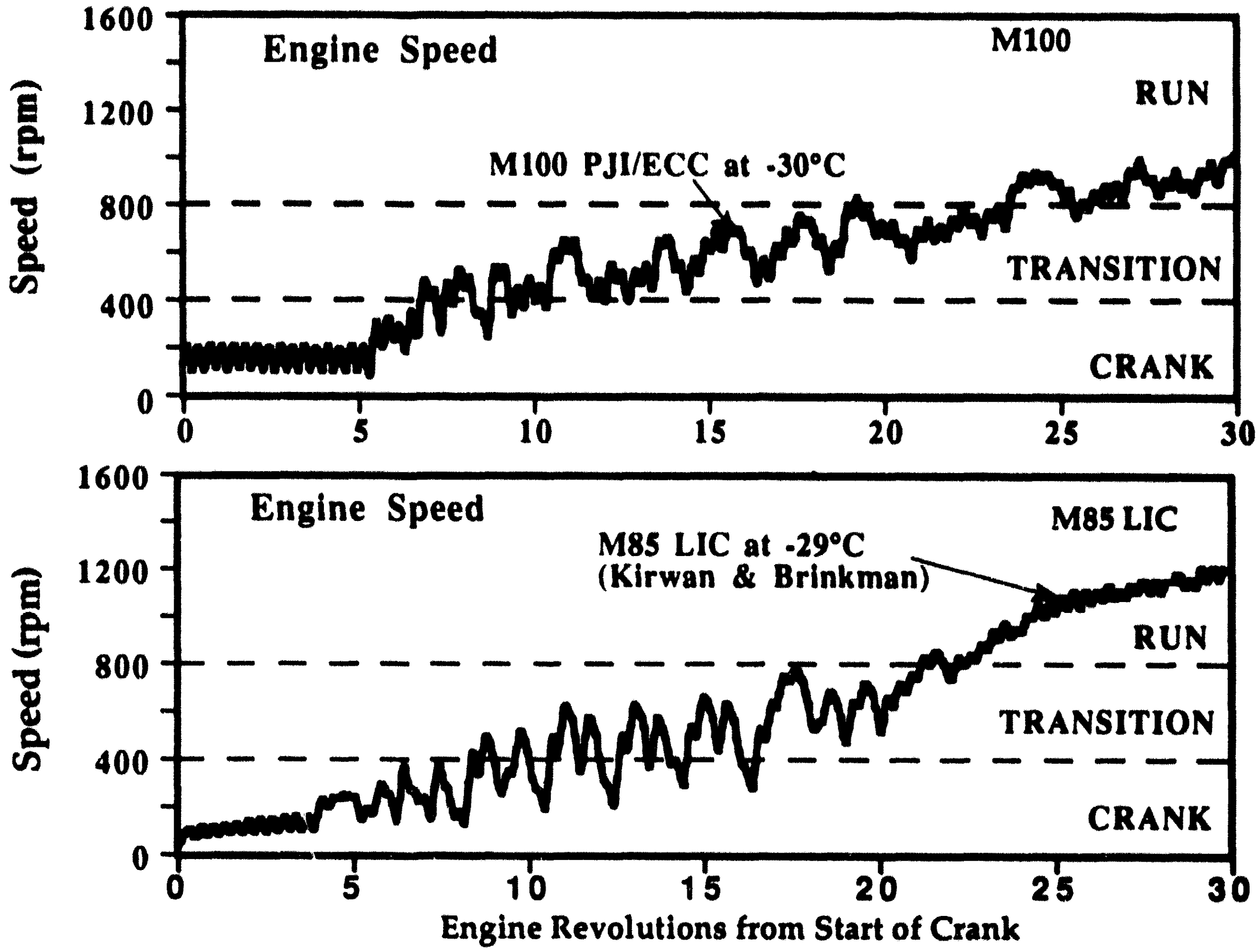
COLD STARTING HYPOTHESIS FOR PJI/ECC

1. First fire achieved by PJI through spark vaporization mechanism

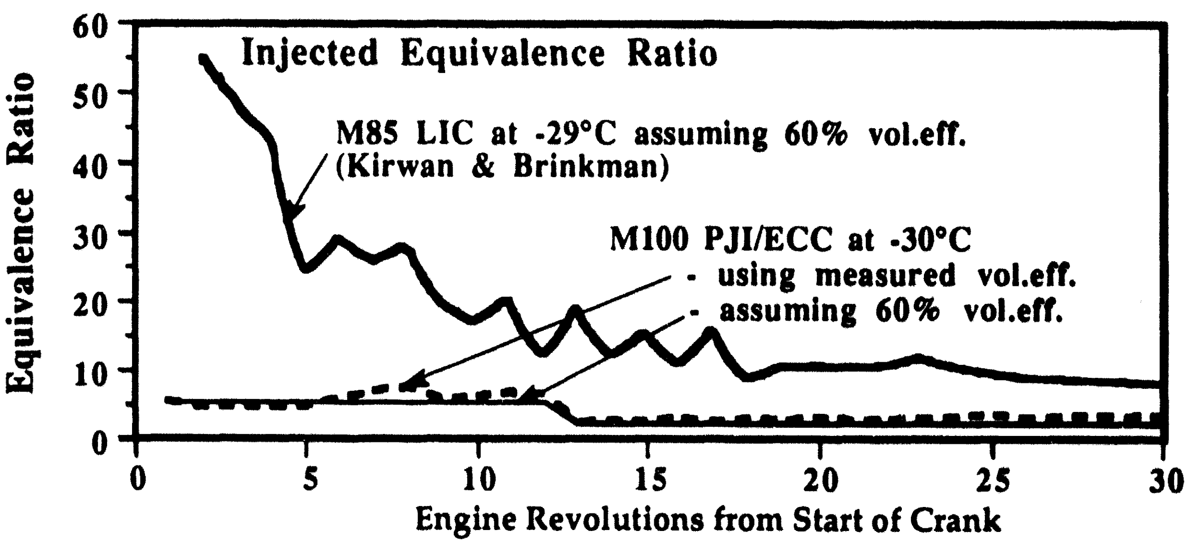
2. Transition to prevaporized combustion mode achieved by ECC through hot product recycle



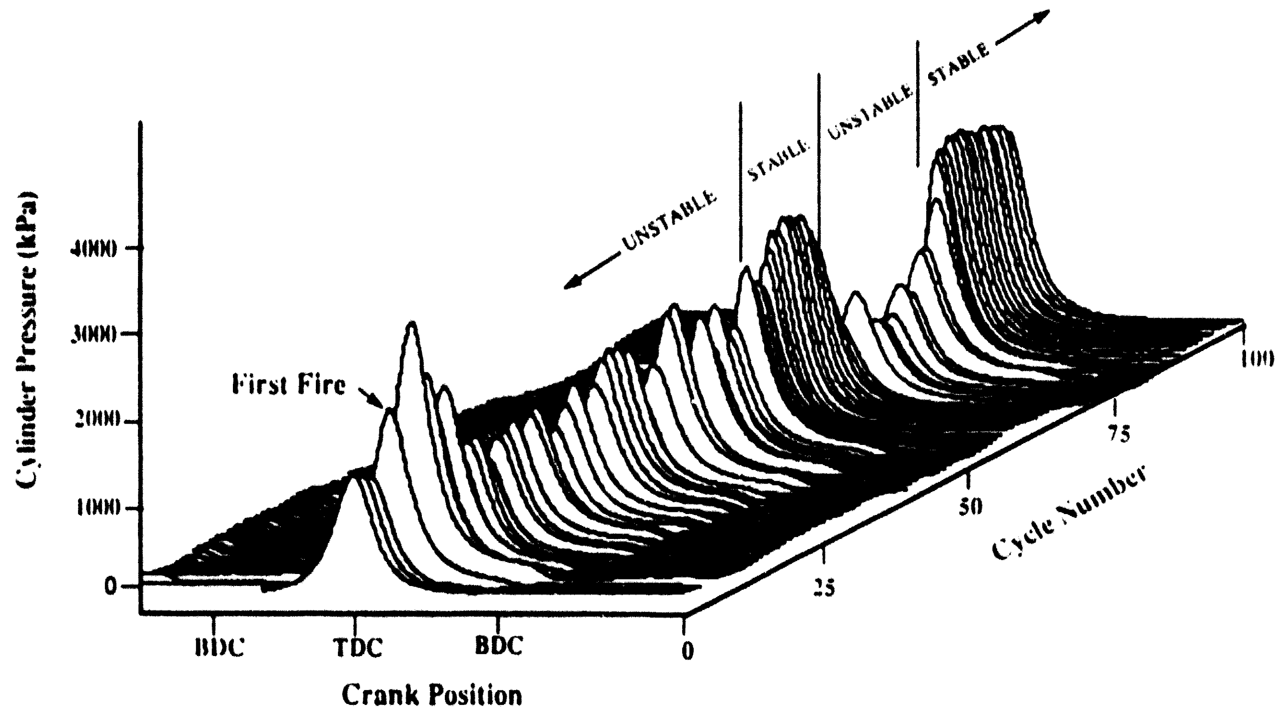
TIME TO RUN AND IDLE WITH M100 PJI/ECC



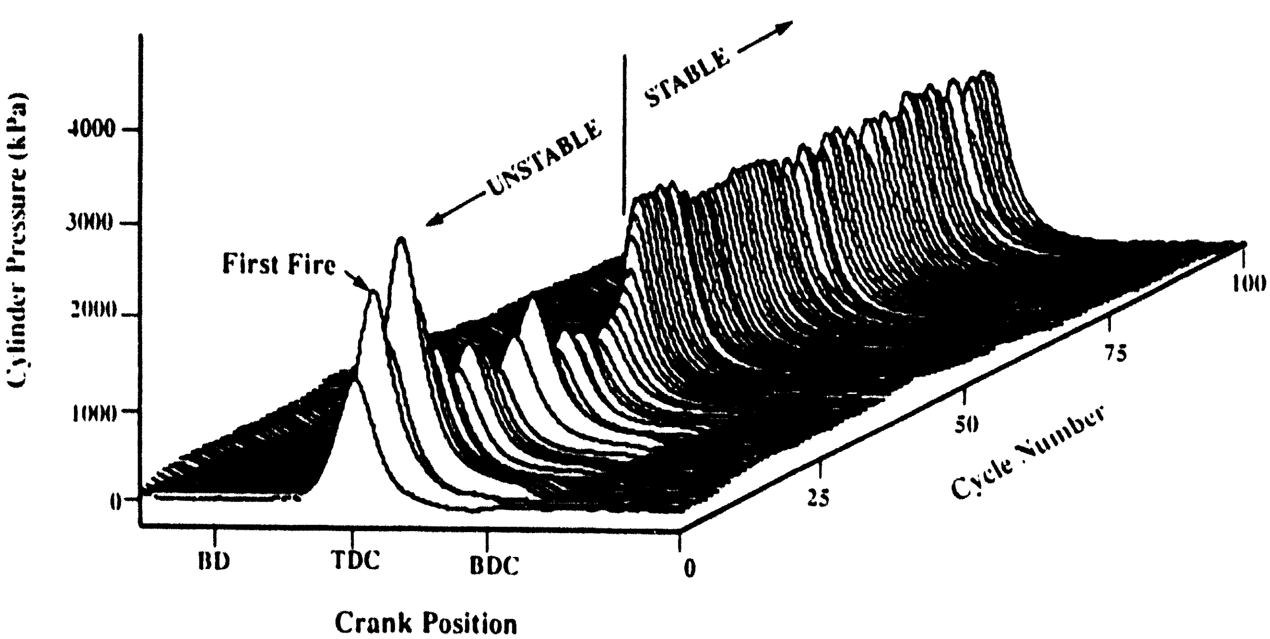
CRANK-TO-RUN BEHAVIOUR



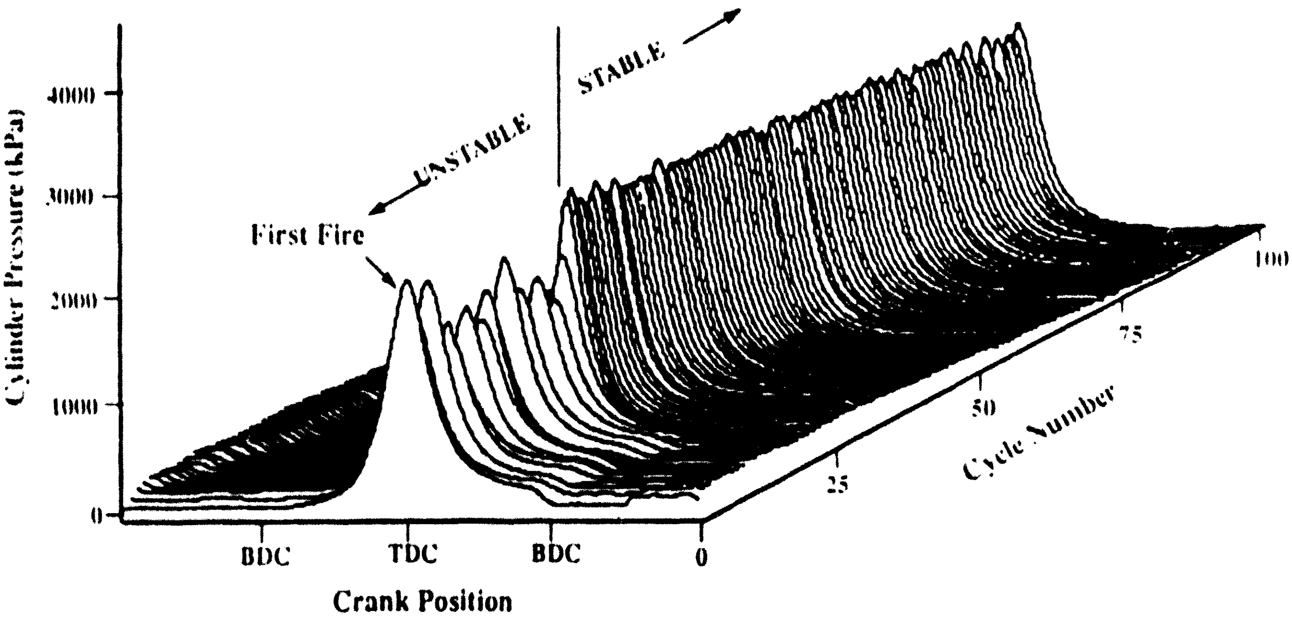
CRANKING EQUIVALENCE RATIO



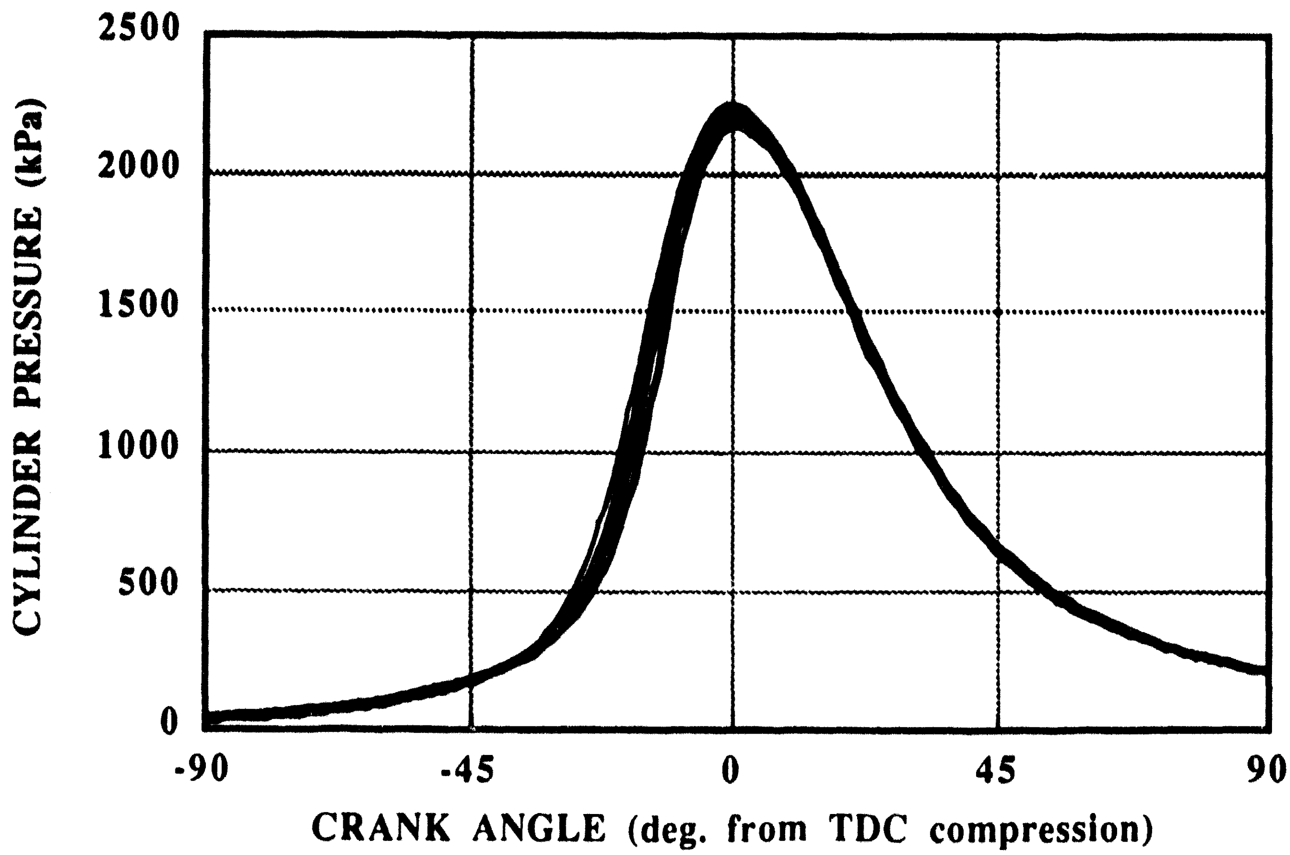
CYLINDER PRESSURE DATA FROM -30°C COLD START TEST



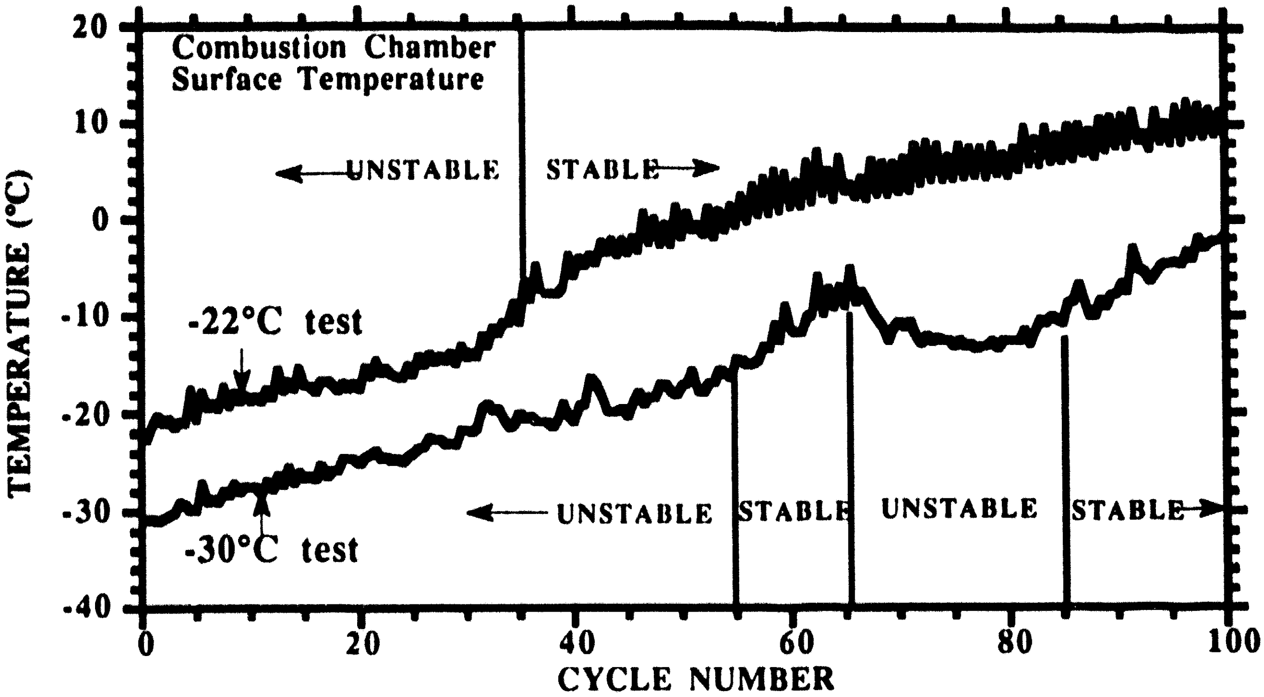
CYLINDER PRESSURE DATA FROM -22°C COLD START TEST



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

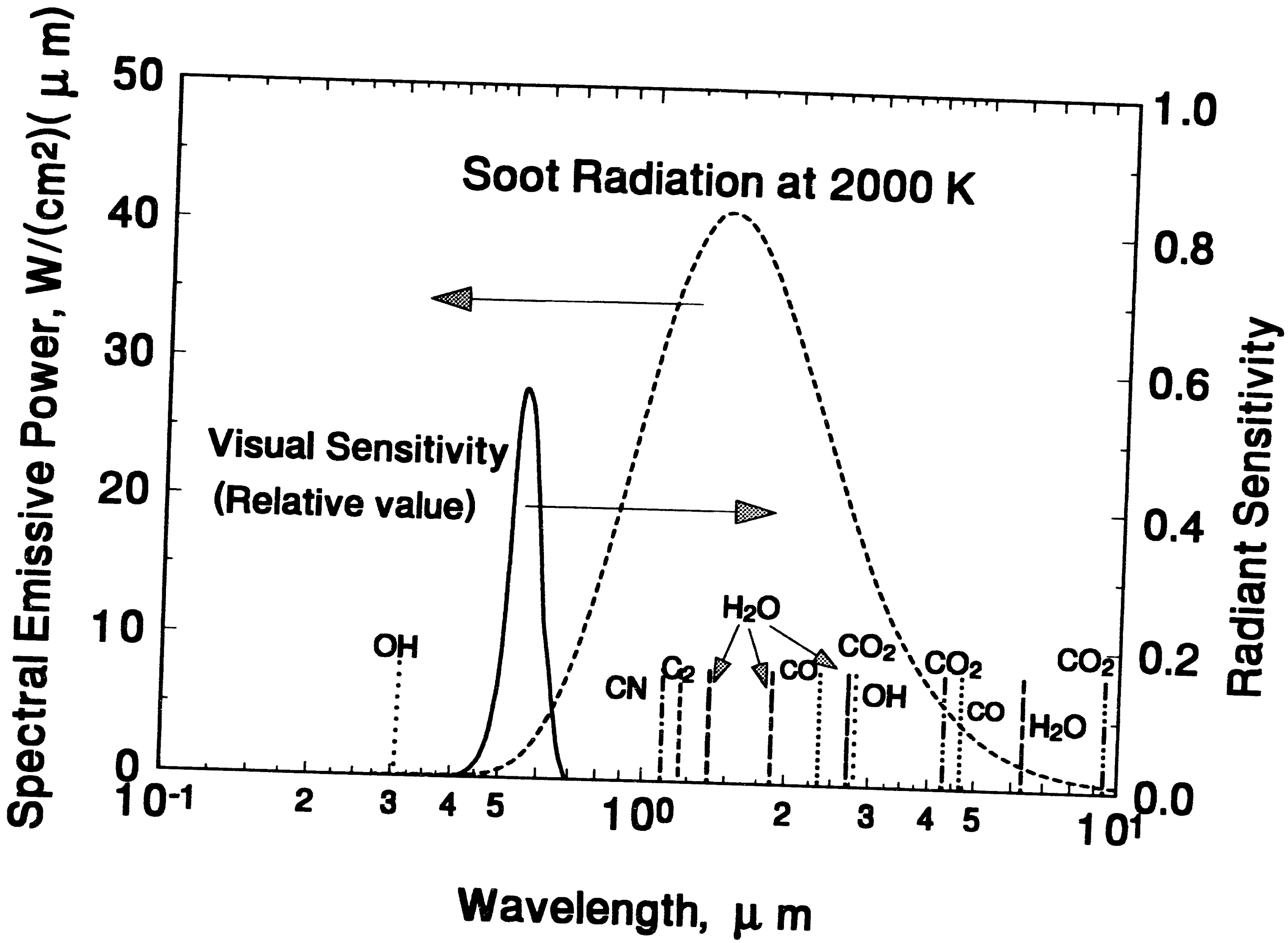
and

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)
OH
CN
C_2
H_2O
CO
CO_2
OH
CO_2
CO
H_2O
CO_2
Spectral Emissive Power, W/(cm²)(μ m)
Radiant Sensitivity
Wavelength, μ m

562

WHY METHANOL DOES NOT SOOT ?

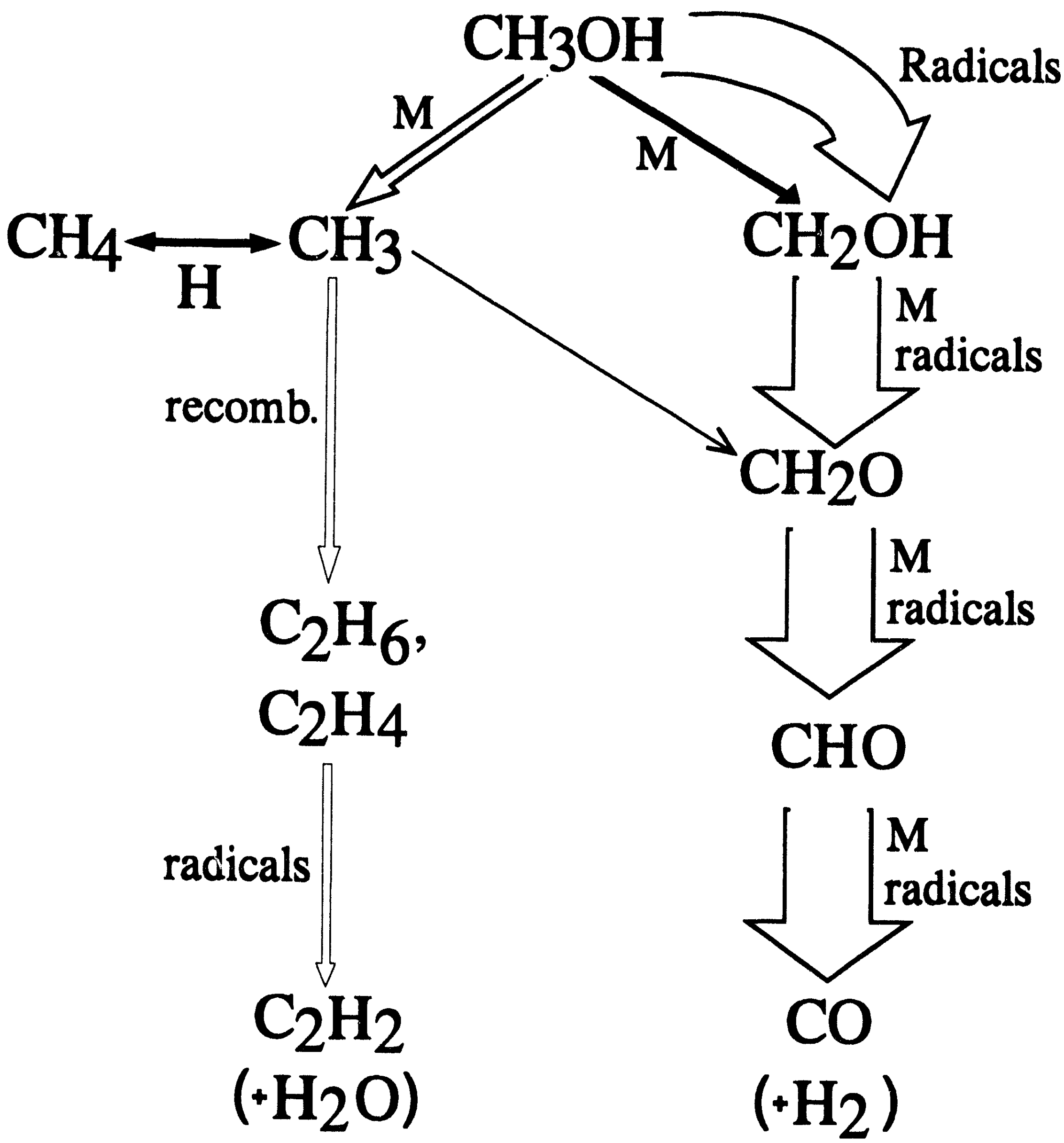
- **No clear answer backed by experimental evidence**

- **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
M
radicals
radicals
C2H2
(+H2O)
CO
(+H2)

POTENTIAL ANSWERS

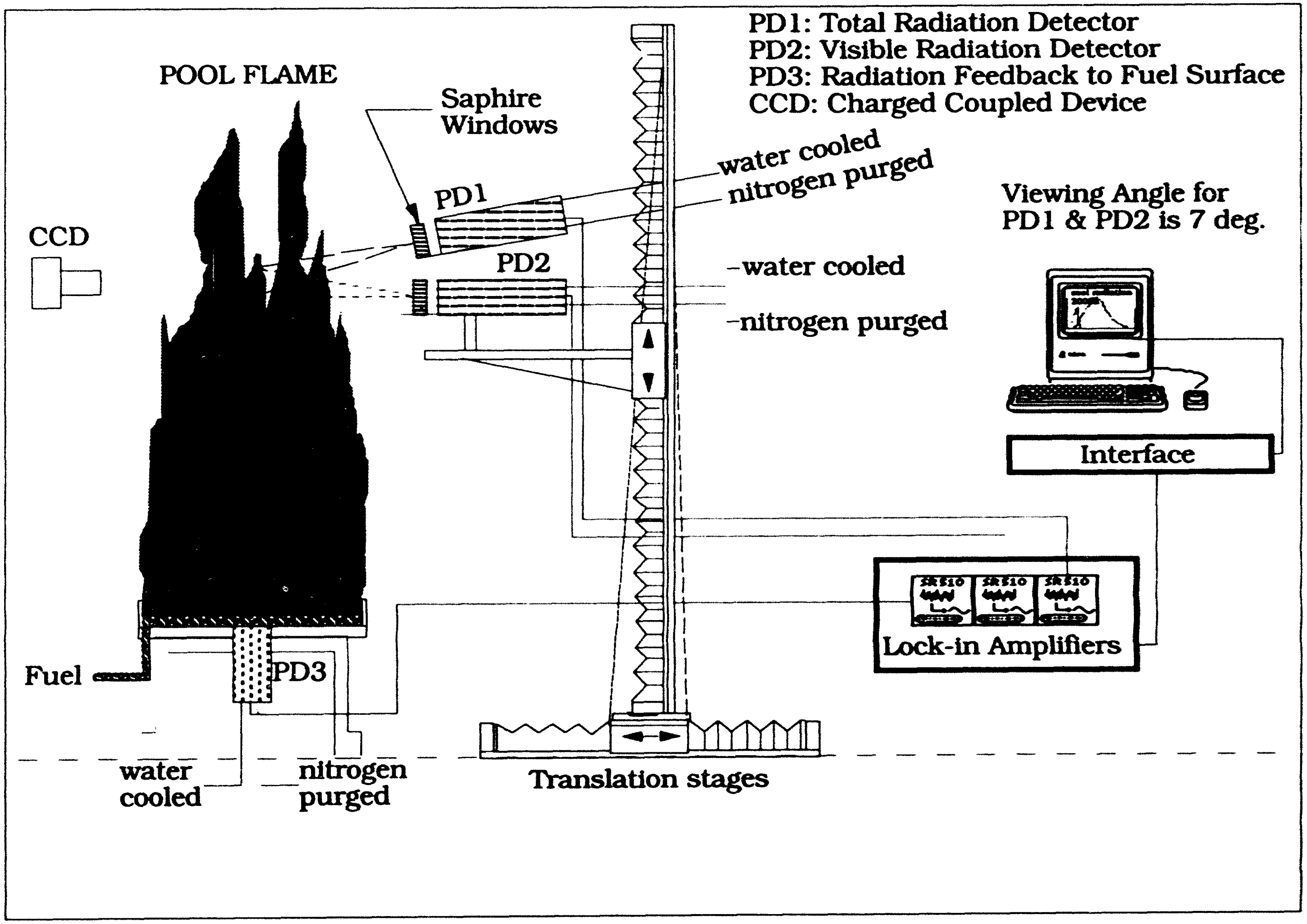
- **During pyrolysis, almost all methanol dissociates into carbon monoxide and hydrogen. Very small amount of acetylene(s) formed**

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

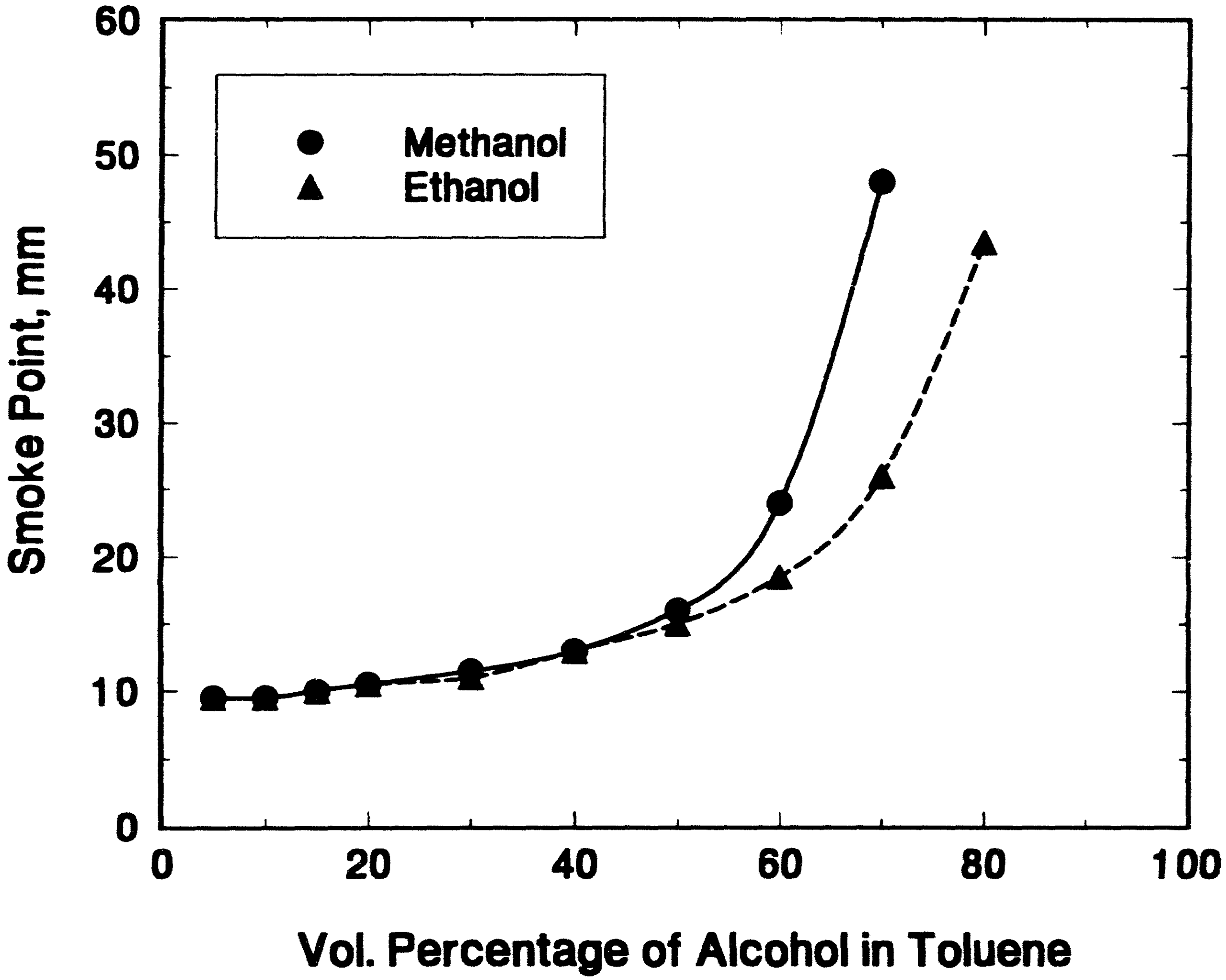
- **Due to existence of oxygen atom in fuel structure OH radical is readily formed, and can oxidize any potential soot precursor**

EXPERIMENTAL WORK

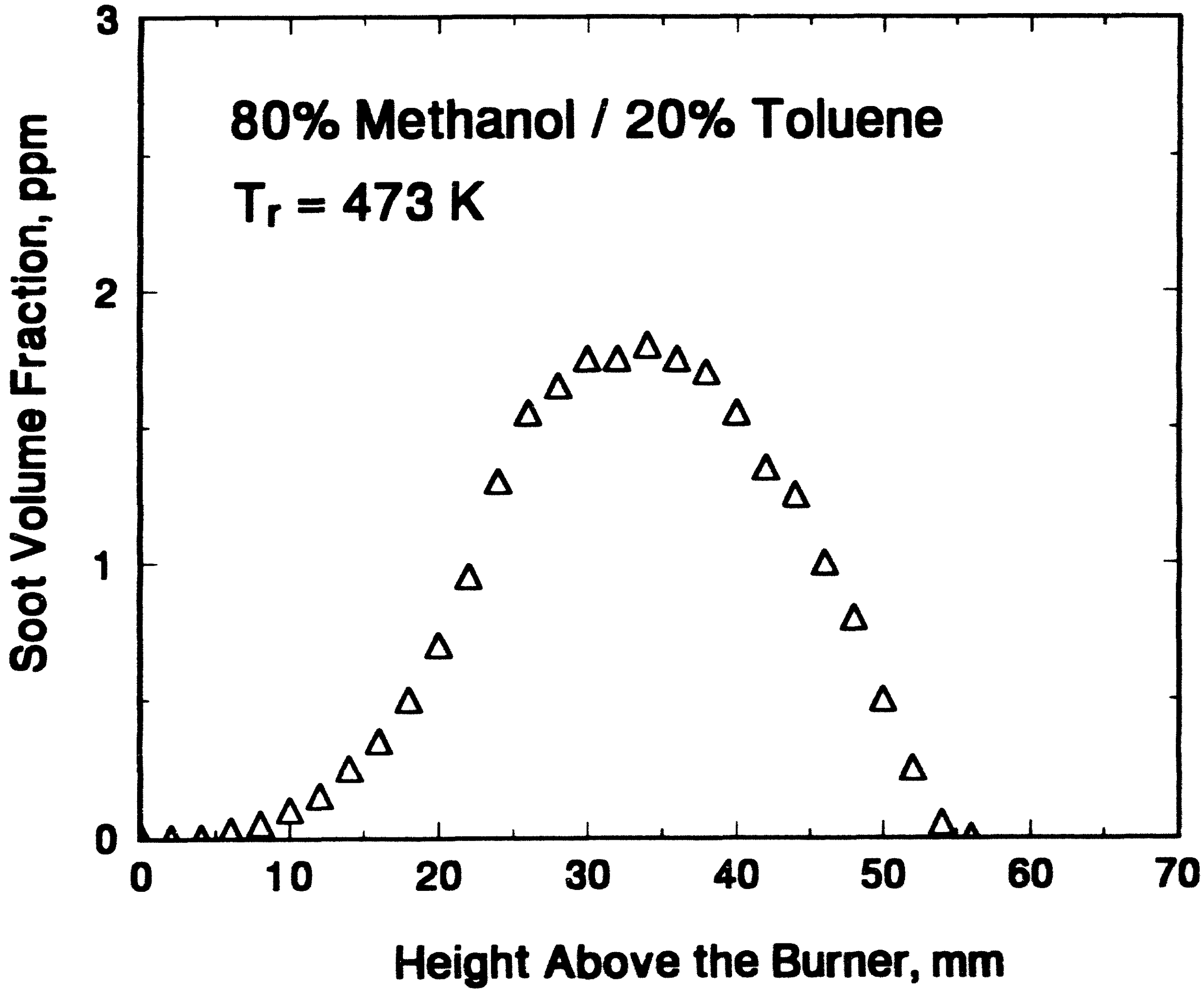
- Laminar diffusion flame experiments: *SOOT*
  - Methanol and air are heated to 673 K to elevate the flame temperature
  - Methanol hydrocarbon blends
  - Methanol with additives
- Pool flame experiments: *RADIATION*
  - Two different pool flames: 0.1 m & 0.3 m diameters
  - Methanol with additives



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

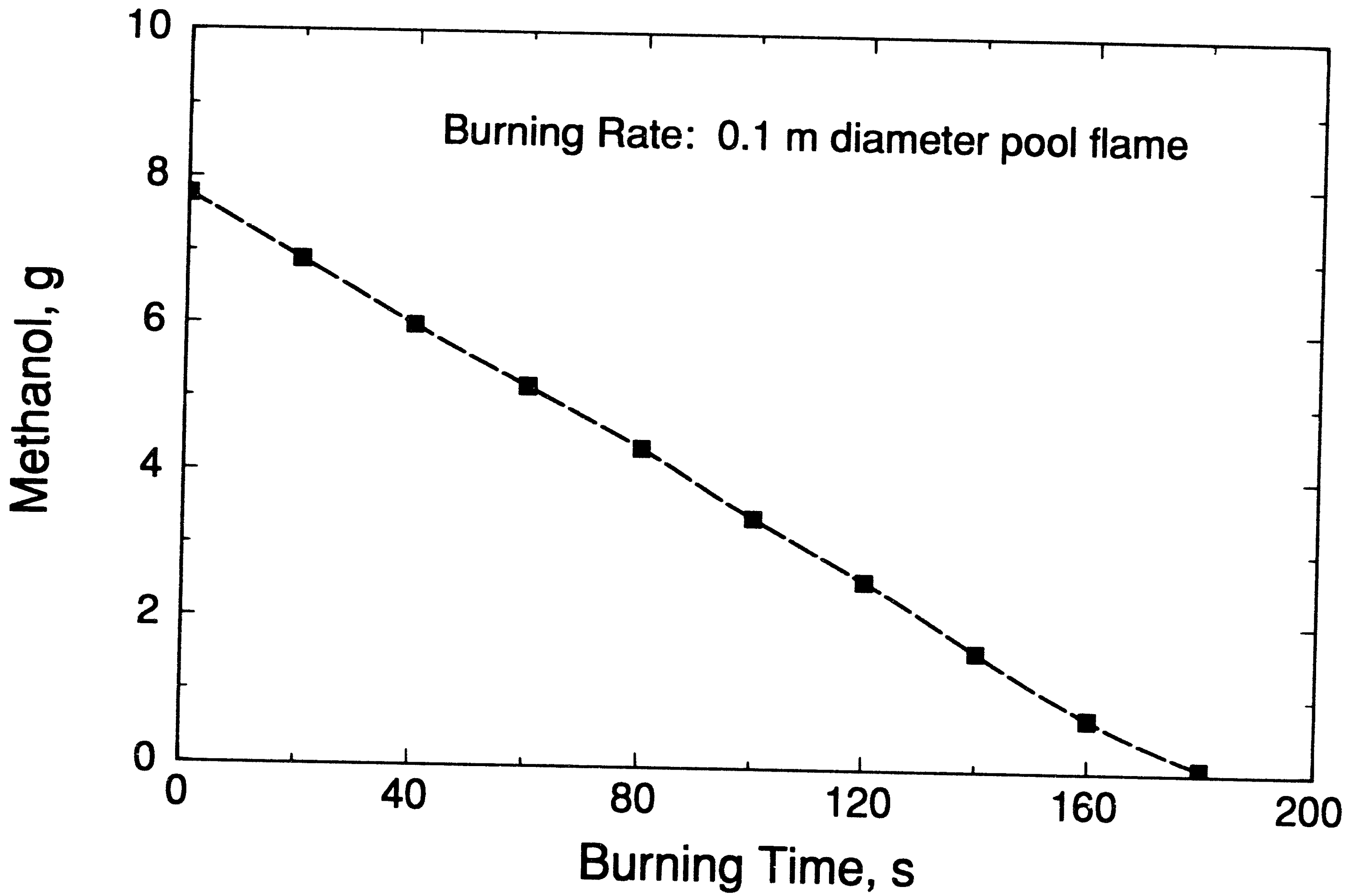
- Three of these ten compounds yielded promising results
- At 0.5 to 1.2% level, measured visible flame luminosity of the pool flames is comparable to the luminosity of M85
- These additives leave some residual material
- These additives may not be suitable for catalytic converters

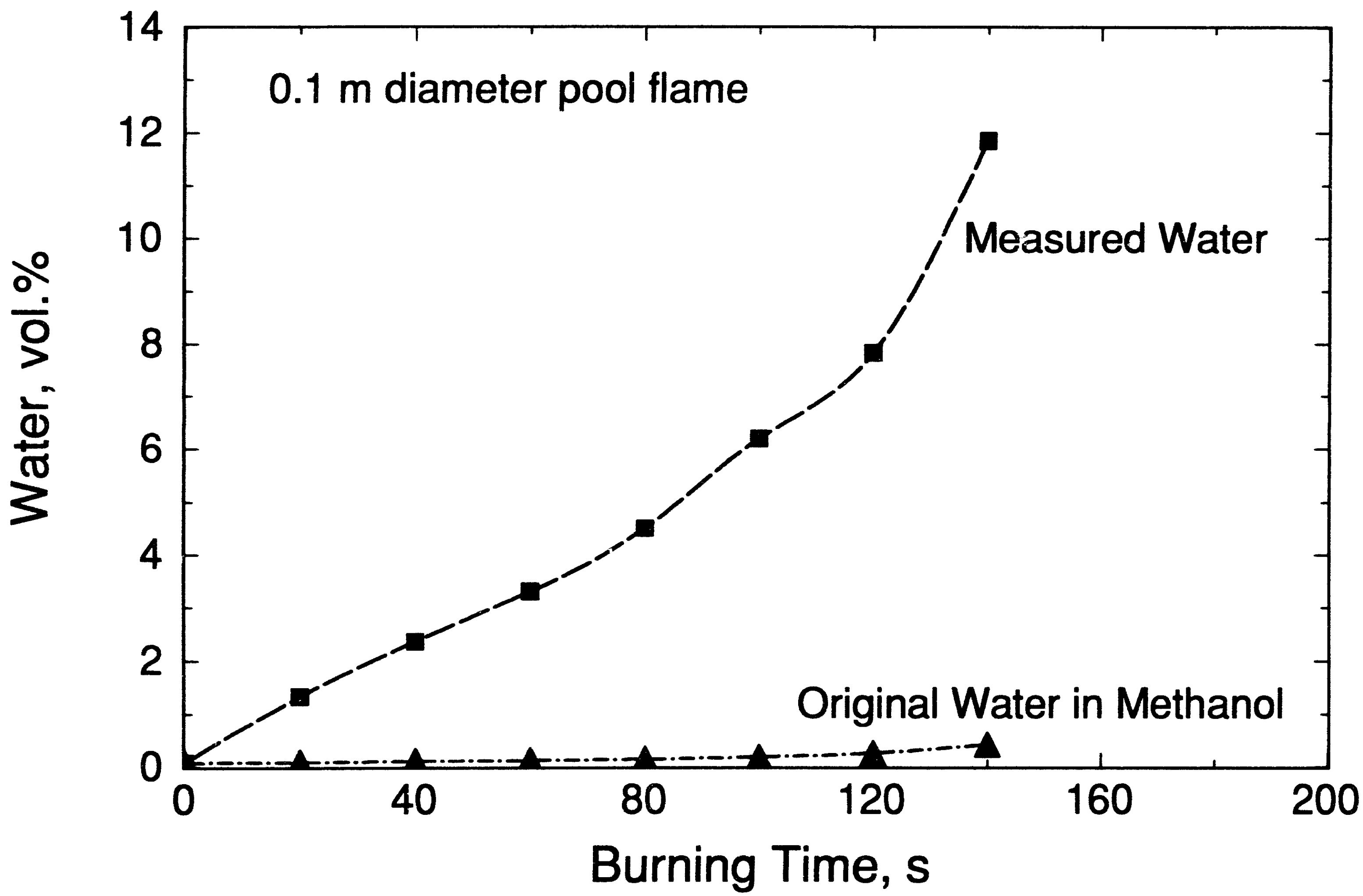
NON-HYDROCARBON ADDITIVES - III

- **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

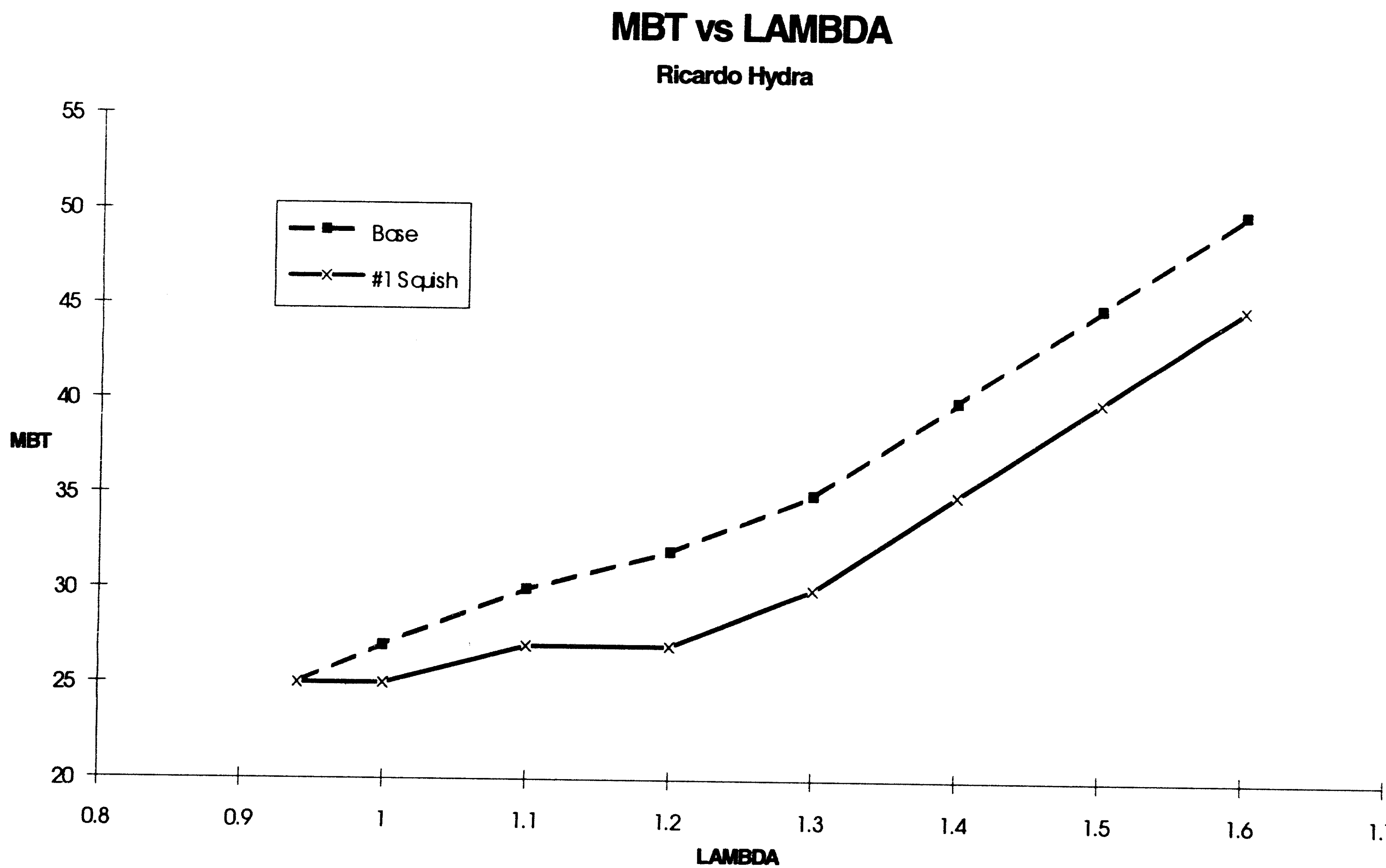
- Evaluate the effect of turbulence generating jets on ignition delay and heat release in a single cylinder NG fueled engine.
- Implement most effective approaches for fast burn on a single cylinder L10 NG engine.
- Implement the best technology on a multi-cylinder L10 and develop a control strategy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

ORTECH

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**

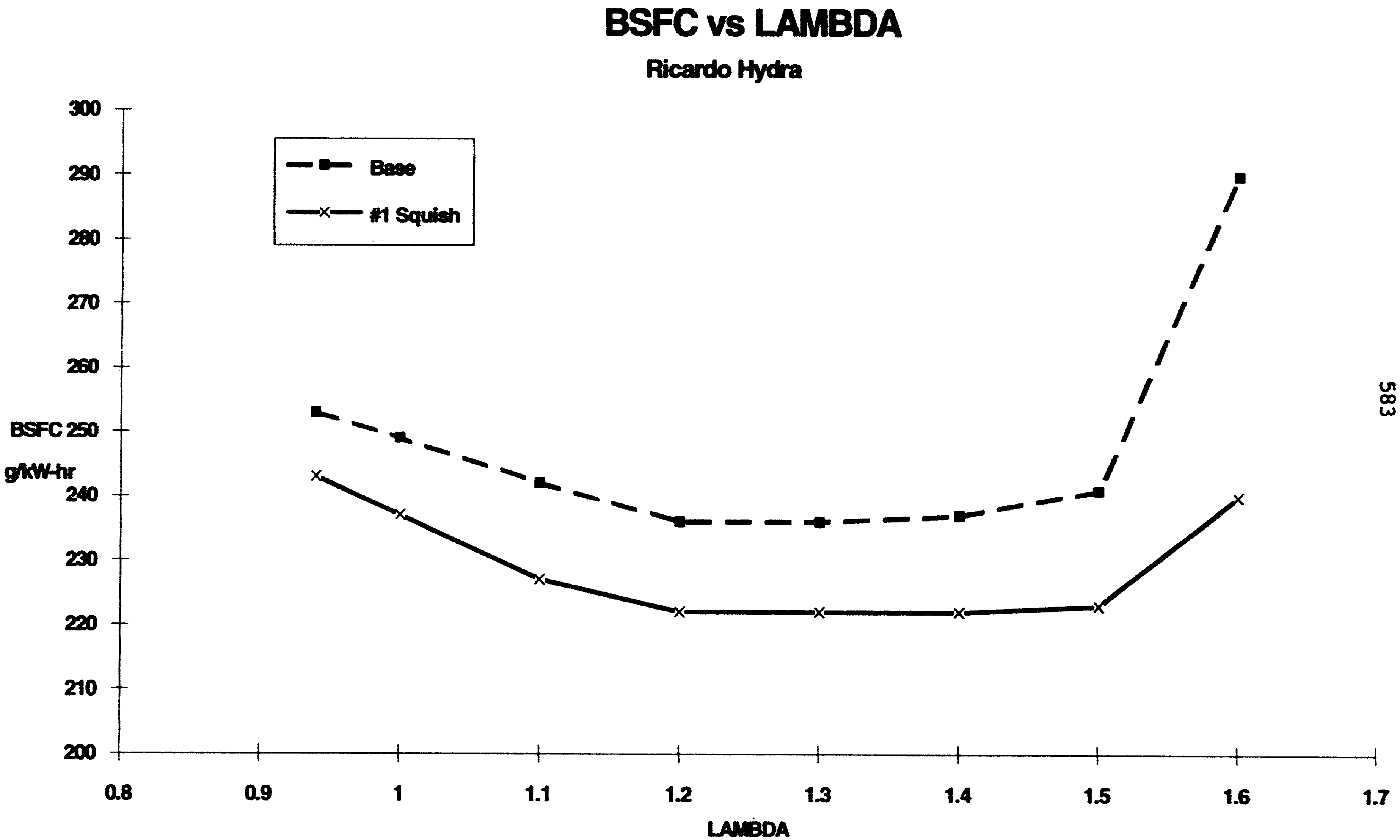
ORTECH



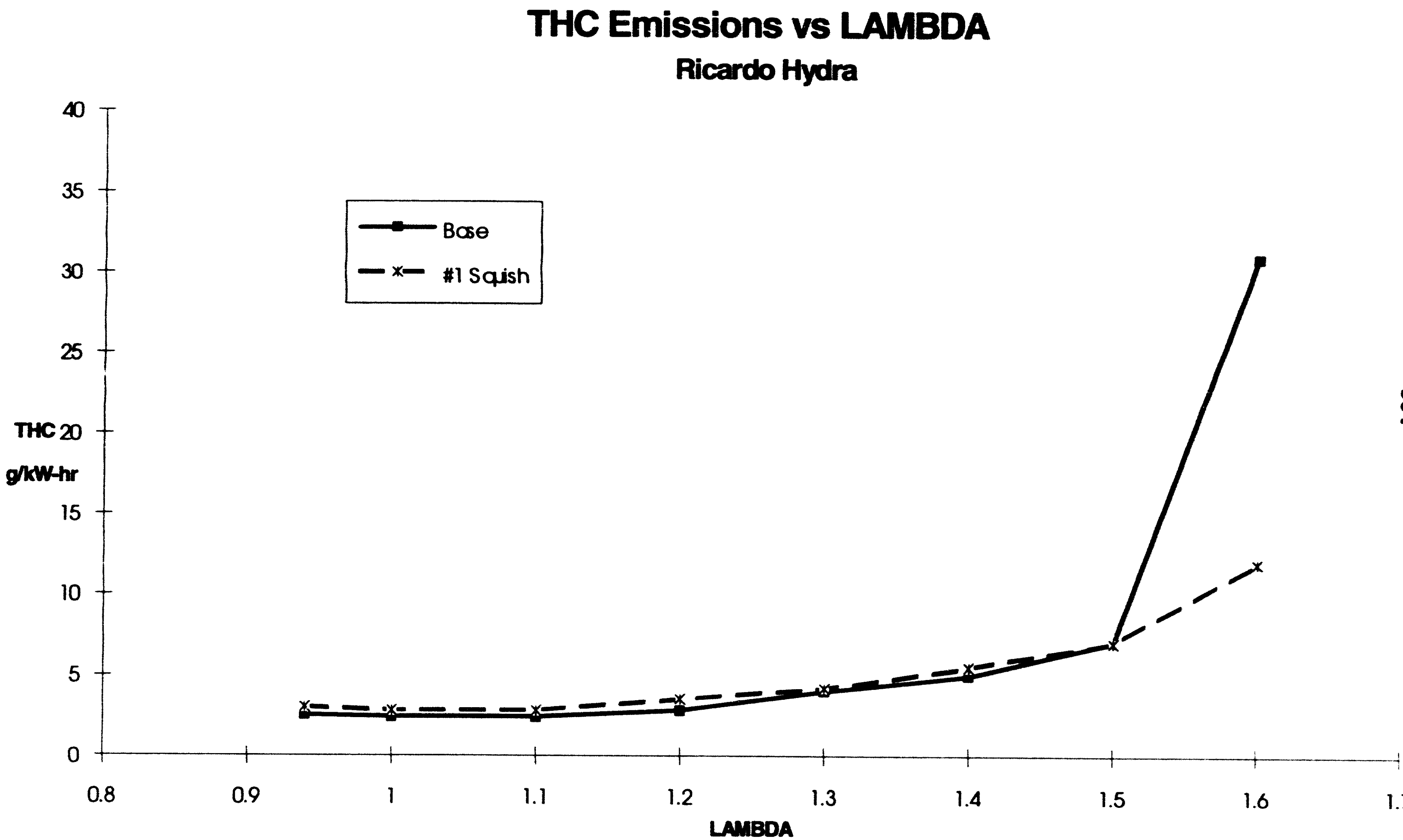
MBT vs LAMBDA
Ricardo Hydra
55
50
45
40
35
30
25
20
MBT
Base
#1 Squish
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
LAMBDA

ORTECH

BSFC vs LAMBDA

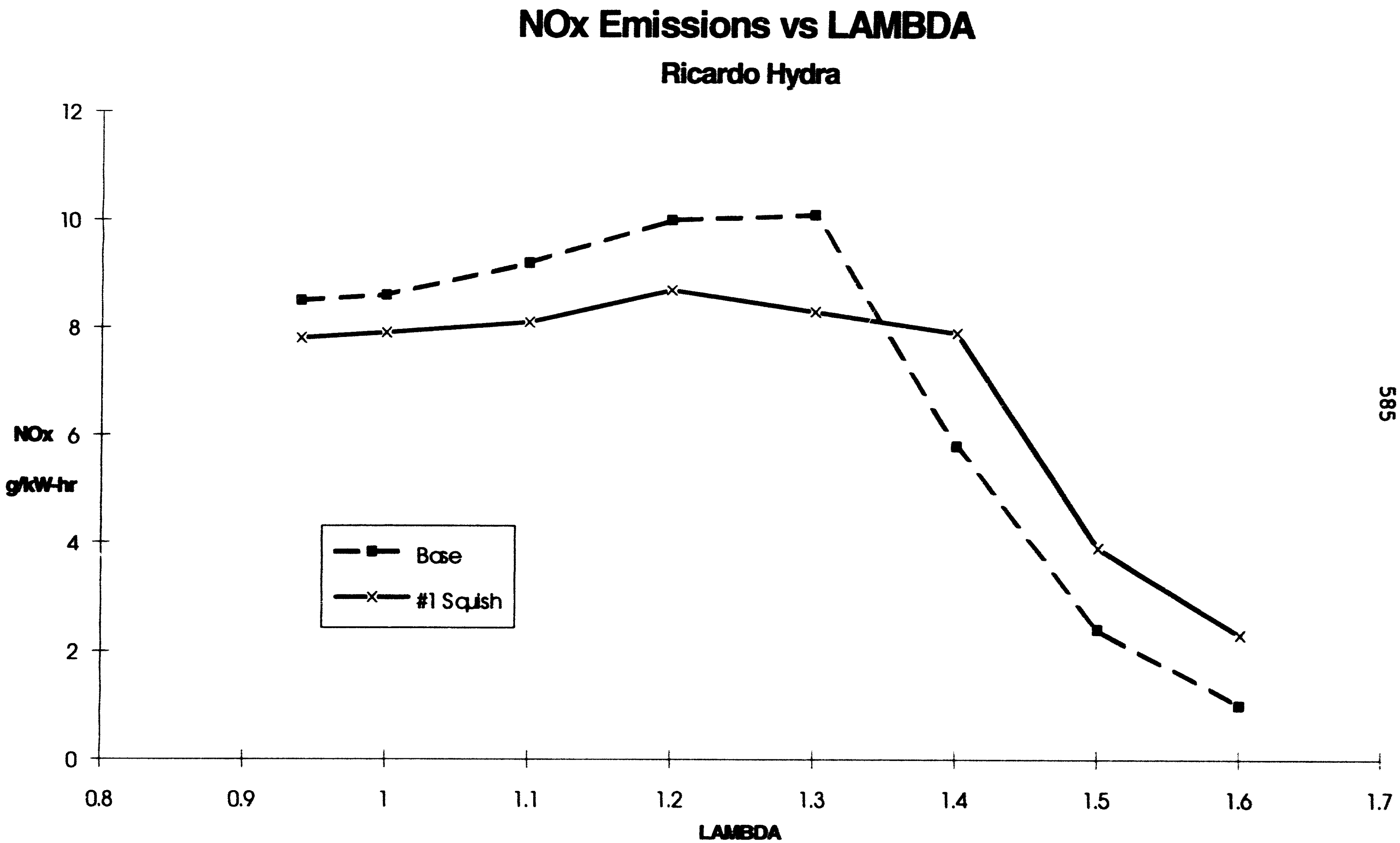


ORTECH



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

ORTECH



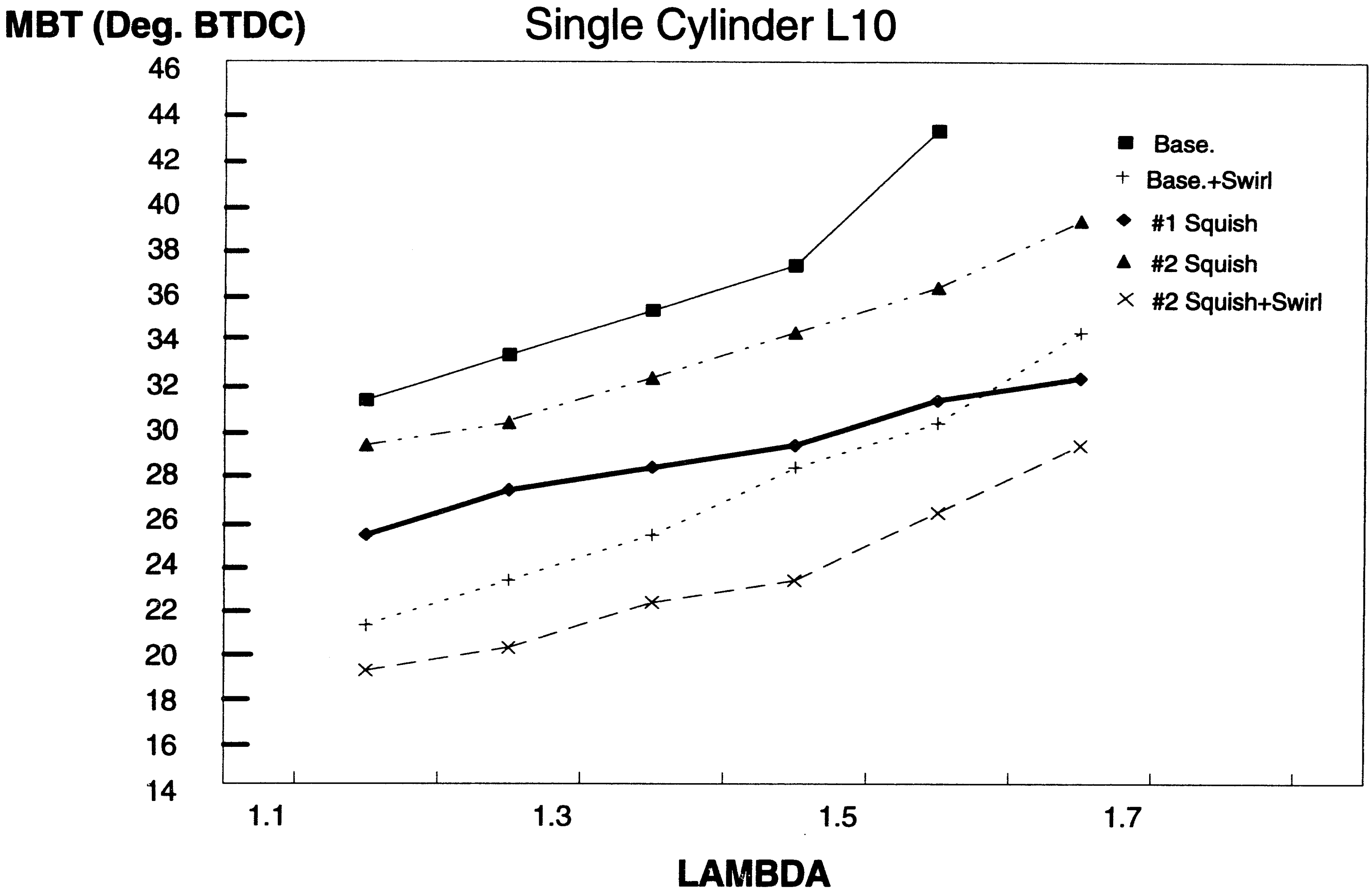
NOx Emissions vs LAMBDA
Ricardo Hydra
NOx
g/kW-hr
0
2
4
6
8
10
12
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
LAMBDA
Base
#1 Squish

ORTECH

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

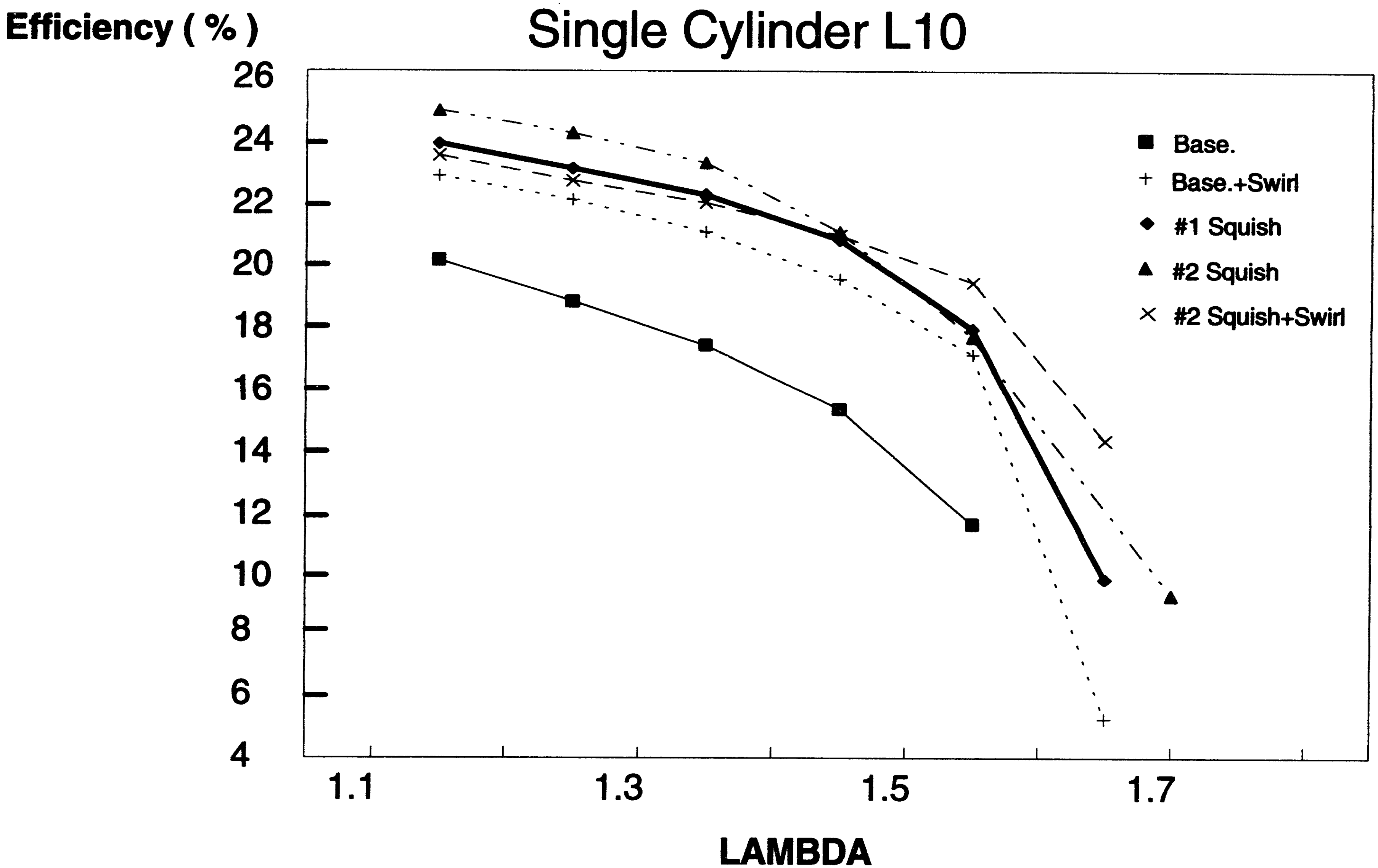
MBT vs. LAMBDA



ORTECH

Efficiency vs. LAMBDA

Single Cylinder L10

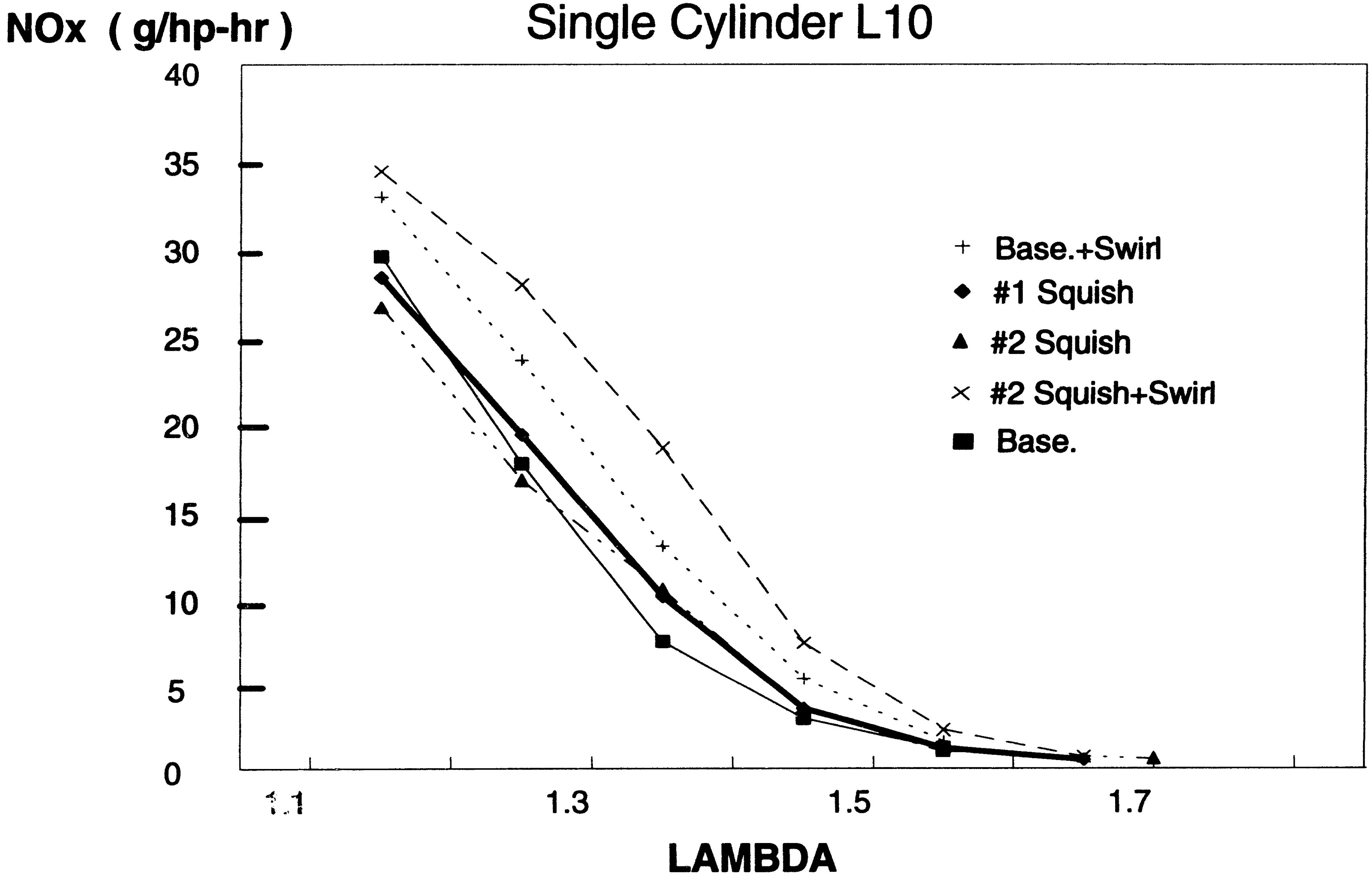


588

ORTECH

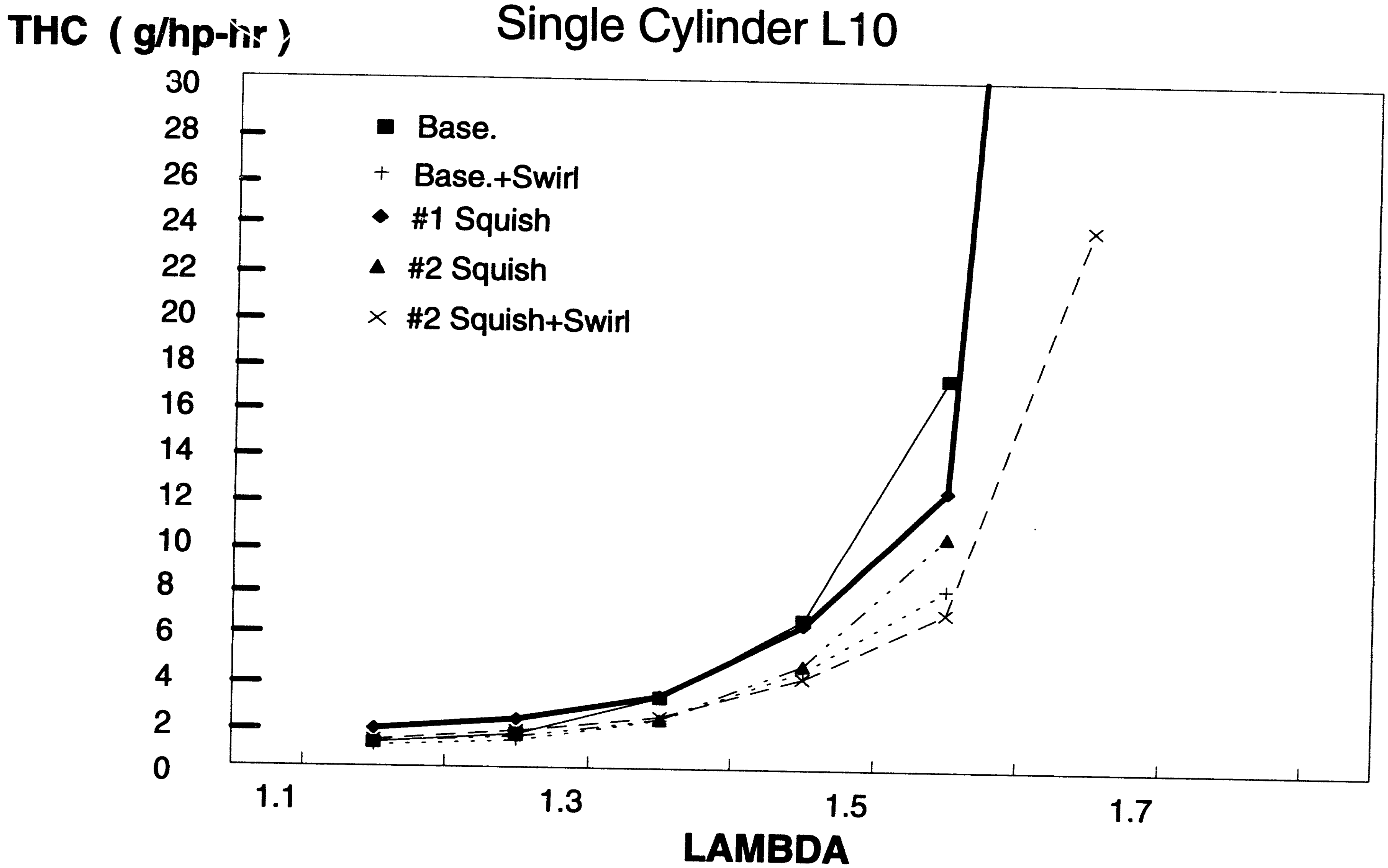
NOx Emissions vs. LAMBDA

Single Cylinder L10



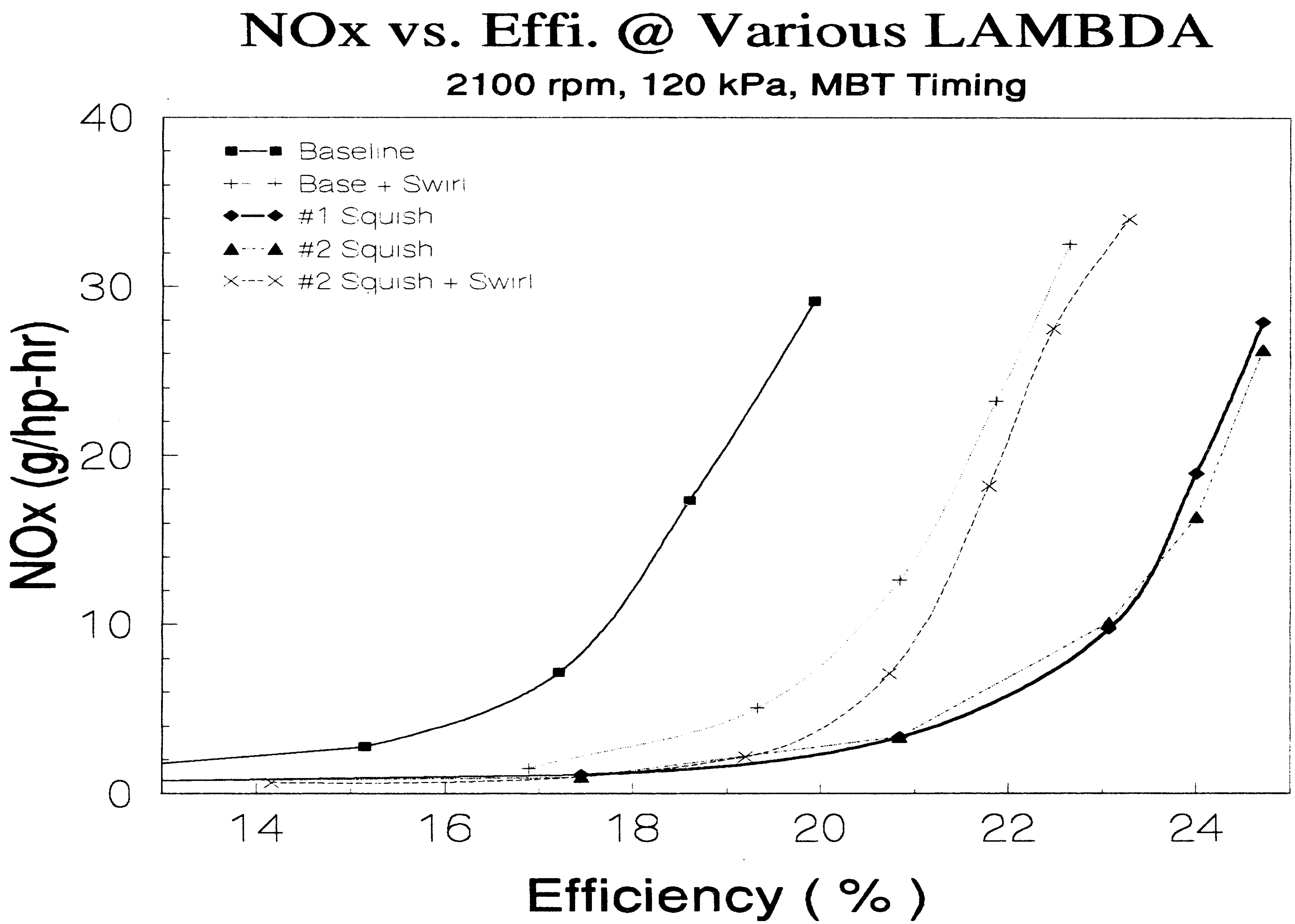
ORTECH

THC Emissions vs. LAMBDA

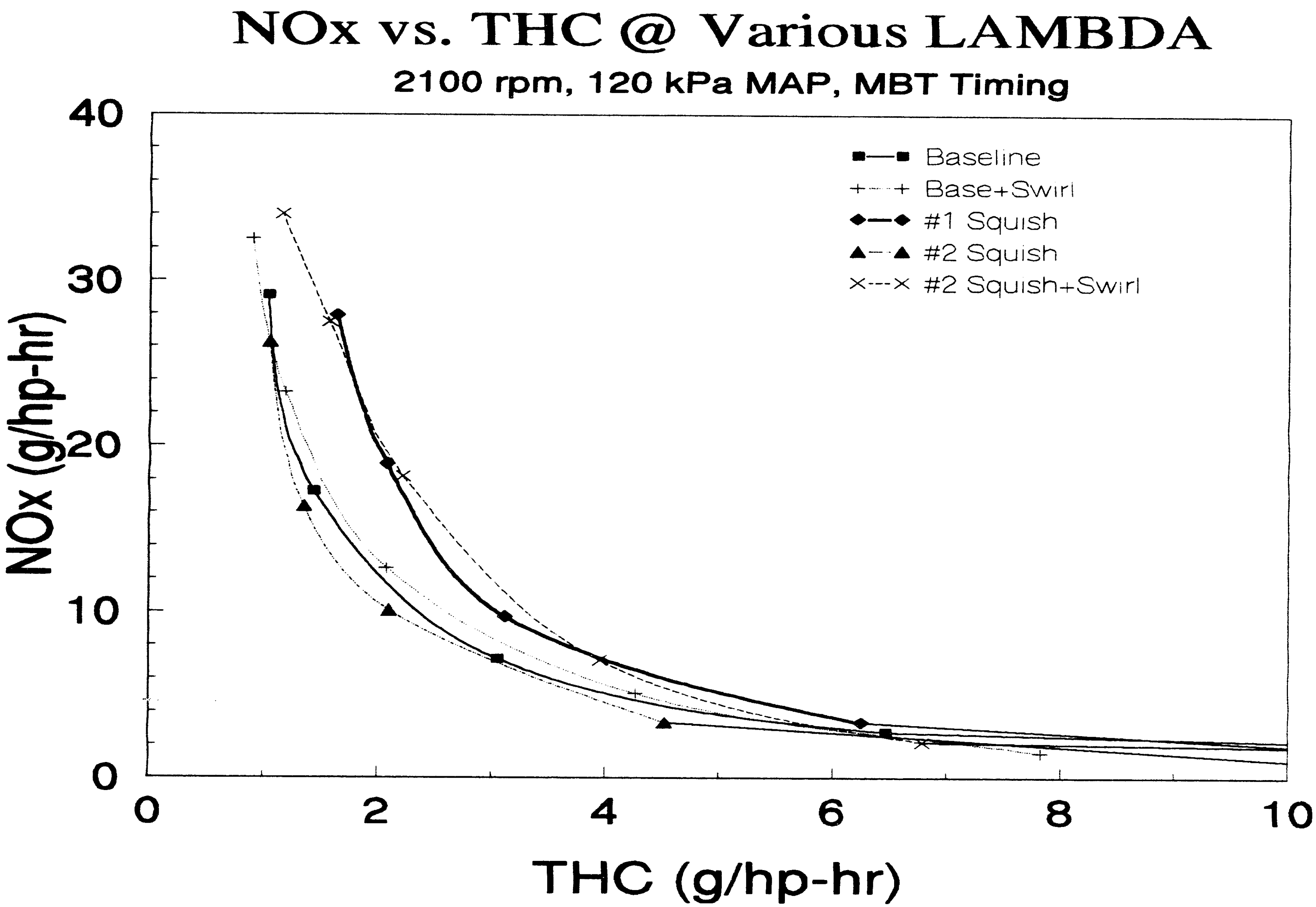


ORTECH

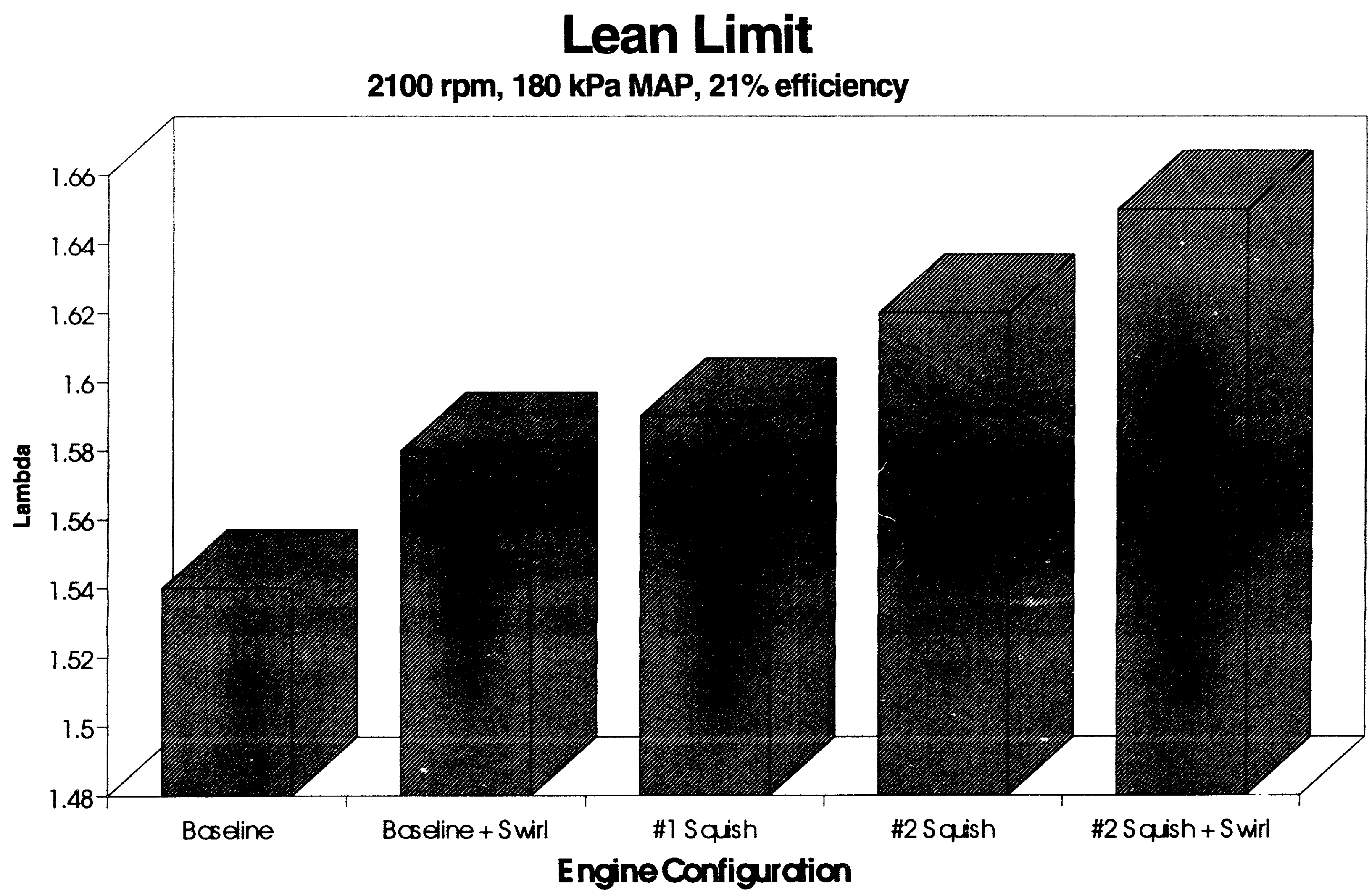
590


NOx vs. Effi. @ Various LAMBDA
2100 rpm, 120 kPa, MBT Timing
Baseline
Base + Swirl
#1 Squish
#2 Squish
#2 Squish + Swirl
NOx (g/hp-hr)
Efficiency (%)
0
10
20
30
40
14
16
18
20
22
24

ORTECH


NOx vs. THC @ Various LAMBDA
2100 rpm, 120 kPa MAP, MBT Timing
Baseline
Base+Swirl
#1 Squish
#2 Squish
#2 Squish+Swirl
NOx (g/hp-hr)
THC (g/hp-hr)
0
10
20
30
40
0
2
4
6
8
10

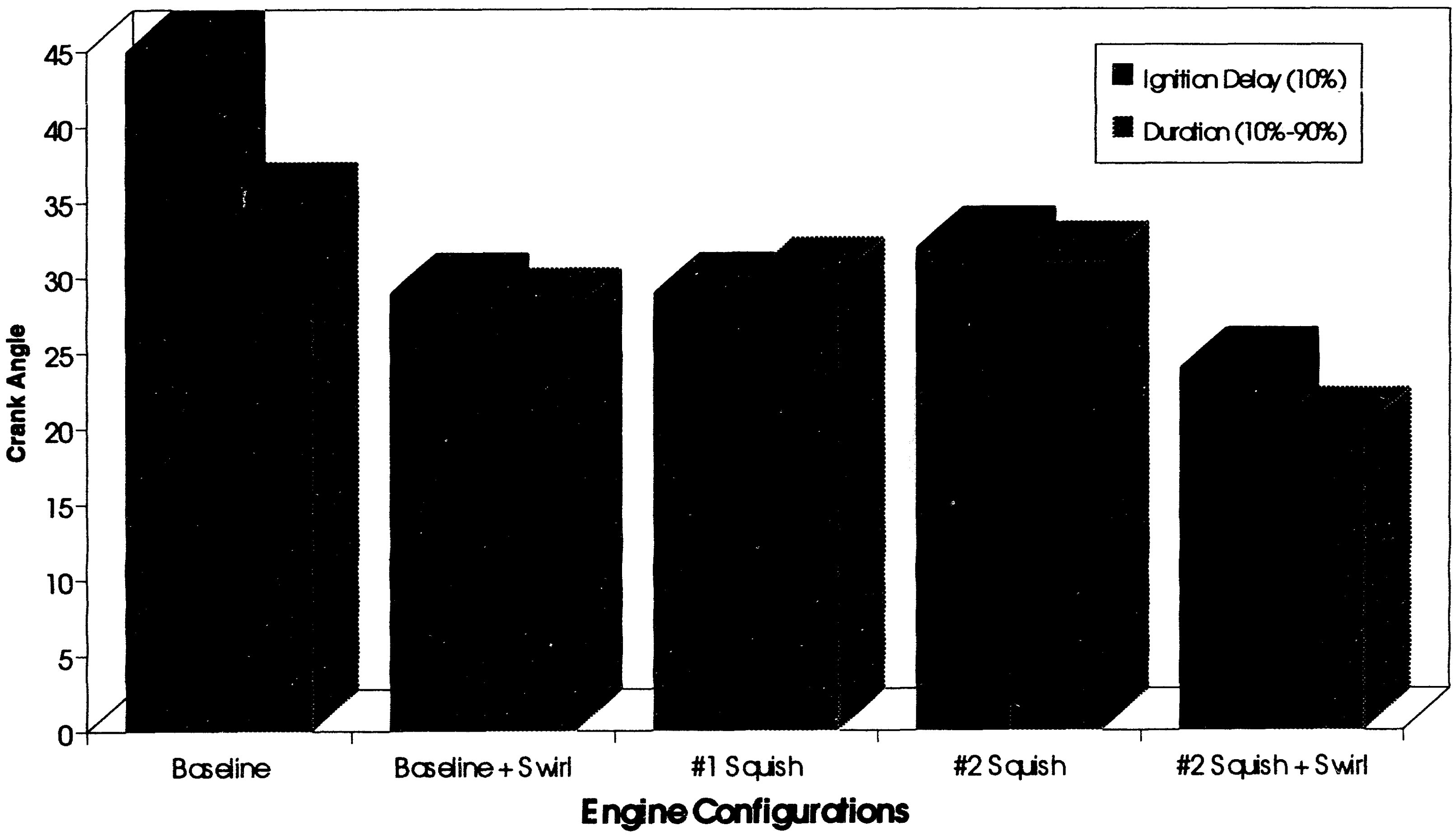
ORTECH


Lean Limit
2100 rpm, 180 kPa MAP, 21% efficiency
Lambda
1.66
1.64
1.62
1.6
1.58
1.56
1.54
1.52
1.5
1.48
Baseline
Baseline + Swirl
#1 Squish
#2 Squish
#2 Squish + Swirl
Engine Configuration

ORTECH

Ignition Delay & Combustion Duration

2100 rpm, 120 kPa MAP, 1.55 Lambda @ MBT



ORTECH

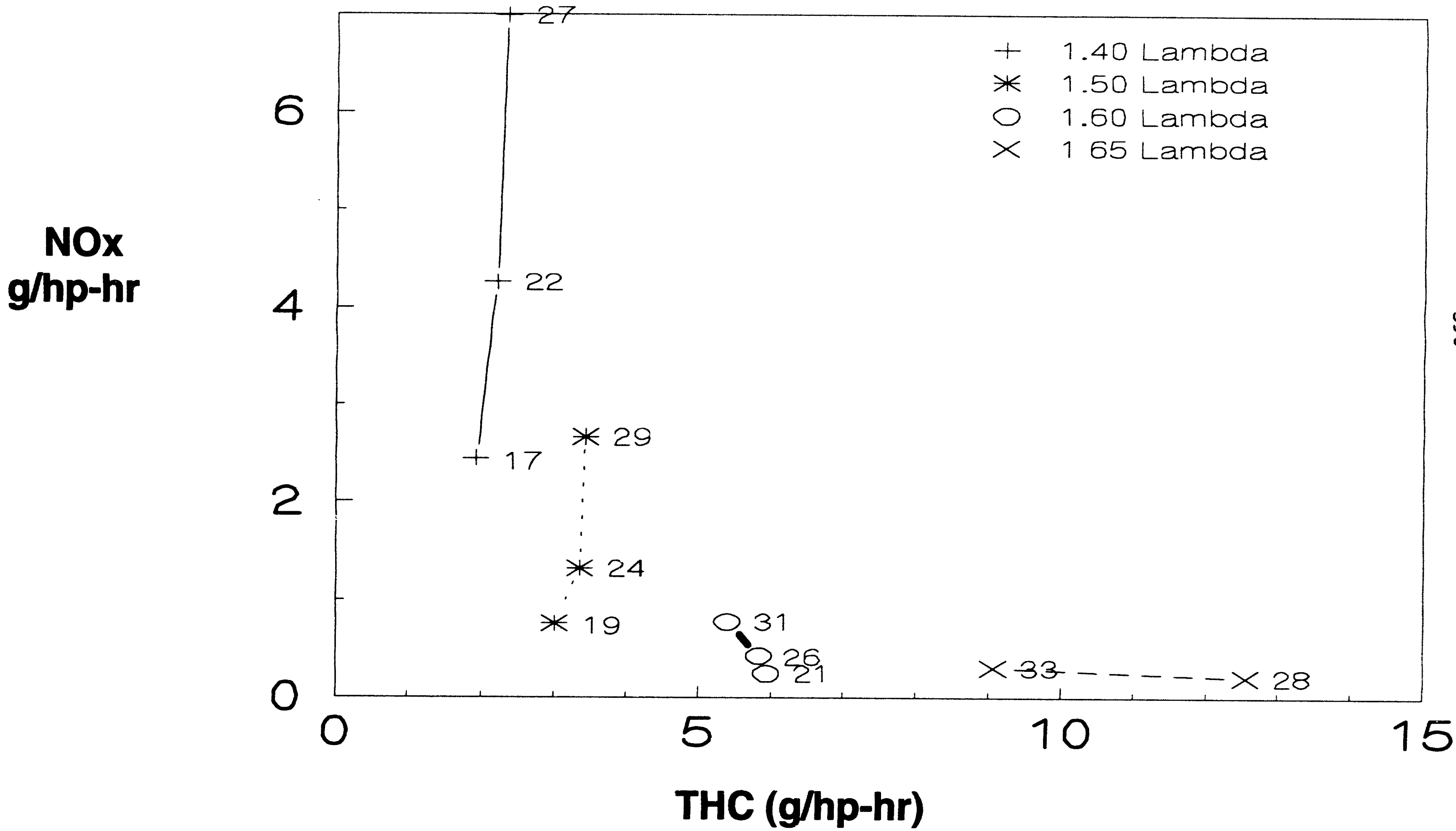
Single Cylinder Results

- 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

ORTECH

NOx vs. THC

Multi-cylinder L10

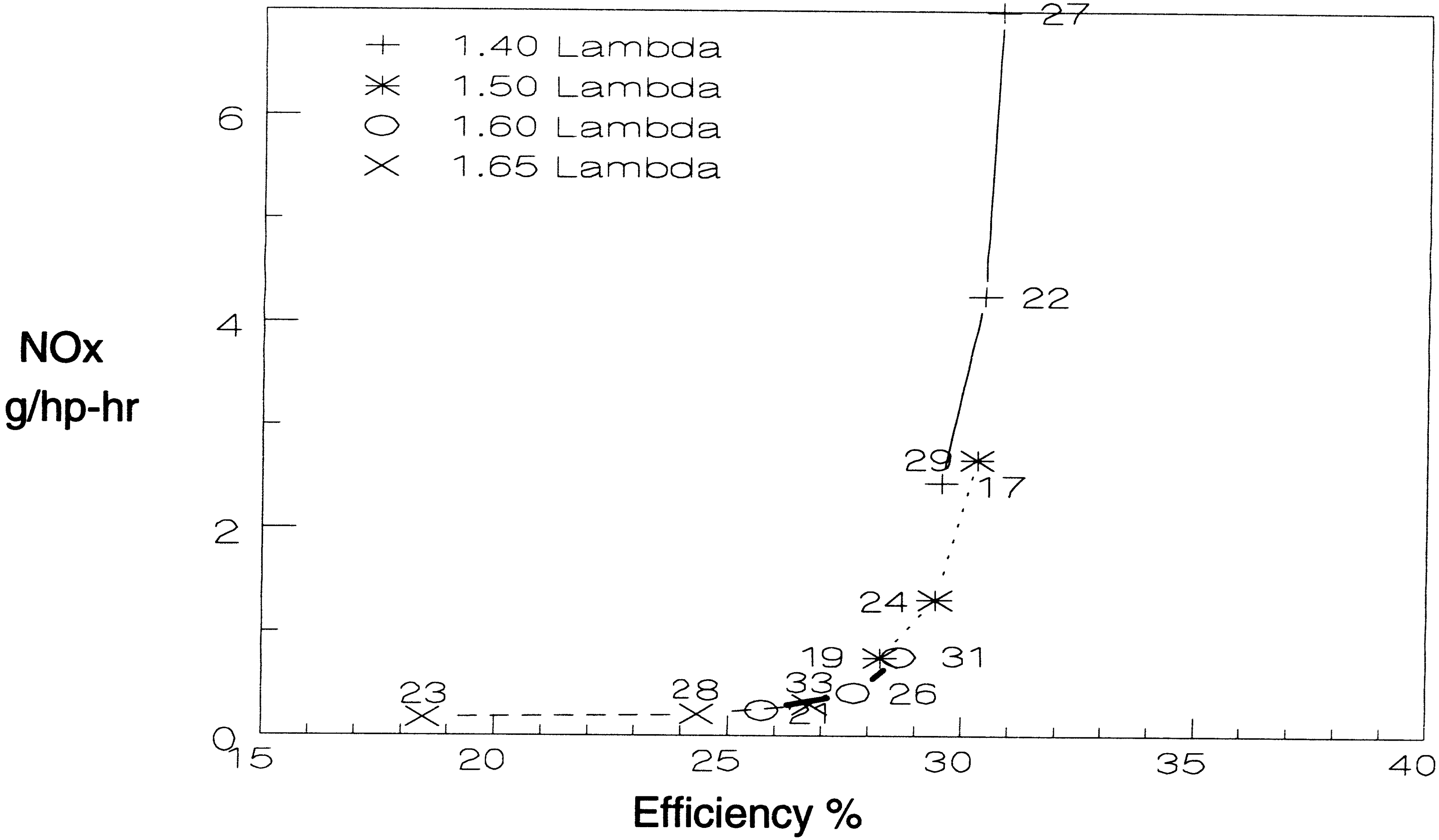


596

ORTECH

NOx vs. Efficiency

Multi-cylinder L10



ORTECH

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.

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

605

Fueling Systems

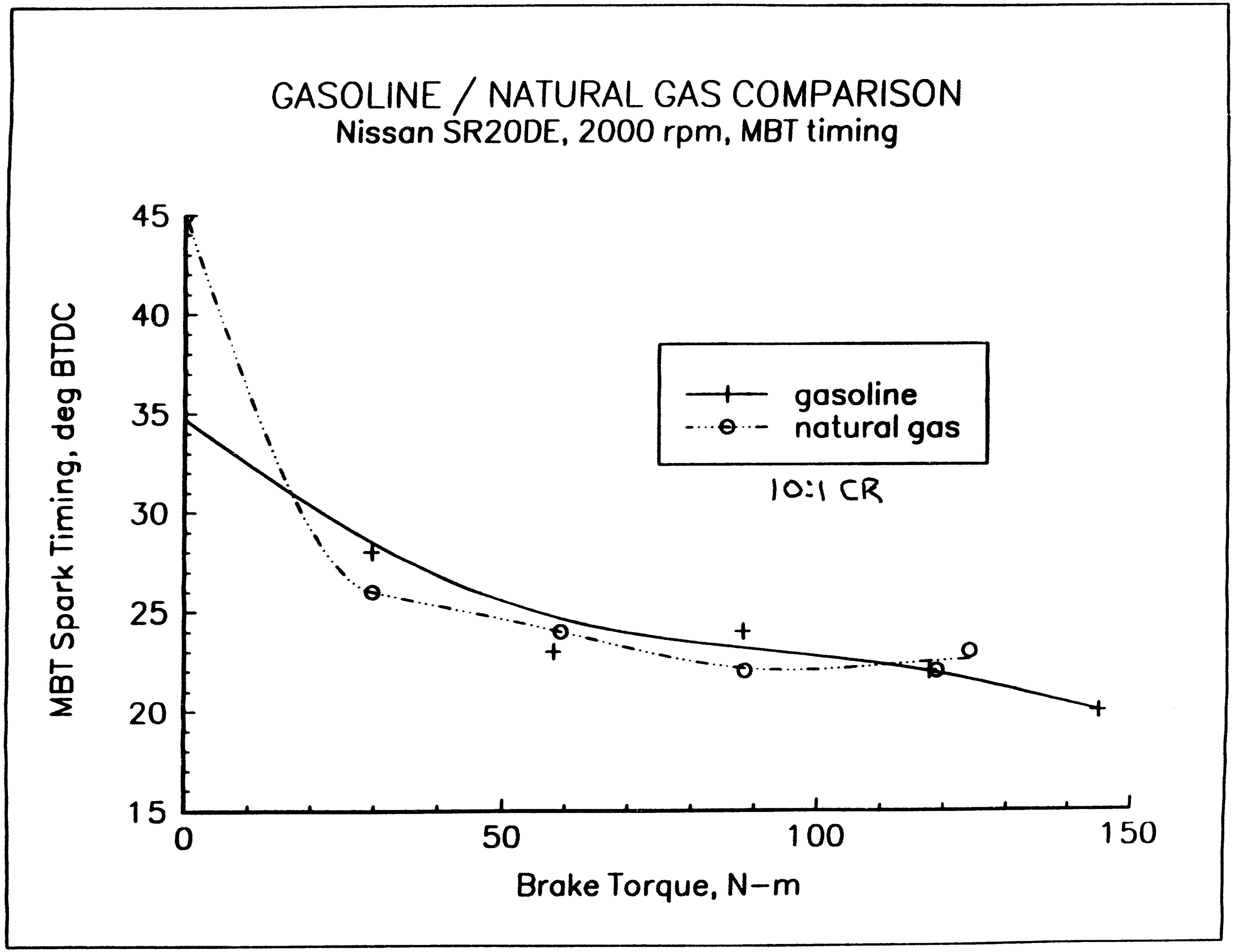
Gasoline:

closed-loop, sequential, port fuel injection.

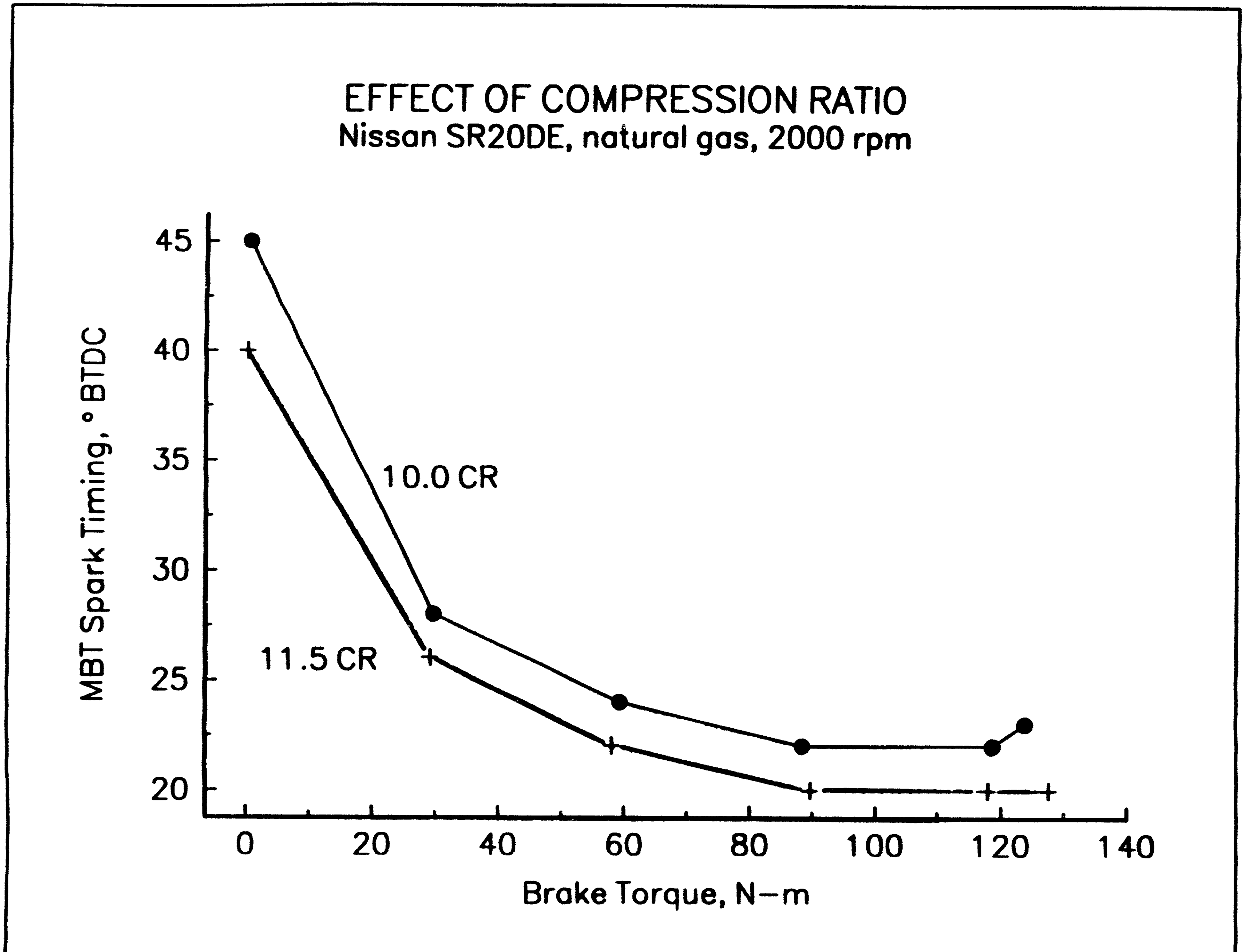
Natural Gas: Aftermarket

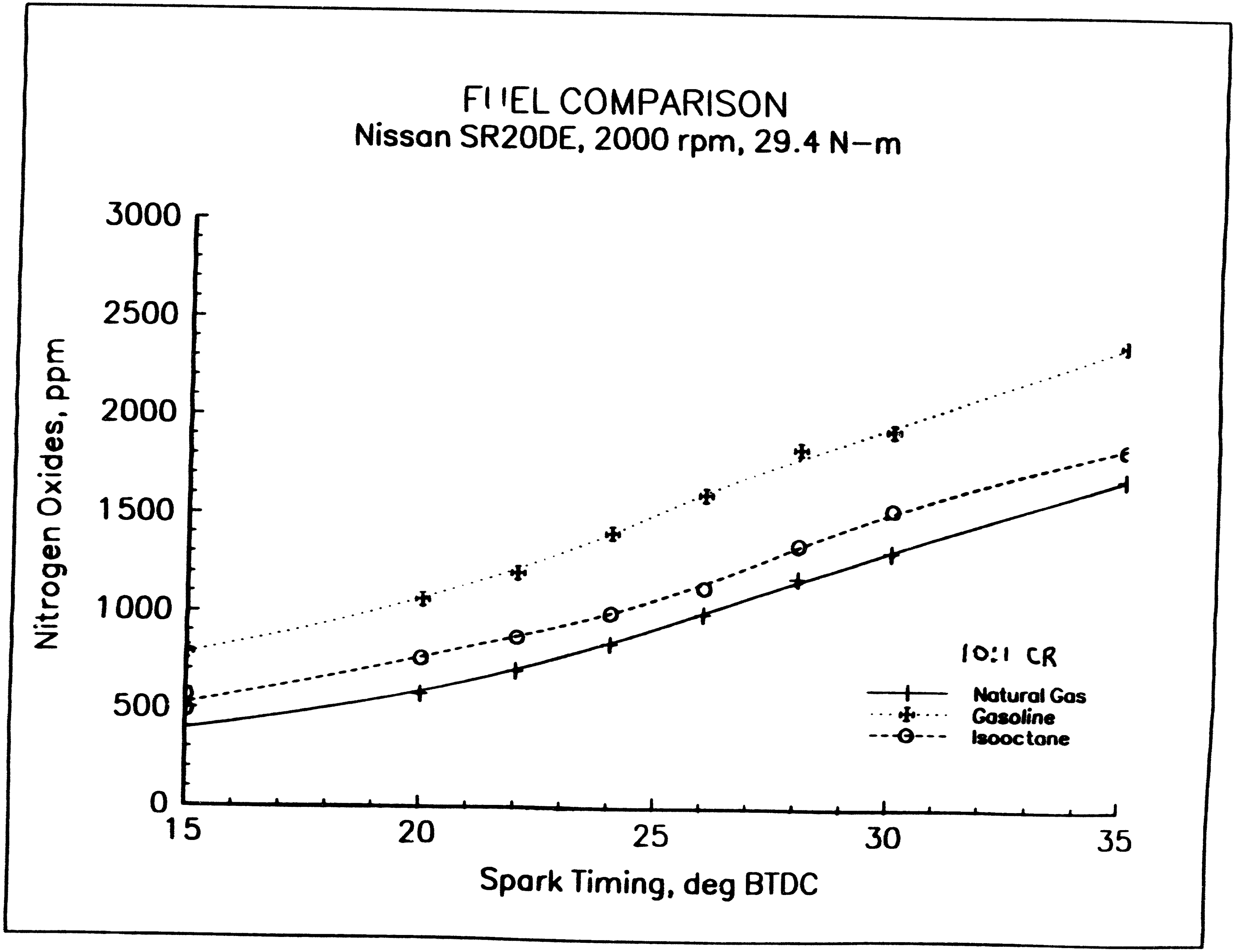
closed-loop carburetion, air valve type mixer.

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
MBT Spark Timing, ° BTDC
45
40
35
30
25
20
10.0 CR
11.5 CR
0
20
40
60
80
100
120
140
Brake Torque, N–m



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

610

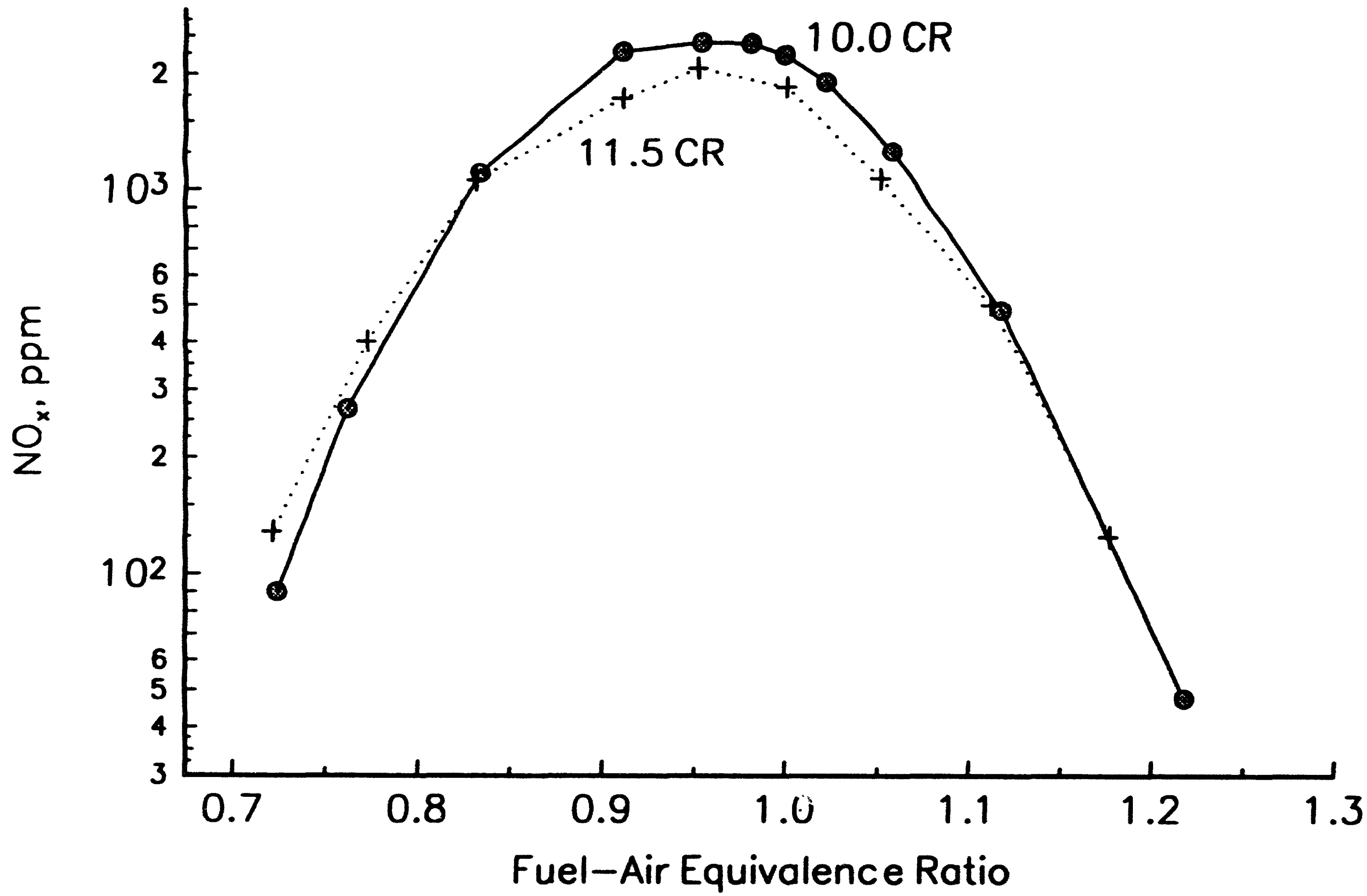
For similar spark timing, the lower flame temperature of natural gas produces less NO_x.

Adiabatic Flame Temperatures in Air:

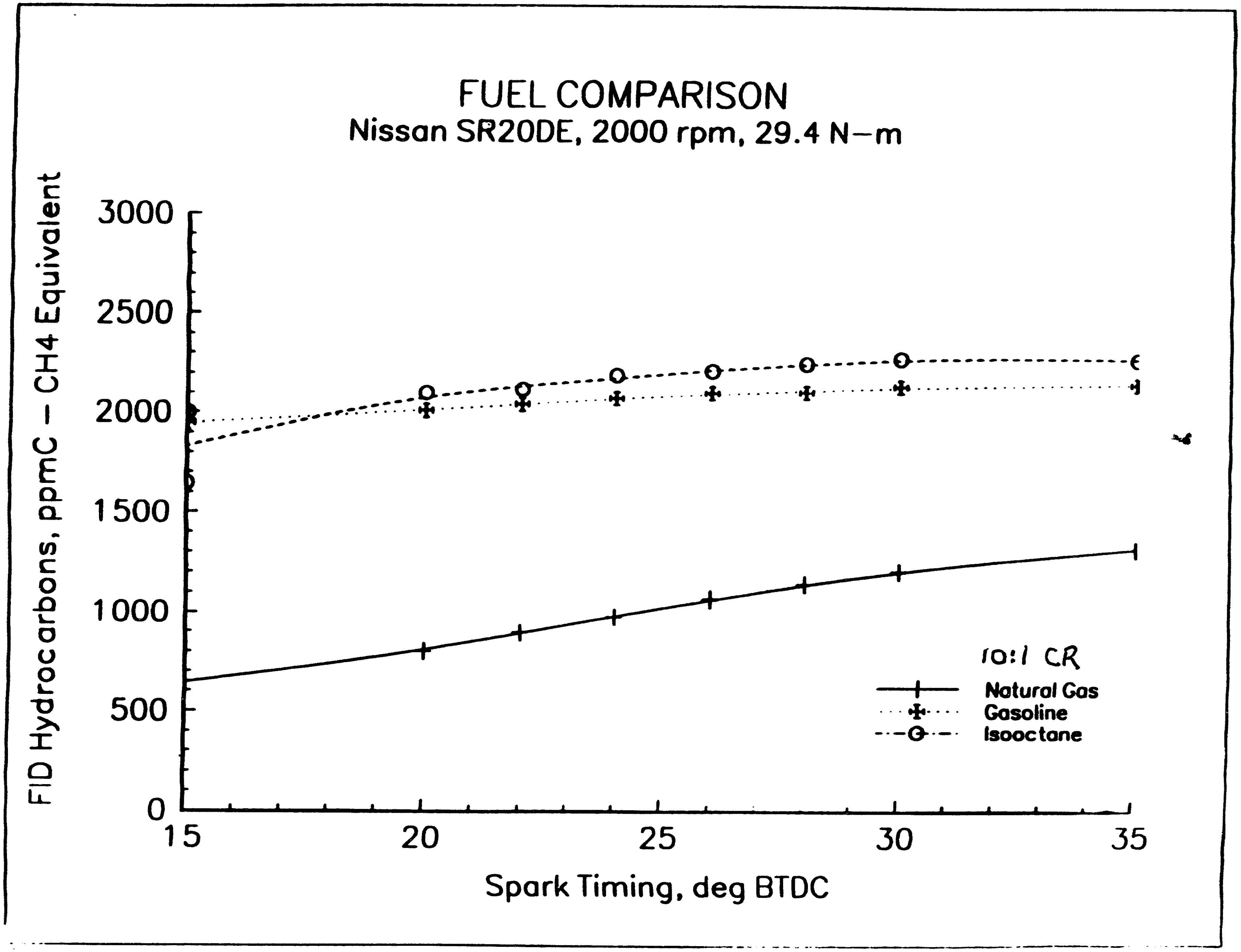
Methane	2236 K
Isoocatne	2302 K
Benzene	2365 K

Effect of Compression Ratio

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



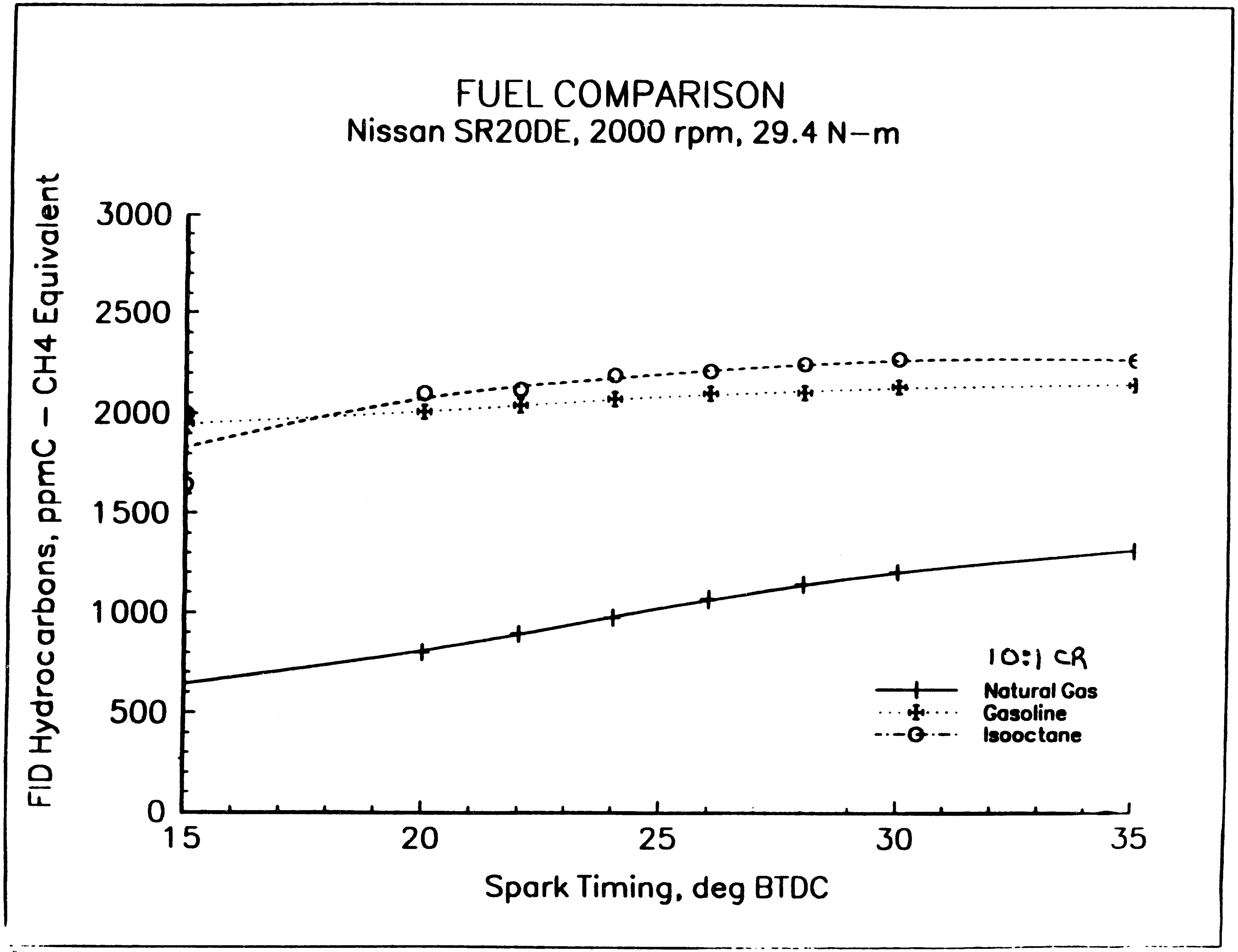
Spark advance held constant at stoichiometric MBT


FUEL COMPARISON
Nissan SR20DE, 2000 rpm, 29.4 N-m
FID Hydrocarbons, ppmC - CH4 Equivalent
3000
2500
2000
1500
1000
500
0
15
20
25
30
35
Spark Timing, deg BTDC
10:1 CR
Natural Gas
Gasoline
Isooctane

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
FID Hydrocarbons, ppmC - CH4 Equivalent
3000
2500
2000
1500
1000
500
0
15
20
25
30
35
Spark Timing, deg BTDC
10:1 CR
Natural Gas
Gasoline
Isooctane

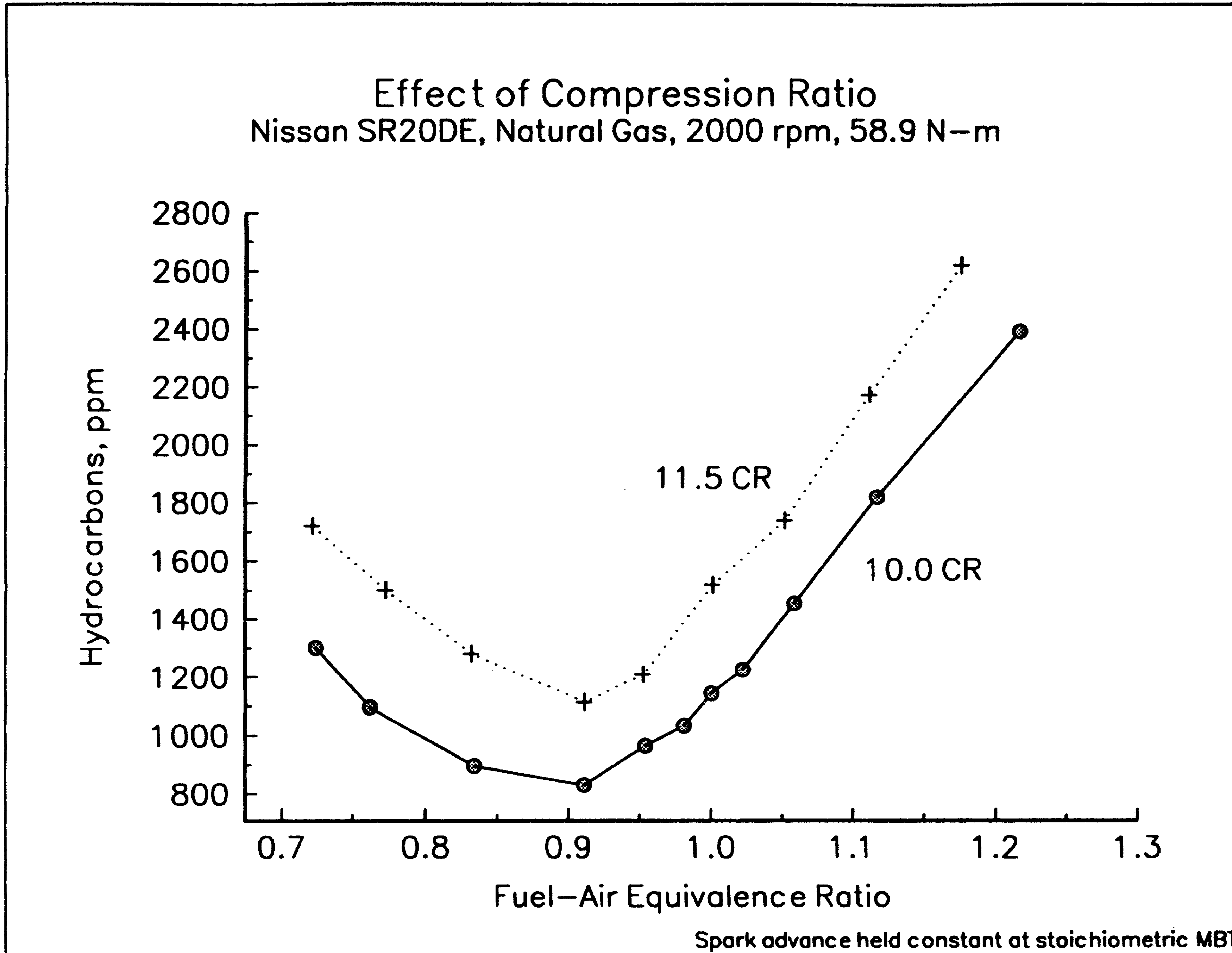
Gasoline Hydrocarbon Sources:

1. Crevices.
2. Oil layer.

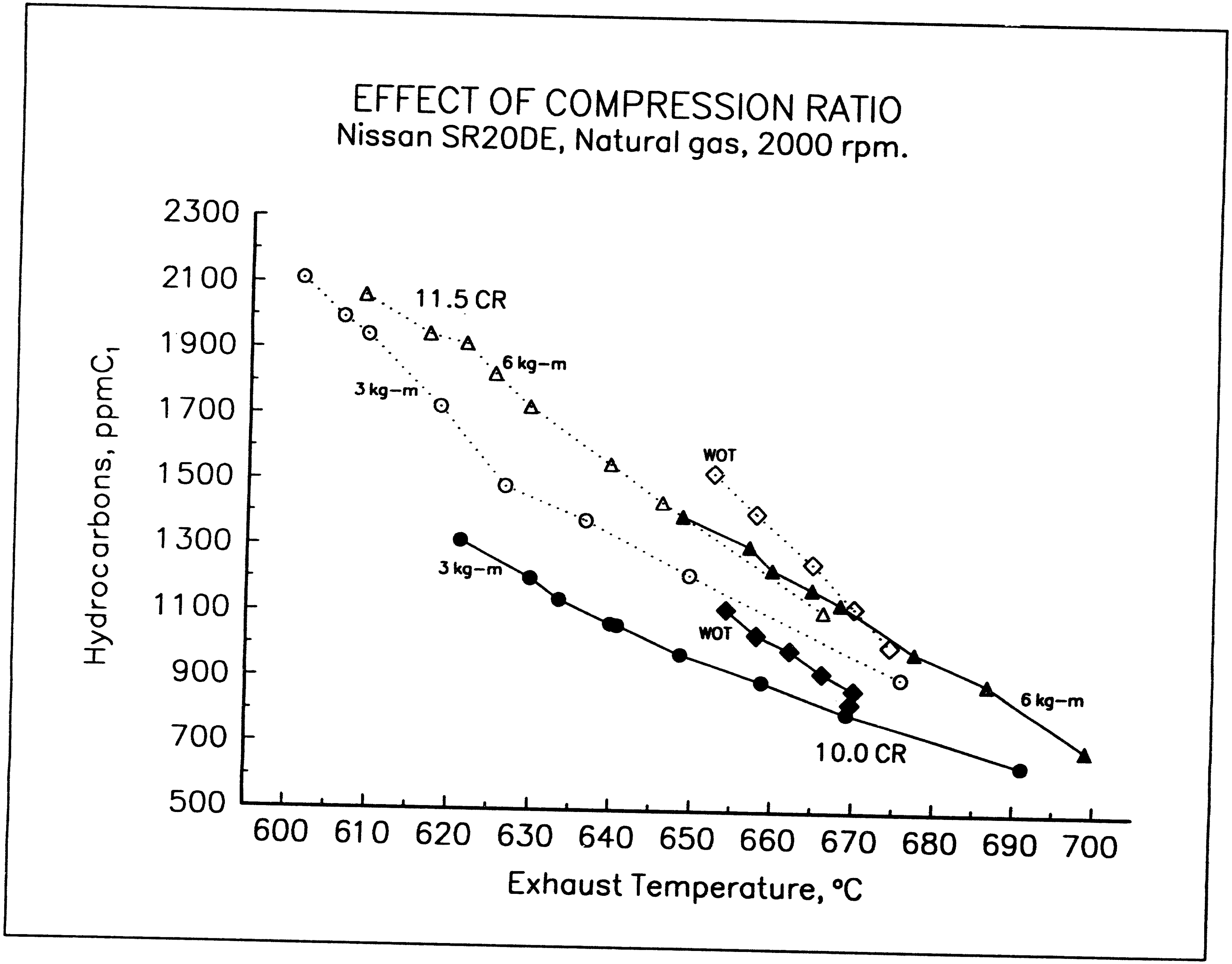
Natural Gas Hydrocarbon Sources:

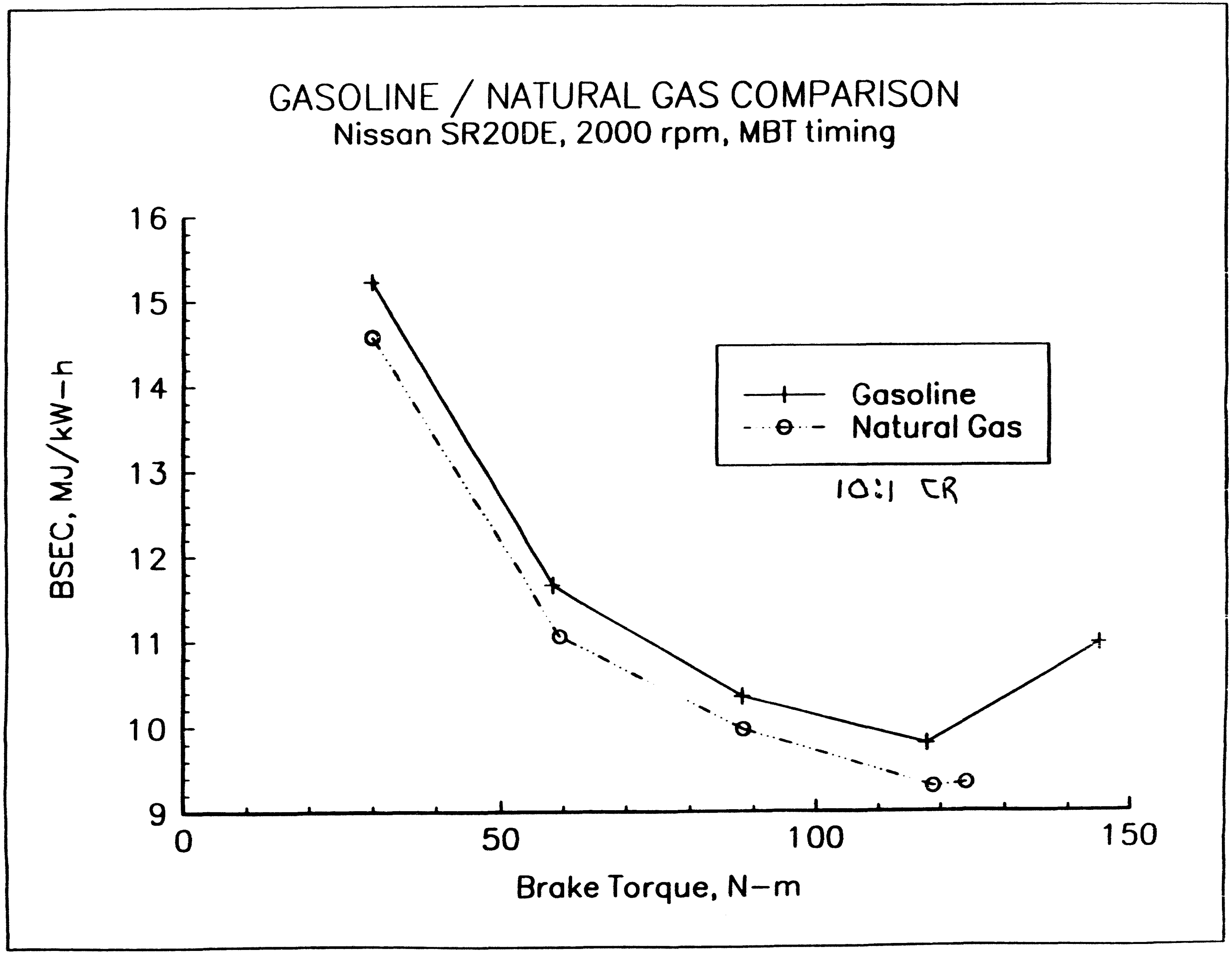
Oil layer mechanism virtually eliminated because of low solubility of methane in oil.

1. Crevices.



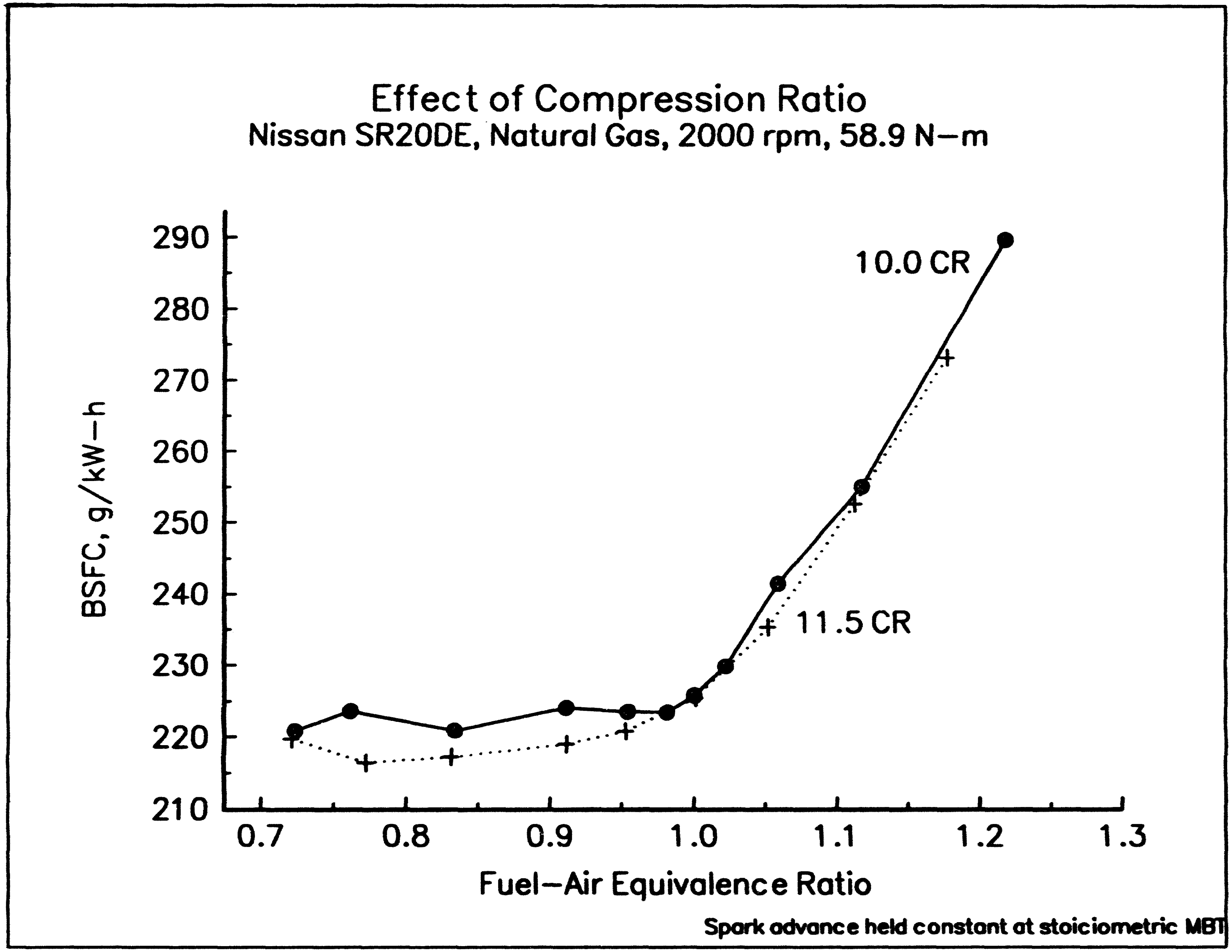
Effect of Compression Ratio
Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N−m
Hydrocarbons, ppm
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
11.5 CR
10.0 CR
0.7
0.8
0.9
1.0
1.1
1.2
1.3
Fuel−Air Equivalence Ratio
Spark advance held constant at stoichiometric MBT


EFFECT OF COMPRESSION RATIO
Nissan SR20DE, Natural gas, 2000 rpm.
Hydrocarbons, ppmC1
Exhaust Temperature, °C
11.5 CR
6 kg-m
3 kg-m
WOT
3 kg-m
WOT
6 kg-m
10.0 CR
2300
2100
1900
1700
1500
1300
1100
900
700
500
600
610
620
630
640
650
660
670
680
690
700

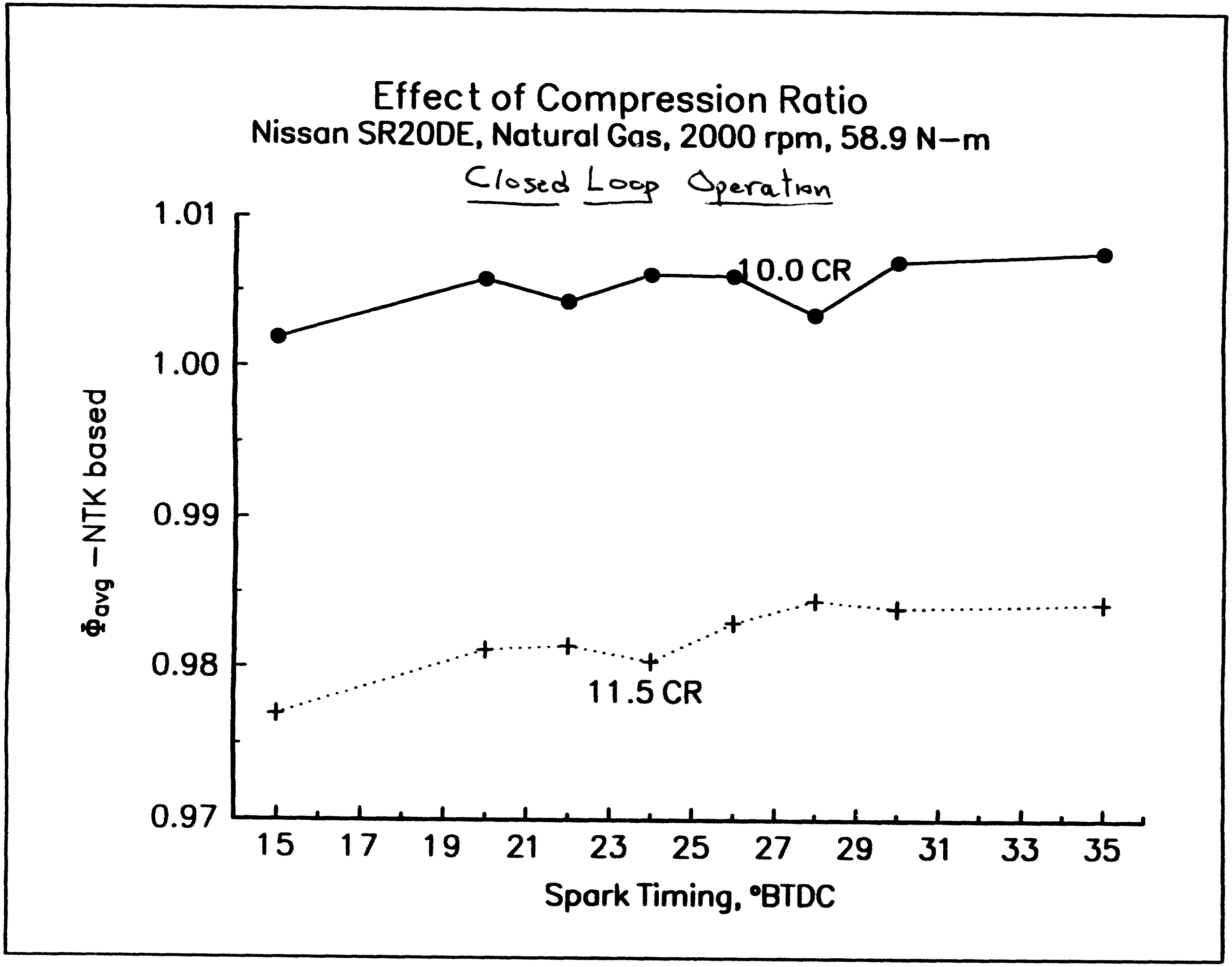

GASOLINE / NATURAL GAS COMPARISON
Nissan SR20DE, 2000 rpm, MBT timing
BSEC, MJ/kW-h
Brake Torque, N-m
Gasoline
Natural Gas
10:1 CR
9
10
11
12
13
14
15
16
0
50
100
150

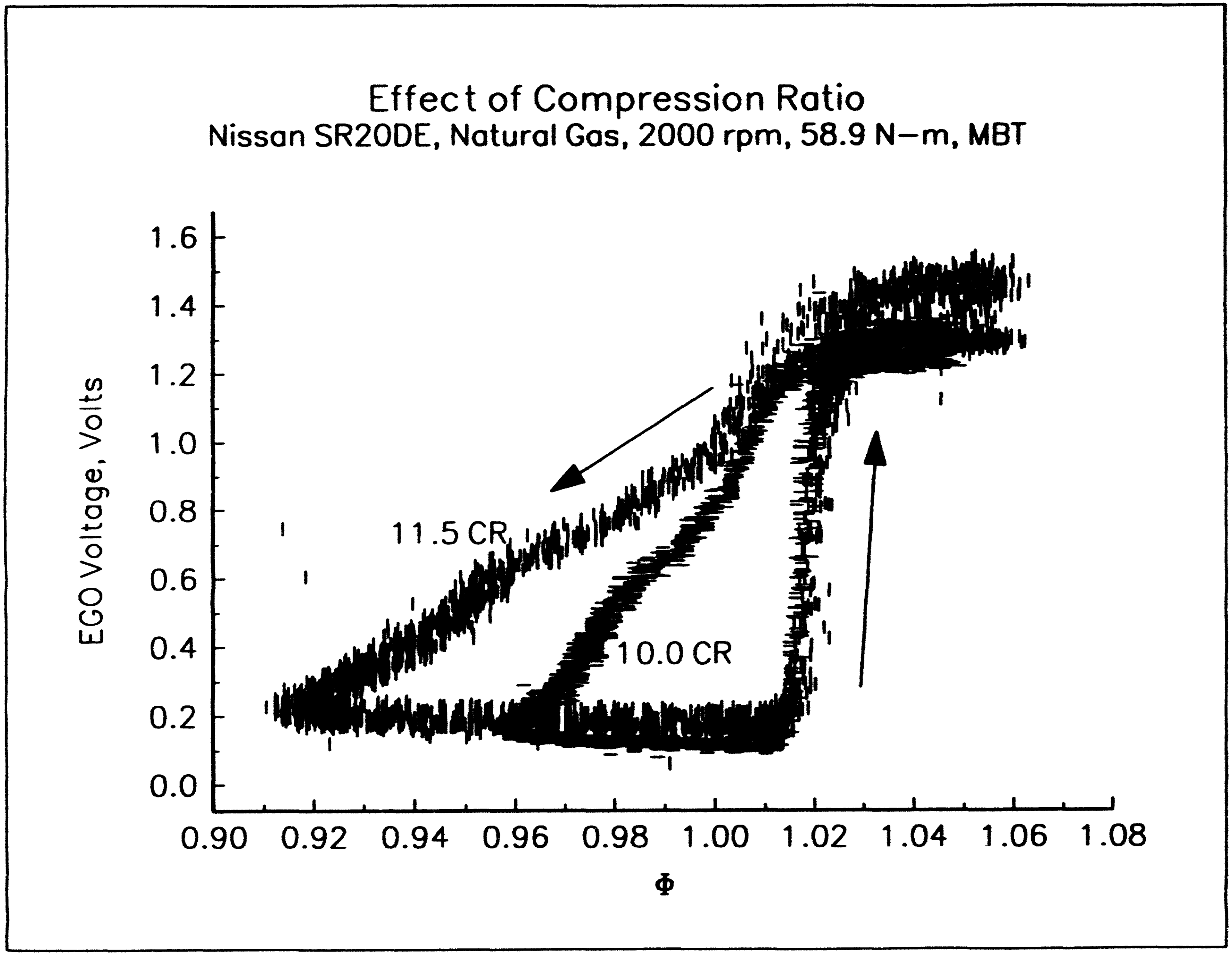
Improved efficiency with natural gas:

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

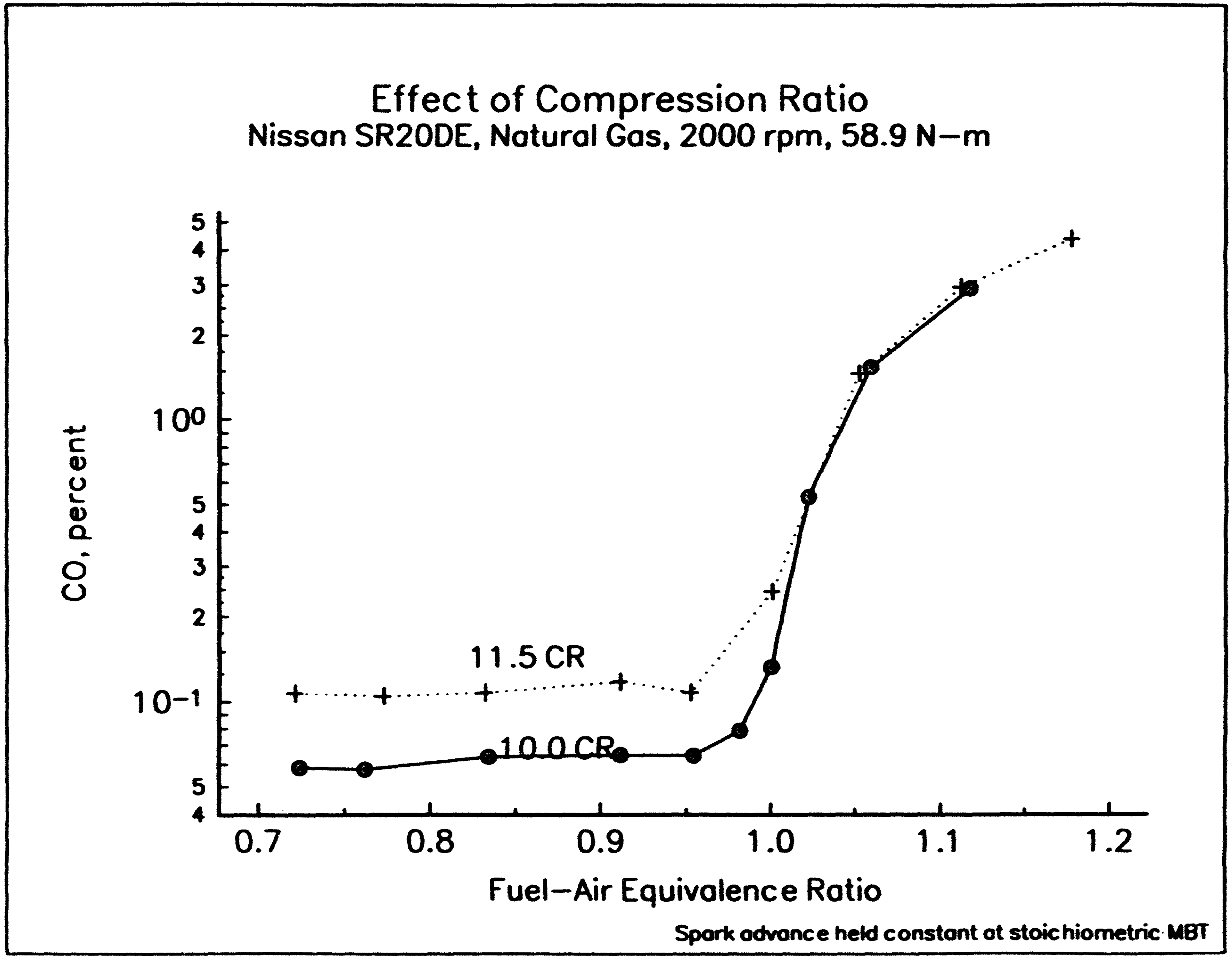


Effect of Compression Ratio
Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N-m
BSFC, g/kW-h
290
280
270
260
250
240
230
220
210
0.7
0.8
0.9
1.0
1.1
1.2
1.3
Fuel-Air Equivalence Ratio
10.0 CR
11.5 CR
Spark advance held constant at stoiciometric MBT


Effect of Compression Ratio
Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N−m
Closed Loop Operation
10.0 CR
11.5 CR
1.01
1.00
0.99
0.98
0.97
Φ_{avg} −NTK based
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
EGO Voltage, Volts
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
11.5 CR
10.0 CR
0.90
0.92
0.94
0.96
0.98
1.00
1.02
1.04
1.06
1.08
Φ



Effect of Compression Ratio
Nissan SR20DE, Natural Gas, 2000 rpm, 58.9 N-m
CO, percent
5
4
3
2
10⁰
5
4
3
2
10⁻¹
5
4
11.5 CR
10.0 CR
0.7
0.8
0.9
1.0
1.1
1.2
Fuel-Air Equivalence Ratio
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:

Nissan Canada Inc.

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. Jaasekiainen 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

630

Toros/93-41-867/Wksp

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.

Ontario TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Toroa/93-41-007/Wksp

BACKGROUND

- Ontario transit systems are demonstrating:
  - CNG (75 buses in Hamilton, Toronto, and Mississauga)
  - Methanol (6 buses in Windsor)
  - Diesel particulate traps (8 buses in Ottawa)

- The Ministry of Transportation of Ontario is the overall coordinator of the program

Ontario TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Toros/93-41-007/Wksp

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**

Ontario TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

SCOPE OF TEST PROGRAM

- Test buses representative of each new technology and compare them with corresponding baseline diesels under "identical" conditions

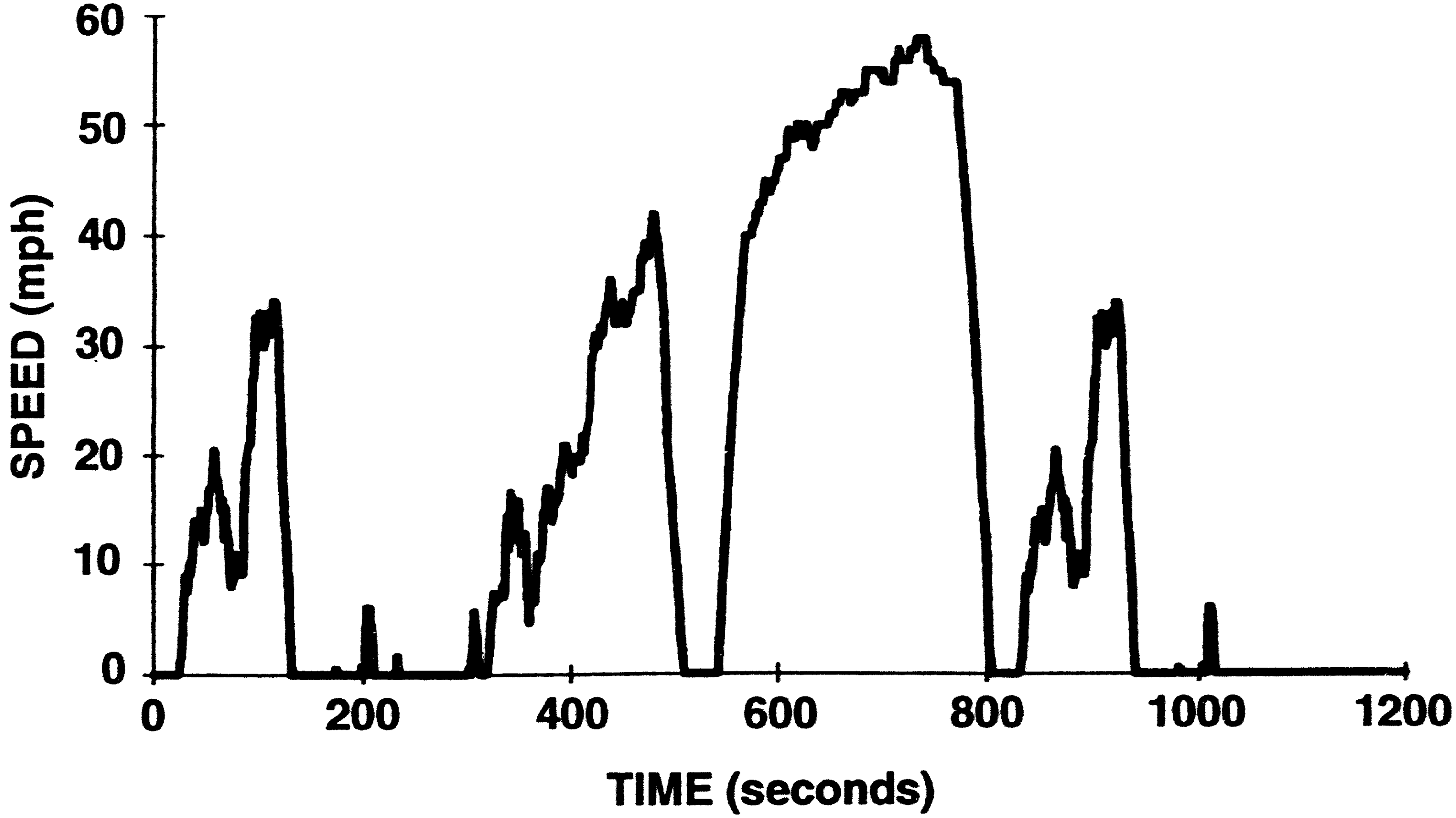
- Repeat testing over a substantial portion of useful bus life to assess long-term performance

- Measure exhaust emissions of:
  - Particulate matter (PM)
  - Oxides of nitrogen (NO_x)
  - Carbon monoxide (CO)
  - Hydrocarbons (HC)
  - Carbon dioxide (CO_2)
  - Formaldehyde (HCOH)
  - Corbonyls (RCOH)

Ontario TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

[illegible]/93-41-[illegible]/Wksp

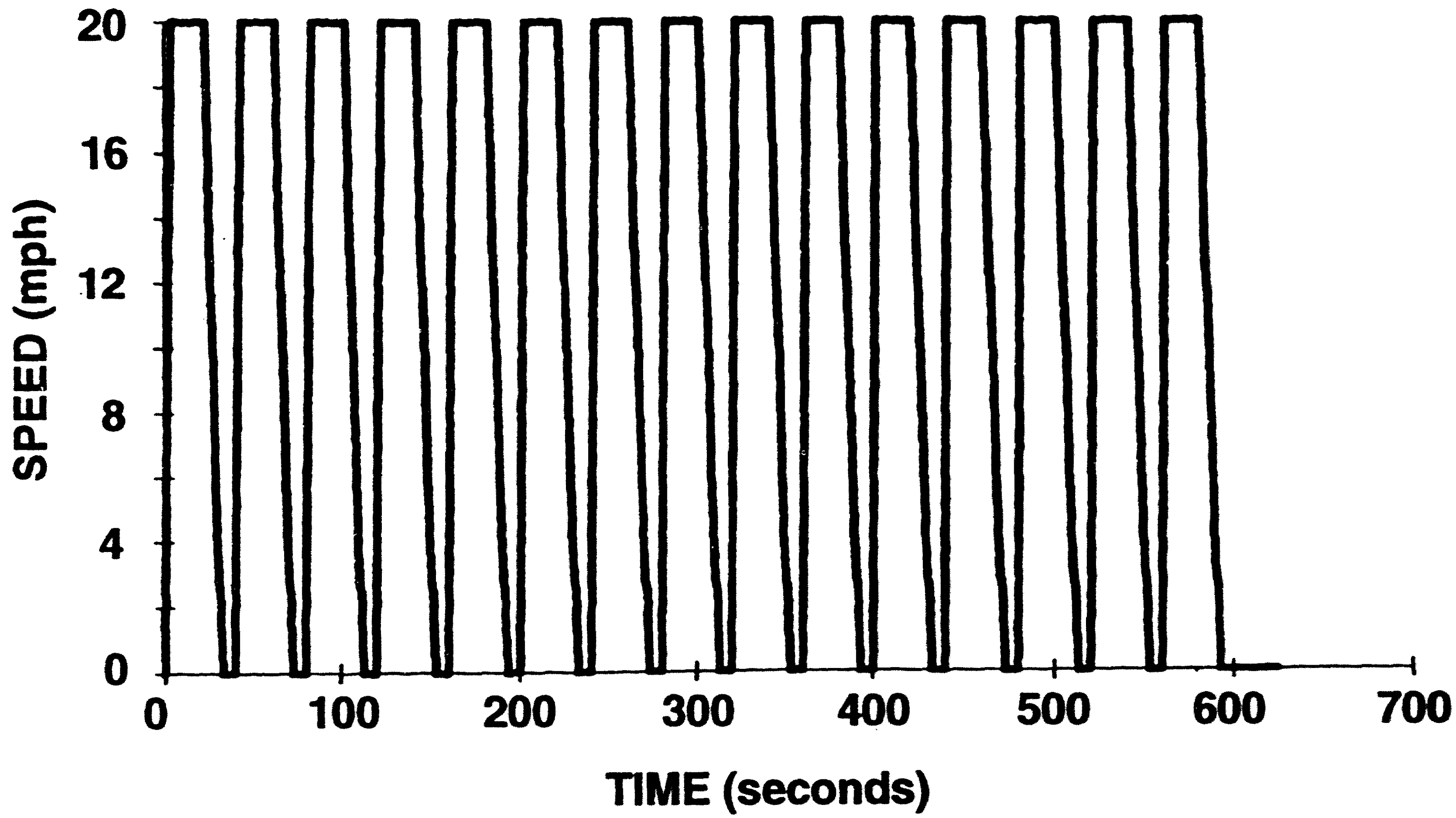
EPA HEAVY-DUTY CHASSIS TRANSIENT CYCLE



Ontario

TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

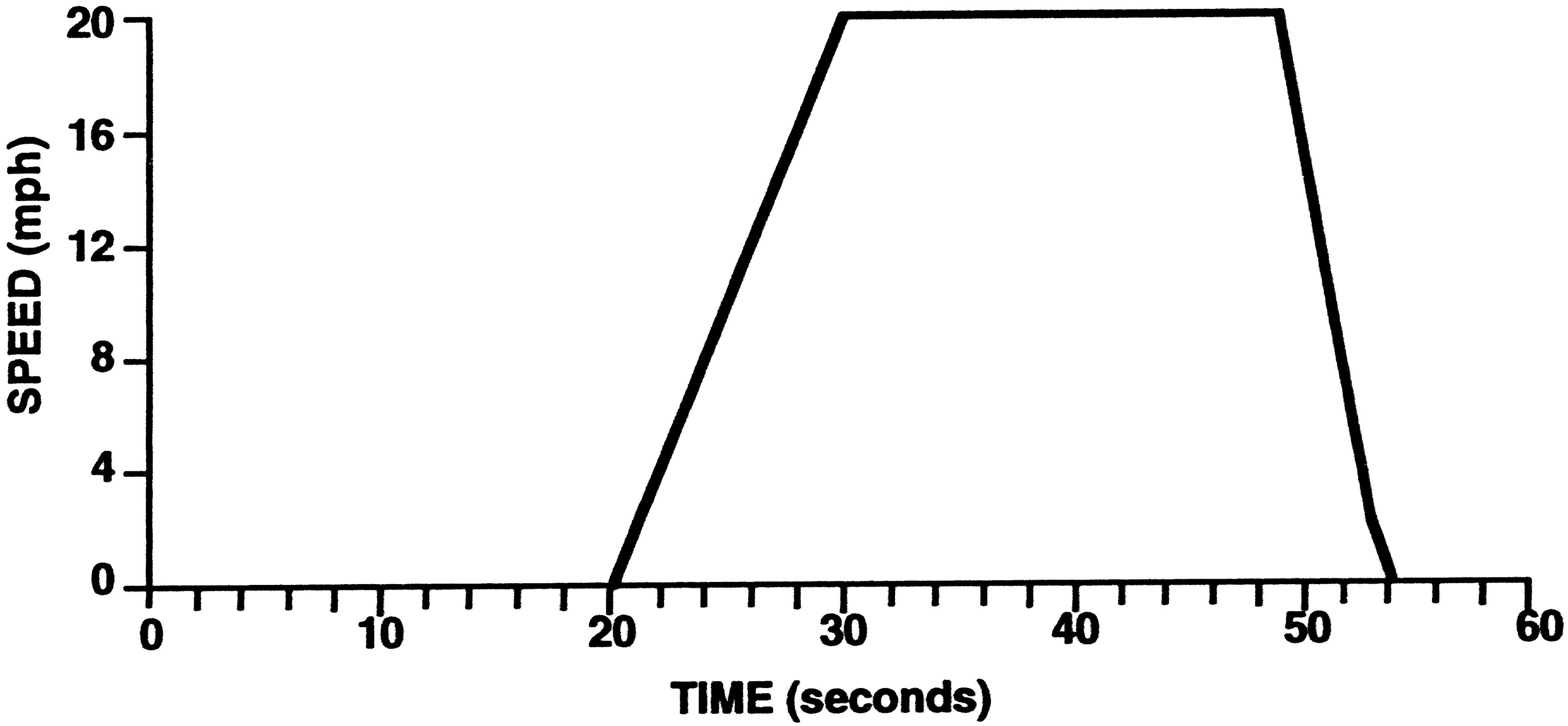
CENTRAL BUSINESS DISTRICT



Ontario

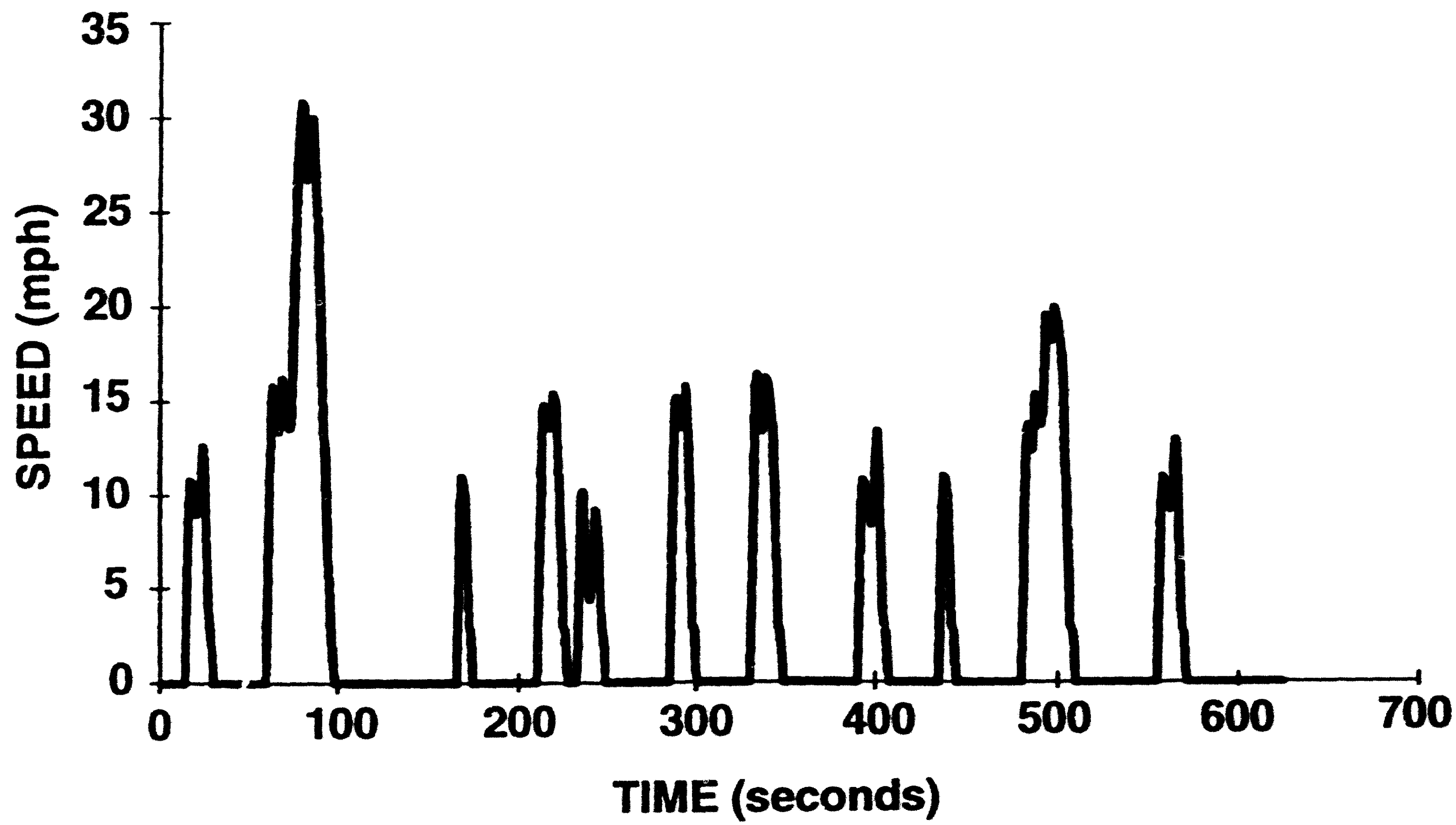
TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

ONE SEGMENT OF THE CENTRAL BUSINESS DISTRICT CYCLE



Ontario **TRANSPORTATION TECHNOLOGY & ENERGY BRANCH**

NEW YORK BUS CYCLE



Ontario

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

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

Toros/93-41-007/Wksp

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

Toros/93-41-007/Wksp

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

645

Toros/93-41-007/Wksp

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

Ontario TRANSPORTATION TECHNOLOGY & ENERGY BRANCH

Toroa/93-41-007/Wksp

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.

---

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

g:wpdocs\transpor\exec-lm 6/6/93

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

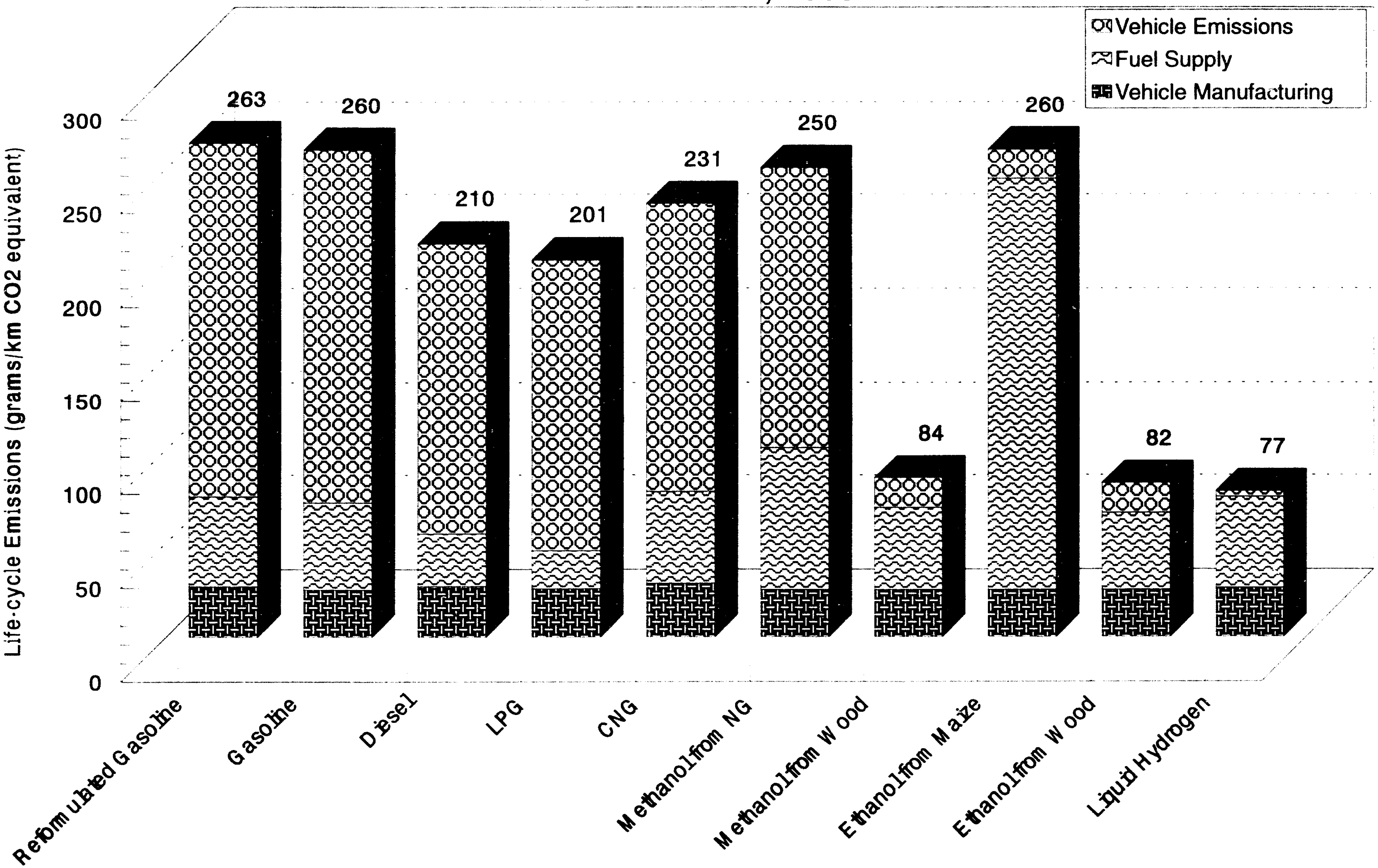


Figure 2.
Greenhouse Gas Emissions from Alternative Fuels
(Reformulated Gasoline=100)

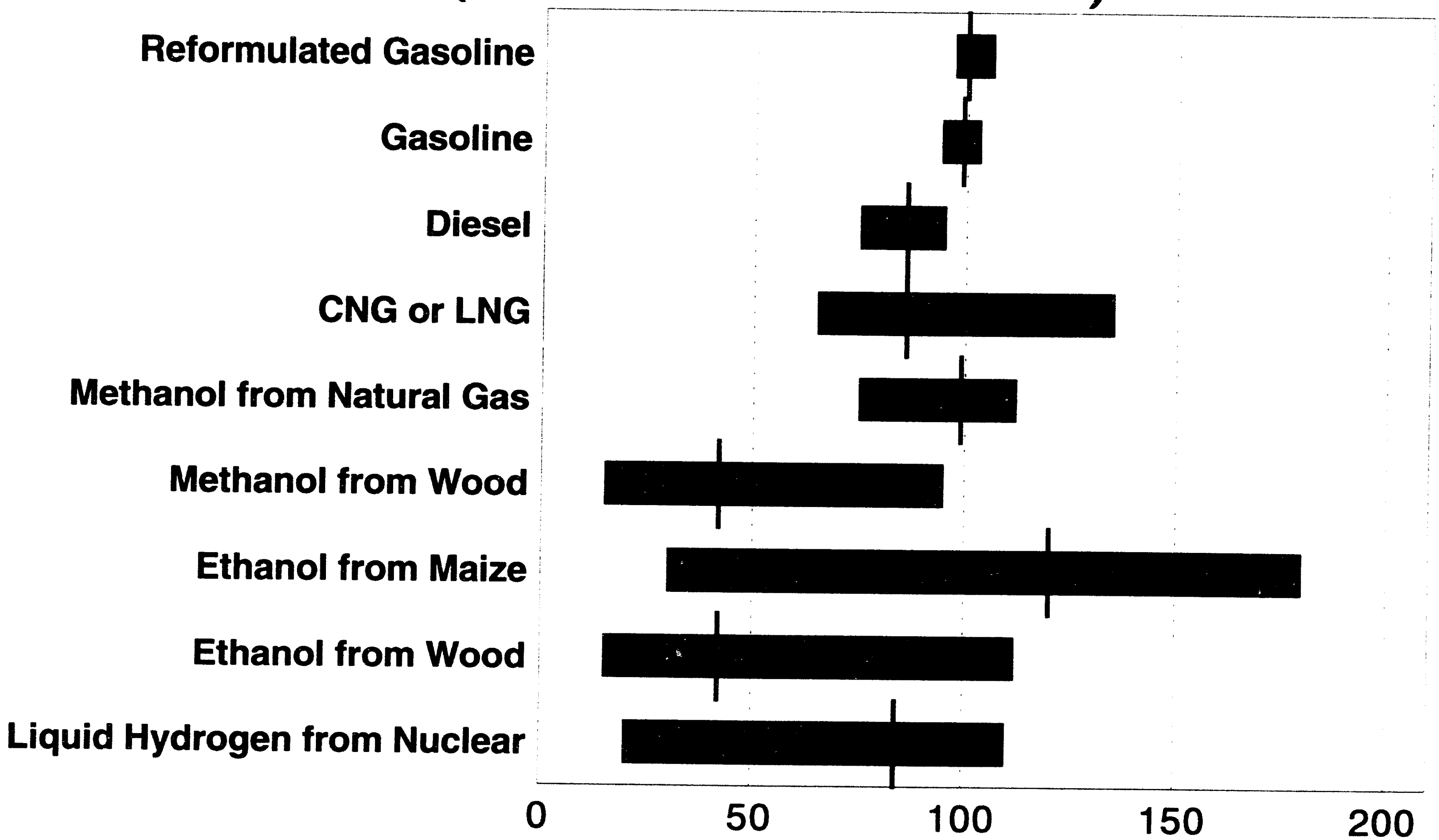
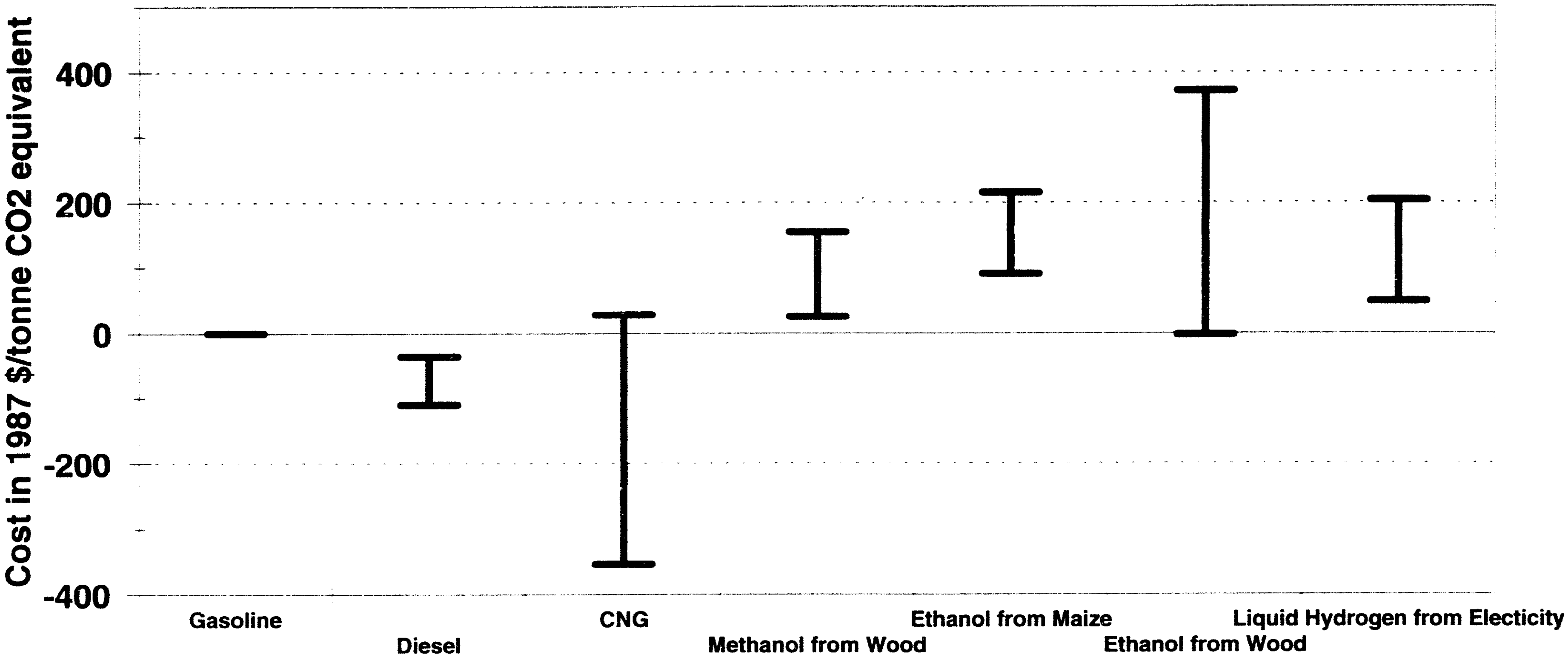


Figure 3
Alternative Fuels Cost-Effectiveness for Greenhouse Gas Abatement

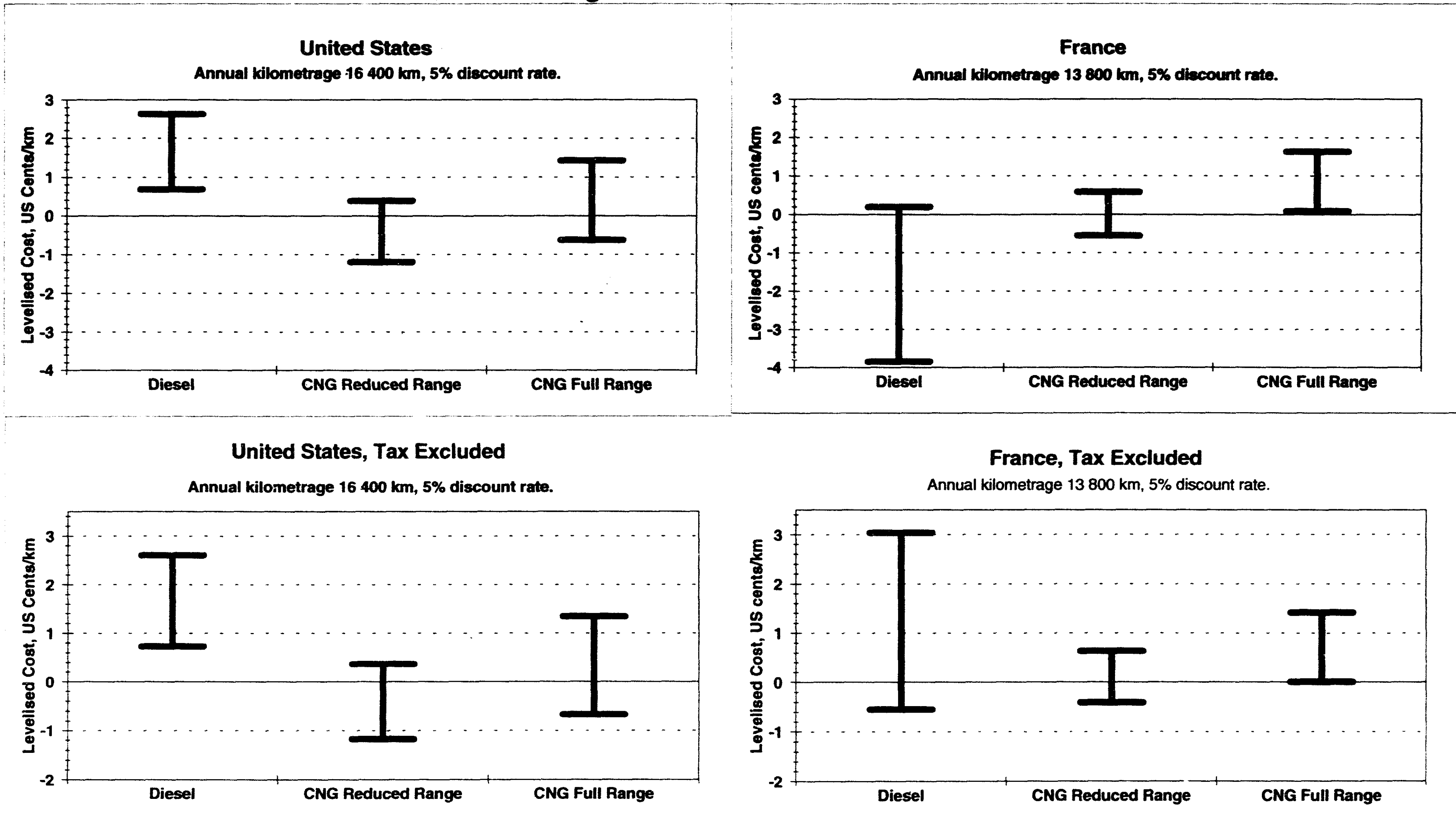
(Fuel cost relative to gasoline in 1987 US \$/metric ton CO2 equivalent not emitted)



Sources: IEA 1990
Department of Energy 1990
CEC 1992

figs7.wb1

Figure 4
Cost of Switching from Gasoline to Diesel or CNG



figs7.wb1 page c

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

Cars and Climate Change

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

Further work needed:

National analyses

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

Interaction with econometric modellers of car market

Conclusions

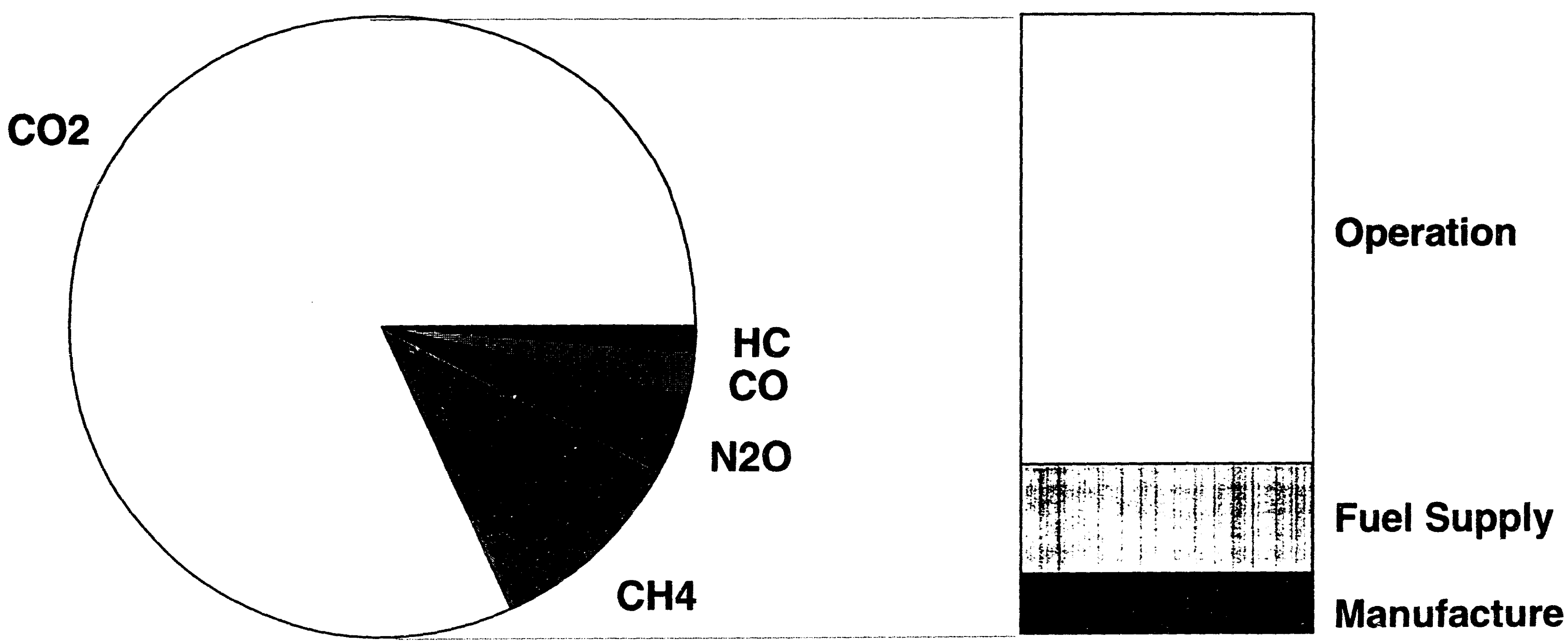
Technical potential is considerable:
could reduce emissions per VKT by 80%

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

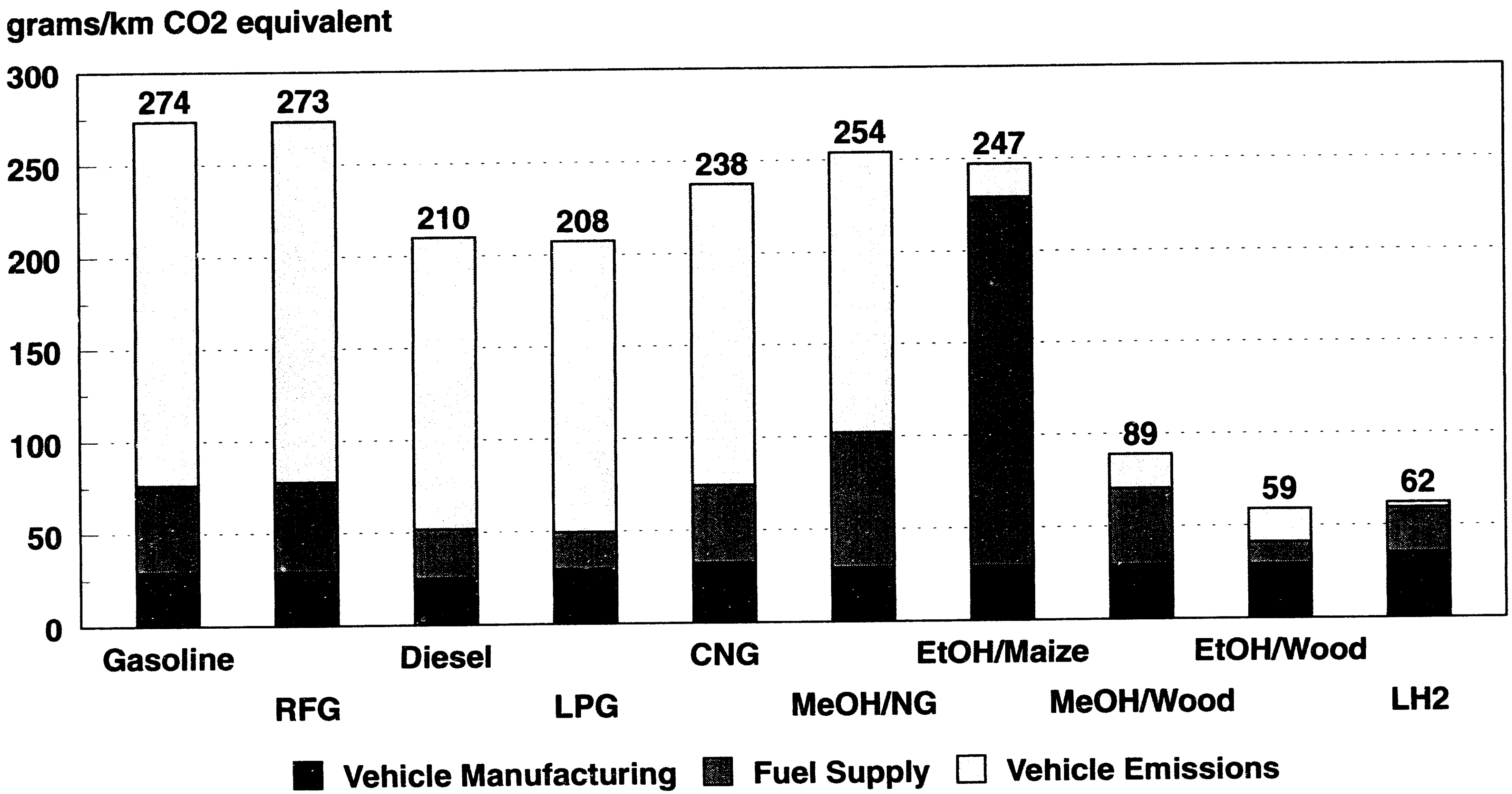
Greenhouse Forcing by Gas, and by Lifecycle Stage



Cars and Climate Change

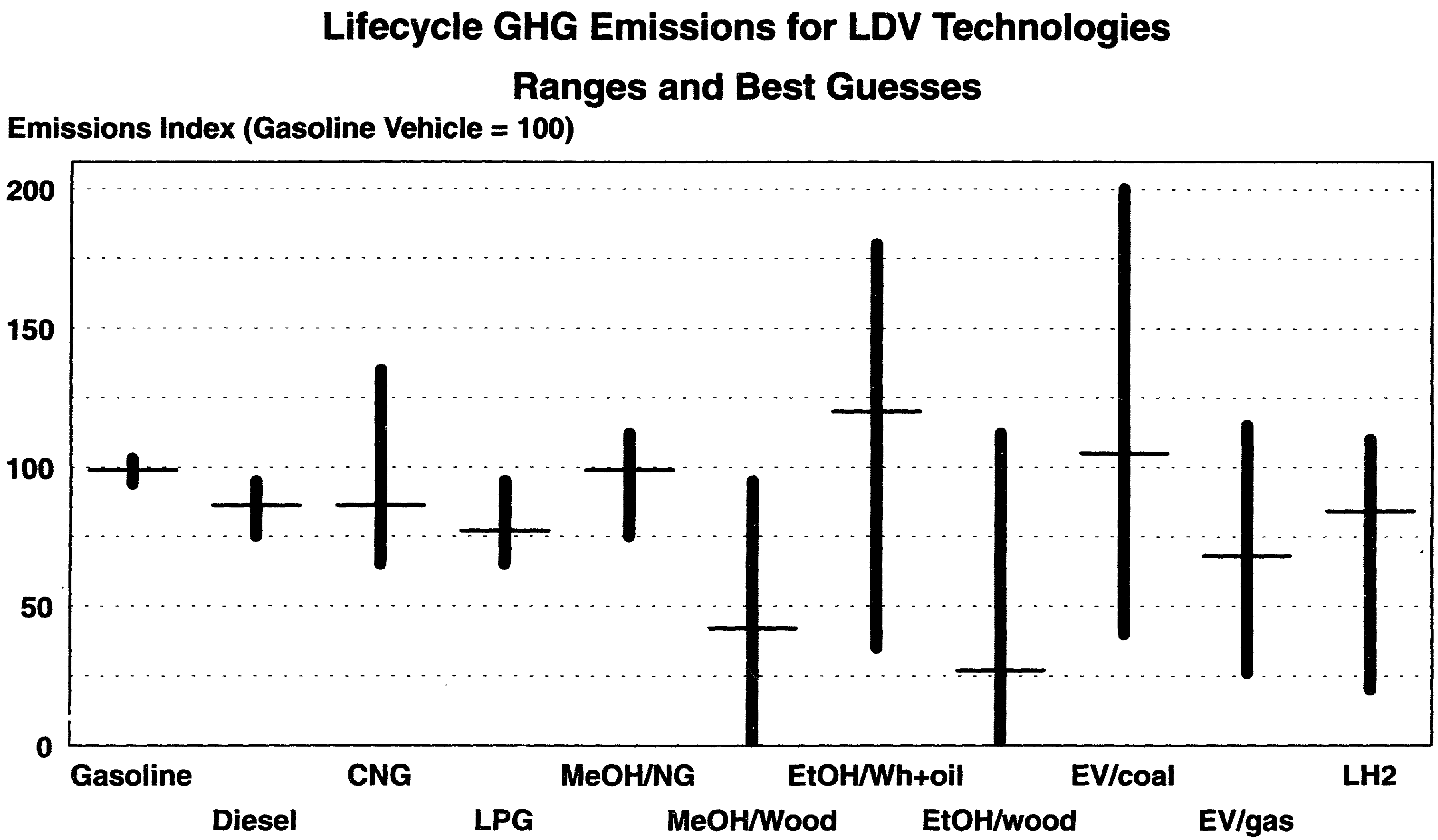
Alternative Fuel Vehicle

Lifecycle Greenhouse Gas Emissions



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

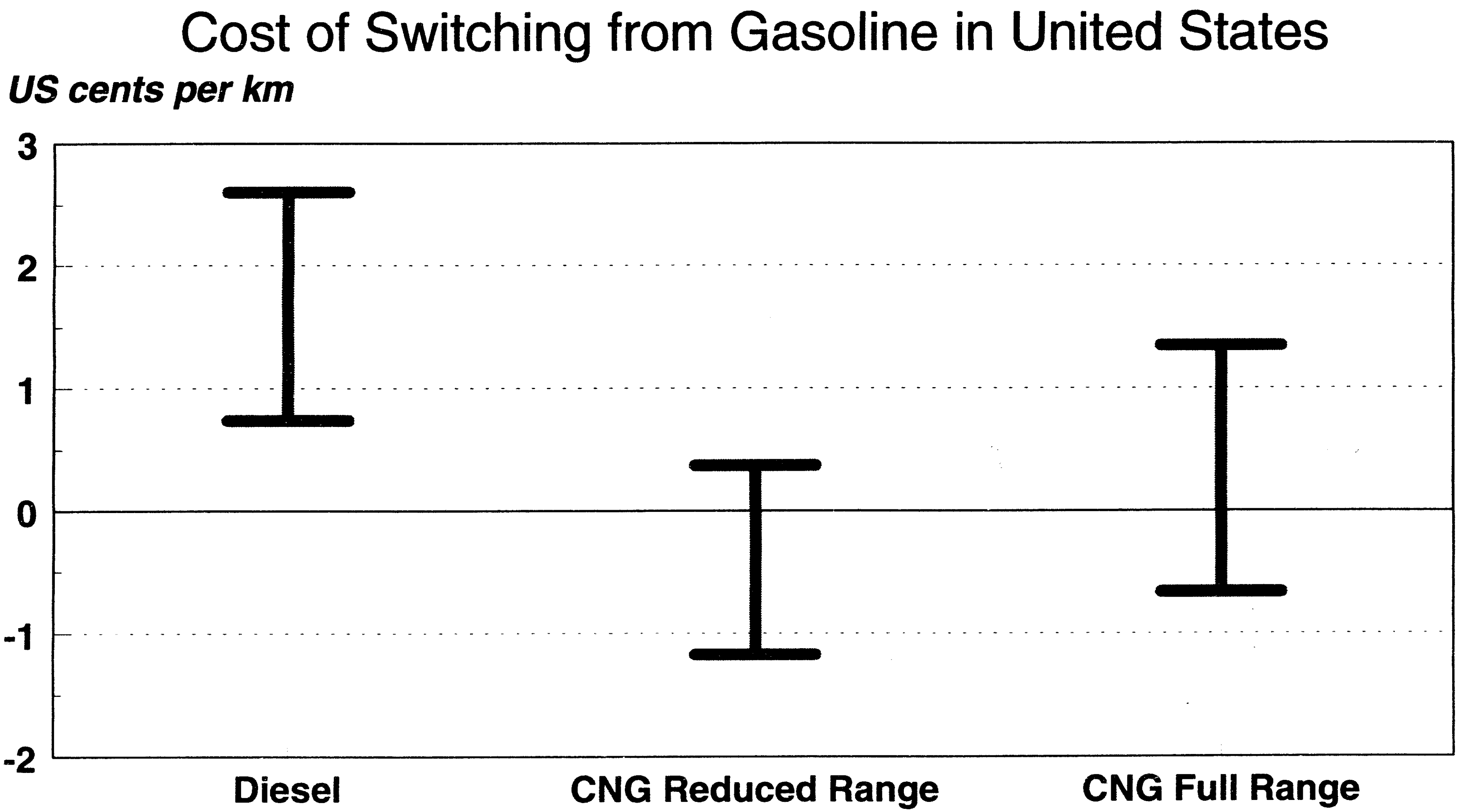
Cars and Climate Change



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

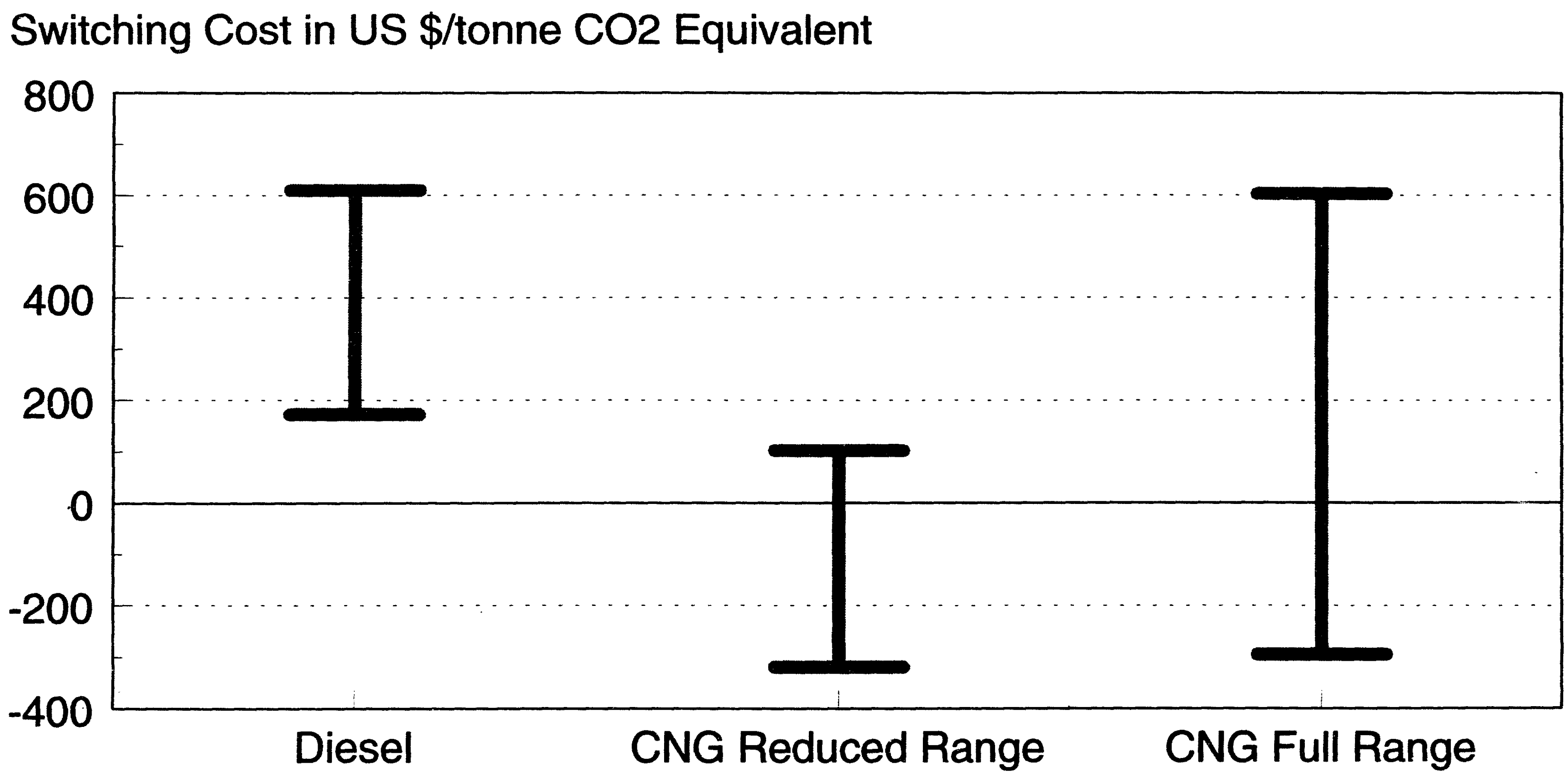
672

Cars and Climate Change



Cars and Climate Change

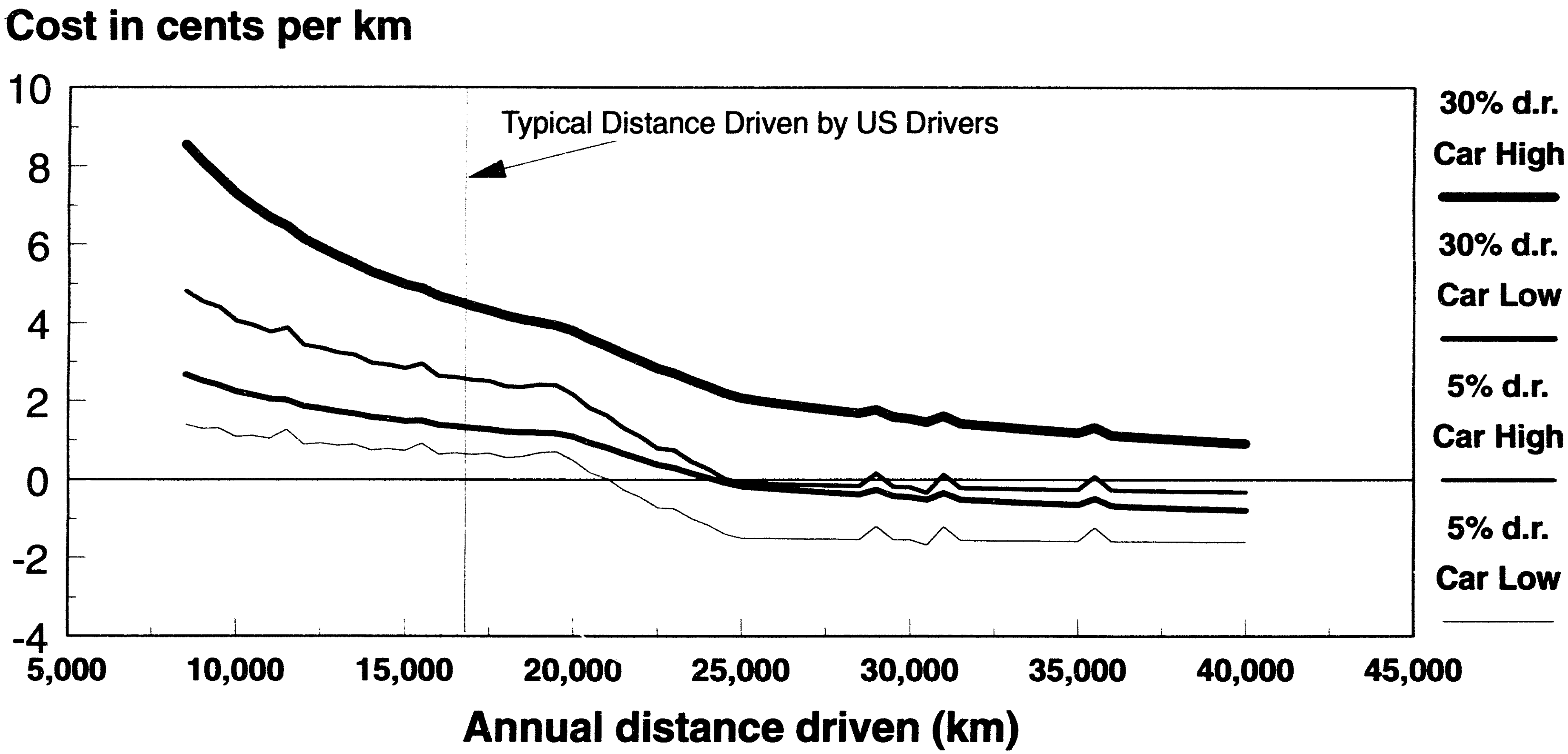
Cost of Reducing Greenhouse Gas Emissions by Switching from Gasoline in the United States



674

Cars and Climate Change

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



675

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.

LIST OF PARTICIPANTS

Participants List - 1993 Windsor Workshop on Alternative Fuels

Luc Allard	**Advanced Engine Technology Ltd.** 17 Fitzgerald Road Suite 102 Nepean, ON K2H 9G1 Canada	613-721-1234
Sandra Allen	**ORTECH International** 2395 Speakman Drive Mississauga, ON L5K 1B3 Canada	416-822-4111 X464
Jerry Allsup	**U.S. Department of Energy** Forrestal Building, CE-33 1000 Independence Avenue S.W. Washington, D.C. 20585 USA	202-586-9120
Oscar Alonso Standards Engineer	**Fuels Safety Branch** **MCCR** 3300 Bloor Street West 4th Floor Etobicoke, ON M8X 2X4 Canada	416-234-6044
Ruben Alvarez Engineering Technol.	**Southwest Research Institute** 6220 Culebra Road San Antonio, TX 78228-0510 USA	210-522-3264
Robert Alvey	**Brooklyn Union Gas Co.** 1 Metrotech Center Brooklyn, NY 11201 USA	718-403-3011
Gregory Andersen Methanol Fuels Manager	**Novacor Chemicals** P.O. Box 2535 Station M Calgary, AB T2P 2N6 Canada	403-290-8995
Vance Anderson Director of NGV Programs	**Consumers Power Company** 212 W. Michigan Avenue, H-160 Jackson, MI 49201 USA	517-788-2251
S.P. Andrews Deputy Commissioner of Public Works	**City of North York** **Public Works** 5100 Yonge Street 4th Floor North York, ON M2N 5V7 Canada	416-395-6222
Steven C. Anthony Product Manager	**SCI** 325 Enterprise Place Pomona, CA 91768-3268 USA	909-594-7777

Participants List - 1993 Windsor Workshop on Alternative Fuels

David Archbold V.P., Marketing and Sales	**FuelMaker Corporation** 70 Worcester Road Rexdale, ON M9W 5X2 Canada	416-674-3034
Jeffrey S. Armfield Engineer	**Cummins Engine Company, Inc.** Mail Code 50196 Box 3005 Columbus , IN 47202-3005 USA	812-377-4839
Lloyd Austin Director - Alternate Fuels Group	**Stewart & Stevenson Power, Inc.** 5840 Dahlia Street P.O. Box 220 Commerce City, CO 80037 USA	303-287-7441
Brent Bailey Project Engineer	**National Renewable Energy Laboratories** 1617 Cole Boulevard Bldg. 15/1 Golden, CO 80401-3393 USA	303-231-1288
Michel P. Bailiot Sr. Engineer-Emissions Engineering	**Transport Canada Surface** Canada Bldg.-344 Slater Street Ottawa, ON K1A 0N5 Canada	613-998-2669
Eric Balles	**Arthur D. Little, Inc.** 20 Acorn Park Cambridge, MA 02140 USA	617-864-5897
Rodica Baranescu	**Navistar Int'l. Transportation Corp.** 10400 W. North Avenue Melrose Park, IL 60160 USA	708-865-3717
Ewa A. Bardasz Research Scientist	**The Lubrizol Corporation** 29400 Lakeland Blvd. Wickliffe, OH 44092-2298 USA	216-943-4200
Richard L. Bechtold Sr. Project Manager	**EA Engineering, Science and Technology, Inc.** 8401 Colesville Road Suite 500 Silver Spring, MD 20910 USA	301-565-4216
Nick Beck Research Advisor	**Energy, Mines & Resources Canada** **AED - CANMET** 580 Booth Street Ottawa, Ontario K1A OE4 Canada	613-996-6022
Lois E. Bennett Automotive Emission Control	**General Motors** 3044 West Grand Blvd. Rm 12-251 Detroit, MI 48202 USA	313-556-7737

Participants List - 1993 Windsor Workshop on Alternative Fuels

Andy Beregszaszy Research Advisor	**Energy, Mines & Resources Canada** **AED - CANMET** 580 Booth Street Room 714 Ottawa, ON K1A OE4 Canada	613-996-8557
Bruce Bevington Manager, Fuels Technology	**Sunoco Inc.** 36 York Mills Road North York, ON M2P 2C5 Canada	416-733-7059
Linda Bluestein Project Manager	**National Alternative Fuels Hotline** 499 S. Capital St. SW #410 Washington, DC 20003 USA	202-554-5047
Anthony Bobelis Chief Scientist, R&D	**Brooklyn Union Gas Co.** 1 Metrotech Center 18th floor Brooklyn, NY 11201-3850 USA	718-403-3071
Matthew A. Bol Principal	**Sypher:Mueller International** 220 Laurier Avenue W. Suite 500 Ottawa, ON K1P 5Z9 Canada	613-236-4318
Kim Boyer	**Hercules Engines Inc.** 101 Eleventh Street S.E. Canton, OH 44707 USA	216-438-1361
Ron Bright Director - Environmental Affairs	**Ford Motor Company of Canada** The Canadian Road Oakville, Ontario L6J 5E4 Canada	416-845-2511 X1209
Norman Brinkman Sr. Staff Research Engineer	**General Motors Corporation** Research & Development Center P.O. Box 9055 Warren, MI 48084 USA	313-986-1914
Thomas G. Brosey Engineering Director, NG Engines	**Cummins Engine Co. Inc.** P.O. Box 3005 Mail Code 50185 Columbus, IN 47202-3005 USA	812-377-7446
Kevin Brown Catalyst Chemist	**Engine Control Systems Ltd.** 165 Pony Drive Newmarket, ON L3Y 7V1 Canada	416-853-5500
Christopher Brown Sales Engineer	**SCI** 325 Enterprise Place Pomona, CA 91768-3268 USA	909-594-7777

Participants List - 1993 Windsor Workshop on Alternative Fuels

Don Brunson Environmental Program Mgr.	**Xerox Corporation** 1851 East First Street Suite 1600 Santa Ana, CA 92705 USA	714-565-1705
Stanley Bull Director for Transportation Programs	**National Renewable Energy Laboratories** 1617 Cole Boulevard Golden, CO 80401-3393 USA	303-231-1200
Chris Burgeson Mech. Maintenance Administrator	**City of Glendale** Public Works 541 W. Chevy Chase Dr. Glendale, CA 91204-1813 USA	818-548-3952
Andrew E. Burke Principal Program Specalist	**EG&G Idaho Inc.** P.O. Box 1625 Idaho Falls, ID 83415-3525 USA	208-526-1490
Herbert Burnett Operations Mgr. NG Facilities Group	**Southern California Gas Company** 555 Fifth Street Los Angeles, CA 90013-1011 USA	213-244-5658
Carole Burrell	**Environment Canada** Industrial Programs Branch 351 St. Jospeh Blvd. Hull, Quebec K1A OH3 Canada	819-997-
Scott Carrothers Manager, Marketing Support	**Suncor Inc.** **Oil Sands Group** P.O. Box 4001 Fort McMurray, AB T9H 3E3 Canada	403-743-6795
Stephen Carter Director, Engine Technologies	**ORTECH International** Engine Technologies 2395 Speakman Drive Mississauga, Ontario L5K 1B3 Canada	416-822-4111 X443
Paul Cassidy Consultant/Prog. Mgr. Orchard Eng.	**Orchard Engineering** c/o Detroit Diesel Corp. 2711 Glenmont Road N.W. Canton, OH 44708 USA	313-392-5090
William B. Chamberlin III Research Scientist	**Lubrizol Corporation** 29400 Lakeland Blvd. Wickliffe, OH 44092 USA	216-943-1200 X2496

Participants List - 1993 Windsor Workshop on Alternative Fuels

Anthony Chan Manager-Product Development	**FuelMaker Corporation** 70 Worcester Road Toronto, ON M9W 5X2 Canada	416-674-3034
Rick Chiasson Comm. Officer Light Vehicles	**Industry, Science & Technology Canada** 235 Queen Street Ottawa, ON K1A 0H5 Canada	613-954-3224
John Christie Manager, Powertrain Design	**General Motors of Canada Ltd.** Engineering 098-001 1908 Colonel Sam Drive Oshawa, ON L1H 8P7 Canada	416-644-4171
Jack Chu Officer, Fleet Design & Acquisition	**Canada Post Corporation** **Fleet Management** 2701 Riverside Drive Suite No. 281 Ottawa, ON K1A 0B1 Canada	613-734-7789
Alf Clayton	**Union Gas** 50 Keil Drive N. Chatham, ON N7M 5M1 Canada	519-436-5250
James Cole	**Southwest Research Institute** 6220 Culebra Road P.O. Drawer 28510 San Antonio, TX 78228-0510 USA	210-522-5473
Raymond Colledge Methanol Fuel Program Manager	**Celanese Canada Inc.** 195 The West Mall Suite 1000 Etobicoke, Ontario M9C 5K1 Canada	416-622-2032
George Cornell Vice President, Corporate Development	**Superior Propane Inc.** 75 Tiverton Court Unionville, ON L3R 9S3 Canada	416-475-9200
Susan Cudahy	**Consumers Gas Company** 500 Consumers Road P.O. Box 650 Scarborough, ON M1K 5E3 Canada	416-496-7107
Robert B. Cumming Director, NGV Development	**Canadian Gas Association** 950 Burnhamthorpe Road West Mississauga, ON L5C 3B4 Canada	416-897-1690
Don Cunningham	**Energy, Mines & Resources Canada** Oil & Gas Division 580 Booth St. 18th Floor Ottawa, ON K1A 0E4 Canada	

Participants List - 1993 Windsor Workshop on Alternative Fuels

Nicole DeLint	**ORTECH International** 2395 Speakman Drive Mississauga, ON L5K 1B3 Canada	416-822-4111 X360
A.S. Deshpande Director, Corporate Business Develop.	**ORTECH International** 2395 Speakman Drive Mississauga, ON L5K 1B3 Canada	416-822-4111 X504
Helen Doherty	**Sun Company Inc.** P.O. Box 1135 Marcus Hook, PA 19061 USA	215-447-1937
Allan Dolenko Director - AED	**Energy, Mines & Resources Canada** **AED - CANMET** 580 Booth Street Ottawa, ON K1A 0E4 Canada	613-996-6162
Vinod Duggal	**Cummins Engine Company, Inc.** P.O. Box 3005 Mail Code 50165 Columbus, IN 47202-3005 USA	812-377-7338
Robert Dunn Manager, Analytical Services	**Railroad Technologies** 3950 Hickmore Avenue Montreal, Quebec H4T 1K2 Canada	514-399-6069
David Dunnuck Engineer	**Cummins Engine Co. Inc.** Mail Code 50179 Box 3005 Columbus, IN 47203 USA	812-377-4835
David Elliott Research Engineer	**Ontario Ministry of Transportation** 1201 Wilson Avenue, Rm 328 Downsview, ON M3M 1J8 Canada	416-235-5019
Sid Engler Senior Vice President, LNG Division	**Liquid Carbonic Inc.** 255 Brimley Road Scarborough, ON M1M 3J2 Canada	416-266-3161
Todd Evans	**Consumers Gas** 400 Coventry Road Ottawa, ON K1K 2C7 Canada	613-748-6787
Wayne Evans Sales & Marketing Manager	**FuelMaker Corporation** 70 Worcester Road Rexdale, ON M9W 5X2 Canada	416-674-3034
R.L. Evans Professor	**University of British Columbia** Department of Mechanical Eng. 2324 Main Mall Vancouver, BC V6T 1Z4 Canada	604-822-2781

Participants List - 1993 Windsor Workshop on Alternative Fuels

Andy Fallas	**Petro Canada** 5140 Yonge Street North York, ON M2N 6L6 Canada	416-730-2980
Elson Fernandes Manager-Technical Services	**Meridian Clemmer Industries** 446 Albert Street, P.O. Box 130 Waterloo, ON N2J 4A1 Canada	519-884-4320
Tom Finn Vice-President	**Avis Rent-A-Car** 900 Old Country Road Garden City, NY 11530 USA	516-222-3325
Tom Fisher Major	**Department of National Defence** National Defence HQ, 10th Fl. Centre Bldg. N., M.Gen.George R. Pearkes Bldg. Ottawa, ON K1A OK2 Canada	613-992-6695
Don Fitzsimons	**Methanex Corporation** Suite 1000 1055 West Hastings Vancouver, BC V6E 2E9 Canada	604-684-7500
Daniel Fong Mgr. Trans. Technol. & Fuels Office	**California Energy Commission** 1516 9th Street Mail Stop 41 Sacramento, CA 95814 USA	916-654-4638
John Freel	**Chevron Research & Technology Co.** 100 Chevron Way Richmond, CA 94802 USA	510-242-4080
Neil Fricker Business Area Mgr. NGV	**British Gas plc** Midlands Research Station Wharf Lane Solihull, West Midlands B91 2JW UK	44-21-705-7581
David Gardiner Research Officer	**Royal Military College** **Dept. of Mechanical Engineering** Kingston, Ontario K7K 5L0 Canada	613-541-6092
Brad Garner Snr. Coord. Auto Propane Sales/Service	**Superior Propane** P.O. Box 605 Hwy. 24 South Guelph, ON N1H 6L3 Canada	519-822-7814
Doug Gates Assistant Staff Engineer	**General Motors Corporation** **Powertrain Division** 30003 Van Dyke Avenue Room 2-212 Warren, MI 48090-9060 USA	313-575-7158

Participants List - 1993 Windsor Workshop on Alternative Fuels

William Gaw	**Conoco Inc.** P.O. Box 4784 Houston, TX 77210 USA	713-293-1574
Tom Geddes NGV Technical Specialist	**Centra Gas** P.O. Box 3040 36 Charles Street E. North Bay, Ontario P1B 8K7 Canada	705-474-8480
Ian A. Gibbons Retired Consultant	**I.A. Gibbons** 2132 Lake Bonavista Drive S.E. Calgary, Alberta T2J 3Z6 Canada	403-278-3501
Al Gibson	**ABG Enterprises** 8 Clarinda Driv e Willowdale, ON M2K 2W7 Canada	416-512-6800
Talaat Girgis	**Liquid Carbonic Inc.** 255 Brimley Road Scarborough, ON M1M 3J2 Canada	416-266-3161
Wendel Goetz Manager, Heavy Duty Engines	**ORTECH International** Engine Technologies 2395 Speakman Drive Mississauga, ON L5K 1B3 Canada	416-822-4111 X518
Barbara Goodman Analysis & Project Management Mgr.	**National Renewable Energy Laboratory** 1617 Cole Boulevard Golden, CO 80401-3393 USA	303-231-1005
Barry M. Gore Vehicle Engineer	**London Buses Limited** 172 Buckingham Palace Road London, SW1W 9TN UK	71-918-3827
Tom Gorman National Marketing Manager NGV	**British Gas plc** Staines House London Road Staines, Middlesex TW18 3AE UK	44-784-461666
Bryan Goulden	**Union Gas** 50 Keil Drive N. Chatham, ON N7M 5M1 Canada	519-436-5250
Madan Goyal Manager, Advanced Projects	**John Deere Engine Group** Product Engineering Centre P.O. Box 8000 Waterloo, IA 50704-8000 USA	319-292-8188

Participants List - 1993 Windsor Workshop on Alternative Fuels

Mike Graham Project Manager	**Perkins Technology Limited** Peterborough, PE1 5NA UK	44-733-67474
William Grant Director - Powertrain	**Lucas Automotive** Stratford Road Solihull, West Midlands B90 4LA UK	44-21-627-3909
Robert G. Greven General Manager	**Ontario Ministry of Environment and Energy** 56 Wellesley Street West 11th Floor Toronto, ON M7A 2B7 Canada	416-327-1235
M. James Grieve Consultant	**Geotecnica-Consultant** 30 Gemini Road Willowdale, ON M2K 2G6 Canada	416-730-0842
Mike Grove Manager, Maintenance Systems	**Tri-Met** 4012 S.E. 17th Avenue Portland, OR 97202 USA	503-239-6410
Omer L. Gülder	**National Research Council Canada** Combustion & Fluids Engineering Montreal Road, M-9 Ottawa, ON K1A OR6 Canada	613-993-2176
Joseph Y. Guttman Head Laboratory	**Canadian Gas Research Institute** 55 Scarsdale Road Don Mills, ON M3B 2R3 Canada	416-447-6661
Kong Ha Sr. Environmental Protection Officer	**Hong Kong EPD** **VECS - Air Services Group** 33/F Wanchai, Tower 3 5 Gloucester Road Wan Chai, Hong Kong	852-594-6414
Joe Haddon Diesel Projects Engineer	**B.C. Gas Inc.** #209, 2250 Boundary Road Burnaby, BC V5M 4L9 Canada	604-293-8840
John D. Hainsworth Engineering Technologist	**Toronto Transit Commission** 1138 Bathurst Street Toronto, Ontario M5R 3H2 Canada	416-393-3165
Milt Harmelink	**Ontario Ministry of Transportation** Central Building 1201 Wilson Avenue Downsview, ON M3M 1J8 Canada	416-235-5040

Participants List - 1993 Windsor Workshop on Alternative Fuels

Mones E. Hawley Exec. Vice President	**Jack Faucett Associates** 4550 Montgomery Avenue Bethesda, MD 20814 USA	301-961-8800
Jeffrey M. Headean	**Caterpillar Inc.** 3701 State Road 26 East Lafayette, IN 47905 USA	317-448-5938
Michelle Heath VP- Domestic Oil & Trsp.	**Canadian Energy Research Institute** 150, 3512 - 33 Street NW Calgary, AB T2L 2A6 Canada	403-282-1231
John Heenan Vice President, Marketing	**Sherex Industries Ltd.** 4180 Morris Drive Unit 6 Burlington, Ontario L7L 5L6 Canada	416-639-7701
Richard Henson	**The Adept Group** 10920 Wilshire Blvd. Suite 1203 Los Angeles, CA 90024 USA	310-208-8074
Pat Hickey District Manager, S.W. Ontario	**ICG Propane Inc.** 800A Denison Street Markham, ON L3R 5M9 Canada	416-477-3155
Steve Hood	**Consumers Gas Co.** Technology Development P.O. Box 650 Scarborough, ON M1K 5E3 Canada	416-496-7136
W. Norval Horner Mgr. Eng., NG Liquids/Crude Oil Unit	**Amoco Canada** P.O. Box 200, Station M Calgary, AB T2P 2H8 Canada	403-233-1994
Susan Horton Registration Secretary	**ORTECH International** Engine Technologies 2395 Speakman Drive Mississauga, ON L5K 1B3 Canada	416-822-4111 X515
Ken Hough	**Canadian Renewable Fuels Association** 90 Woodlawn Road Guelph, ON N1E 1B2 Canada	519-767-0431
Paul Howard Vice President	**Ballard Power Systems** 980 West 1st Street Unit 107 North Vancouver, B.C. V7P 3N4 Canada	604-986-9367

Participants List - 1993 Windsor Workshop on Alternative Fuels

David Hudson Technical Sales Rep.	**Williamson Industries Inc.** 102 Armstrong Avenue Georgetown, Ontario L7G 4S2 Canada	416-873-2272
John Hutchison Consultant	**Consultant** 47 Soudan Avenue Toronto, ON M4S 1V5 Canada	416-487-2428
Shinichi Iguchi Vice President	**Nippon Steel U.S.A. Inc.** 10 East 50th Street 29th Floor New York, N.Y. 10022 USA	212-207-0178
Charles R. Imbrecht Chairman	**California Energy Commission** 1516 9th Street Sacramento, CA 95814 USA	916-654-4001
William D. Ingle III Director, Technology Applications	**Gas Research Institute** 8600 West Bryn Mawr Avenue Chicago, IL 60631 USA	312-399-8337
Shunji Inoue Senior Manager, Engineering	**Mitsubishi Motors America, Inc.** 100 Center Square Road P.O. Box 464 Bridgeport, NJ 08014 USA	609 467-4664
Nobuo Iwai Senior Research Engineer	**Japan Automobile Research Institute** 2530 Karima Tsukuba, Ibaraki 305 Japan	81-298-56-1111
Mike Jackson Manager, Alternative Fuels	**Acurex Environmental Corporation** 555 Clyde Avenue P.O. Box 7044 Mountain View, CA 94039 USA	415-961-5700
Bernard James Chief, Alternative Transportation Fuels	**Energy, Mines & Resources Canada** **AED - CANMET** 580 Booth Street Room 720 Ottawa, Ontario K1A OE4 Canada	613-943-2258
Viswanath Jayaraman Manager, Residential & Commercial Res.	**Consolidated Natural Gas** CNG Tower 625 Liberty Avenue Pittsburgh, PA 15222-3199 USA	412-227-1414
Stuart Johnson Sr. Product Engineer	**Volkswagen of America** 3800 Hamlin Road Auburn Hills, MI 48326 USA	313-340-4708

Participants List - 1993 Windsor Workshop on Alternative Fuels

B. Ellen Johnson Research Engineer	**Mobil Research & Development Corp.** Paulsboro Research Lab. P.O. Box 480 Paulsboro, NJ 08066-0480 USA	609-224-2118
Richard Jordecka	**Guide Valve Supply** 7370 Bramalea Road Unit 6&7 Mississauga, ON L5S 1N6 Canada	416-612-1244
Mostafa Kamel	**Cummins Engine Company, Inc.** P.O. Box 3005 Mail Code 50180 Columbus, IN 47202-3005 USA	812-377-7253
Ryan Katofsky	**Princeton University** H-103 Engineering Quad, Center for Energy & Environmental Studies Princeton, NJ 08544 USA	609-258-5190
Franz L. Kelling President	**Kraft Fuels/Alternative Fuels Technology Inc.** 50 Ritin Lane Concord, ON L4K 4L9 Canada	416-738-0287
Erik Kelgard NGV Specialist	**Clean Air Partners** 5066 Santa Fe Street San Diego, CA 92019 USA	619-581-5600
Doug Kennedy	**Toronto Transit Commission** 1138 Bathurst Street Toronto, Ontario M5R 3H2 Canada	416-393-3115
Albert Kinal	**Engelhard Corporation** 101 Wood Avenue Iselin, NJ 08830 USA	908-205-5135
Dan E. Kincaid Manager, Technology Applications	**Gas Research Institute** 8600 W. Bryn Mawr Chicago, IL 60631 USA	312-399-8338
Anthony E. Kirn Manager, Engineering R&D	**Caterpillar Inc.** 124 S.W. Adams Street Peoria, IL 61629-8000 USA	309-675-6264
Morrie Kirshenblatt Sr. Program Engineer	**Environment Canada** **Transportation Systems Division** 351 St. Jospeh Blvd. 13th Floor Hull, Quebec K1A OH3 Canada	819-953-0914

Participants List - 1993 Windsor Workshop on Alternative Fuels

Takanoni Kono Manager	**Idemitsu Kosan Co. Ltd.** 50 Rockefeller Plaza New York, NY 10020 USA	212-757-4433
Todd C. Krenelka Principal Research Scientist	**Battelle** 505 King Avenue Room 11-7-079 Columbus, OH 43201-2693 USA	614-424-5854
Detlef Kretschmer Professor	**Laval University** Dept. of Mechanical Engineering Quebec City, Quebec G1K 7P4 Canada	418-656-5409
Jung Kweon	**Daewoo Heavy Industries Ltd.** 6 Manseog-Dong Dong-Ku, Inchon Korea	
Jim Lanigan Supervisor, Product Engineering	**Chrysler Canada Ltd.** P.O. Box 1621 Windsor, ON N9A 4H6 Canada	519-973-2717
Denis Larable President	**Foratek Forest Products** 40 Art Street Box 819 Smooth Rock Falls, ON P0L 2B0 Canada	705-335-4828
Robert P. Larsen Transp. Systems Engineer	**Argonne National Laboratory** 9700 S. Cass Avenue Bldg. 362-2B Argonne, IL 60439 USA	708-972-3735
Robert J. Last Supervisor, Alternative Fuels	**FEV of America, Inc.** 25899 West 12 Mile Road Suite 130 Southfield, MI 48034 USA	313-352-1400
Alex Lawson President	**Alex Lawson Associates** 542 Stillwater Crescent Burlington, ON L7T 3M7 Canada	416-632-1959
Win Lee	**Energy, Mines & Resources Canada** **Energy Res. Lab. - CANMET** 555 Booth Street Ottawa, ON K1A 0G1 Canada	613-996-3873
Harold M. Lee Dir. of Electrical Engineering	**American Gas & Technology** 23382 Deerfield Road Los Gatos, CA 95030 USA	408-353-3464

Participants List - 1993 Windsor Workshop on Alternative Fuels

Milt Leggett President & Chairman	**Cummins Natural Gas Engines, Inc.** 8713 Airport Freeway Suite 316 Fort Worth, TX 76180 USA	817-581-7575
Joseph Lepley Vice President - Engineering	**Altronics Inc.** 712 Trumbull Avenue Girard, OH 44420 USA	216-545-9768
Jill Lexler Director, Alternative Transp. Fuels	**Amoco Oil Company** 501 West Lake Park Blvd. Houston, TX 77056 USA	713-556-3836
William Liss	**Gas Research Institute** 8600 West Bryn Mawr Chicago, IL 60631 USA	312-399-8352
John Lyon President/CEO	**FuelMaker Corporation** 70 Worcester Road Rexdale, ON M9W 5X2 Canada	416-674-3034
Ian MacIntyre	**Energy, Mines & Resources Canada** **CANMET/EAETB** 580 Booth Street 7th Floor Ottawa, ON K1A OE4 Canada	613-943-2257
Glenn MacIntyre	**EDO Canada Ltd.** 1940 Centre Avenue N.E. Calgary, AB T2E 0A7 Canada	403-569-5400
John Mack Project Manager	**Rotary Power International** P.O. Box 128 Wood-Ridge, NJ 07075-0128 USA	201-470-7015
David MacKinnon President	**ORTECH International** 2395 Speakman Drive Mississauga, ON L5K 1B3 Canada	416-822-4111 X201
Michael MacNeil Managing Consultant LD MeOH Veh.Prog.	**Canadian Oxygenated Fuels Association** 190 Bronson Avenue Ottawa, ON K1R 6H4 Canada	613-232-9729
W. (Addy) Majewski Manager R&D	**Diesel Controls Limited** P.O. Box 850, Stn. B Willowdale, ON M2K 2R1 Canada	416-660-6450

Participants List - 1993 Windsor Workshop on Alternative Fuels

Henry K. Mak Sr. Research Project Eng.	**Southern California Gas Co.** 555 W. 5th Street M.L. 19E0 Los Angeles, CA 90013 USA	213-244-5323
Larry Marigold Consultant	**MG Refining & Marketing** 4925 St. Thomas Drive Fair Oaks, CA 95628 USA	916-961-2349
David Martin NGV Manager	**Sherex Industries Ltd.** 4180 Morris Drive Unit 6 Burlington, Ontario L7L 5L6 Canada	416-639-7701
Harry McAdie Consultant	**H.G. McAdie Associates** 245 Eglinton Avenue East Suite 340 Toronto, ON M4P 3B7 Canada	416-489-7067
Ralph McGill Senior Development Staff Member	**Oak Ridge National Laboratory** P.O. Box 2009 Oak Ridge, TN 37831-8087 USA	615-574-4077
Kirk McNaughton Mgr. Product Quality	**Shell Canada Products Ltd.** 75 Wynford Drive Toronto, ON M3C 2Z4 Canada	416-443-7099
Barry McNutt	**Office of Policy Integration** **U.S. Dept. of Energy** P.E. 23 Washington, D.C. 20585 USA	202-586-4448
Glenn A. Metts Vice President	**P & J Industries, Inc.** 1155 Expressway Drive N. Toledo, OH 43608 USA	419-726-2675
Laurie Michaelis	**International Energy Agency** 2 rue Andre-Pascal 75775 Paris, Cedex 16 France	33-1-45249823
Eric Milkins Senior Technical Advisor	**NGV - Australia** 2 Victor Road Bentleigh, Victoria 3204 Australia	61-3-5590333
Stan Miller	**Detroit Diesel Corporation** 13400 Outer Drive West Alternate Fuel Project Center Detroit, MI 48239-4001 USA	313-592-7046

Participants List - 1993 Windsor Workshop on Alternative Fuels

Bruce Miller Maintenance Manager	**Tri-Met** 4012 S.E. 17th Avenue Portland, OR 97202 USA	503-238-5840
Brian E. Milton Professor	**University of New South Wales** P.O. Box 1 Kensington, New South Wales 2033 Australia	61-2-6974088
Ken Mitchell Senior Research Engineer	**Shell Canada Ltd.** 2415 Lakeshore Road W. Oakville, ON L6J 5C7 Canada	416-827-1141
Terri Morgan	**Consumers Gas** 400 Coventry Road Ottawa, ON K1K 2C7 Canada	613-748-6787
Rob Motta	**National Renewable Energy Laboratory** 1617 Cole Blvd. Bldg. 15/1 Golden, CO 80401-3393 USA	303-231-7882
Norman Moyer Assistant Deputy Minister	**Corporate Policy and Communications Sector, Energy, Mines & Resources** Ottawa, ON K1A OE4 Canada	613-992-0207
Gary Murray Market Development Officer	**Energy, Mines & Resources Canada** Transportation Energy Division 580 Booth Street, 15th Floor Ottawa, ON K1A OE4 Canada	613-996-8736
Ron Neville V.P. Transportation Systems	**ORTECH International** 2395 Speakman Drive Mississauga, Ontario L5K 1B3 Canada	416-822-4111 X254
Henry Ng	**Argonne National Laboratory** 9700 S. Cass Avenue Argonne, IL 60439 USA	708-252-3758
Rob E. Nicolle Asst. Mgr. Marketing R&D	**Caterpillar Inc.** 124 S.W. Adams Street Peoria, IL 61629-8000 USA	309-675-1897
Alan Niedzwiecki	**EDO Canada Ltd.** 1940 Centre Avenue N.E. Calgary, AB T2E 0A7 Canada	403-569-5400
John Nikiforuk Product Mgr., Industrial Compressors	**SSCAN Technologies** 90 West Beaver Creek Road Richmond Hill, Ontario L4B 1E7 Canada	416 222-4111, X215

Participants List - 1993 Windsor Workshop on Alternative Fuels

Roy Nishizaki Senior Development Officer	**Transportation Development Centre** 200 Rene Levesque Blvd. W. Suite 601, West Tower Montreal, Quebec H2Z 1X4 Canada	514-283-0026
Joseph Notardonato Project Manager	**NASA** 21000 Brookpark Cleveland, OH USA	216-835-0090
David Ogilvie	**National Association of Fleet Administrators, Inc.** 6877 Goreway Drive Mississauga, ON L4V 1M8 Canada	416-678-9430
Shiro Okazaki Proj. Mgr. Prime Mover Emissions	**Gas Research Institute** 8600 West Bryn Mawr Chicago, IL 60631-3562 USA	312-399-5463
Masayoshi Okoshi Project Leader, Joint Research Div.	**NEDO** Sunshine 60, 21F, 1-1, 3-Chome Higashi-ikebukuro, Toshima ku Tokyo, 170 Japan	81-3-3987-9357
George A. Olah Principal	**George A. Olah Consulting Services** 19 Chase Road North York, ON M2J 2S1 Canada	416-733-4302
Douglas S. Orrin Manager, Automotive Business Devel.	**ORTECH International** 100 West Big Beaver Road Suite 200 Troy, MI 48084 USA	313-680-6688
Madis Paas Director of Technical Services/Oper.	**ICG Propane Inc.** 175 Hargrave Street 7th Floor Winnipeg, Manitoba R3C 4S6 Canada	204-949-6622
Colleen Paton Sr. Market Development Officer	**Energy, Mines & Resources Canada** Transportation Energy Division 580 Booth Street, 15th Floor Ottawa, ON K1A OE4 Canada	613-996-0765
Don Pearson Bus Engine Business Manager	**Cummins Ontario Inc.** 150 North Queen Street Etobicoke, ON M9C 1A8 Canada	416-622-9921
Campbell Perry Project Manager	**B.C. Research** 3650 Wesbrook Mall Vancouver, B.C. V6S 2L2 Canada	604-224-4331

Participants List - 1993 Windsor Workshop on Alternative Fuels

Robert E. Petsinger President	**CNG Services of Pittsburgh** 7125 Saltsburg Road Pittsburgh, PA 15235 USA	412-795-4698
Rene Pigeon Research Advisor	**Energy, Mines & Resources Canada** **AED, CANMET** 780 Booth Street Ottawa, ON K1S 1Z2 Canada	613-943-4480
Simon Pitts	**Ford Motor Company** 21500 Oakwood Blvd. EEE Bldg., Mail Drop 19 Dearborn, MI 48121-2053 USA	313-845-8991
Frederick L. Potter President	**Information Resources Inc.** 499 A. Capitol St. S.W. Suite 406 Washington, DC 20003 USA	202-554-0614
Chandra Prakash Head, Transportation Fuels	**Environment Canada** Industrial Programs Branch 351 St. Jospeh Blvd. Hull, Quebec K1A OH3 Canada	819-997-1614
Ralph Rackham V.P., Production & Engineering	**FuelMaker Corporation** 60 Worcester Road Rexdale, Ontario M9W 5X2 Canada	416 674-3034
Peter Reilly-Roe	**Energy Mines & Resources Canada** **EAEB - CANMET** 580 Booth Street 15th Floor Ottawa, ON K1A OE4 Canada	613-996-6001
Mark Riechers Fuel/Eng. Systems Engineer- AMFA	**National Renewable Energy Laboratory** 1617 Cole Blvd. Bldg. 15/1 Golden, CO 80401-3393 USA	303-231-7853
Tony Rinaldi	**Environment Canada** 351 St. Joseph Blvd. Hull, Quebec K1A OH3 Canada	819-997-
James Rinke President	**Vehicle Research & Development, Inc.** 3863 Van Dyke Almont, MI 48003 USA	313-798-3911

Participants List - 1993 Windsor Workshop on Alternative Fuels

David Rodgers	**U.S. Department of Energy** 1000 Independence Avenue S.W. CE-331 Washington, DC 20585 USA	202-586-7182
Gerald Roger Sales & Marketing Manager	**Sherex Industries Ltd.** 4180 Morris Drive Unit 6 Burlington, Ontario L7L 5L6 Canada	416-639-7701
Todd W. Rogers President	**Cardinal Automotive Inc.** 7200 Fifteen Mile Road Sterling Heights, MI 48312-4524 USA	313-268-3800
Ivan Z. Rohac Environmental Fuels Eng.	**Ministry of Environment & Energy** 125 Resources Road, West Wing Etobicoke, ON M9P 3V6 Canada	416-235-6257
Jordan B. Rothwell Senior Development Officer	**Office of the Chairman** **Municipality of Metro Toronto** Station 1084, 8th Floor, Metro Hall 55 John Street Toronto, ON M5V 3C6 Canada	416-392-3386
Floyd R. Running Sales and Marketing	**Gas Equipment Supplies** 6597 Kitimat Road Mississauga, ON L5N 4J4 Canada	416-858-8440
John A. Russell Director, Alternative Fuel Utilization	**U.S. Department of Energy** Forrestal Bldg. CE-332 1000 Independence Avenue S.W. Washington, DC 20585 USA	202-586-8038
Barbara A. Salter Marketing Coordinator	**The Lubrizol Corporation** 29400 Lakeland Blvd. Wickliffe, OH 44092 USA	216-943-4200
Marie A. Schingh Advisor, Alternative Energy	**Energy, Mines & Resources Canada** 580 Booth Street Room 1566 Ottawa, ON K1A OE4 Canada	613-995-8401
Jack W. Schmidt Director, Powertrain Systems	**GM Powertrain Division** **General Motors Corporation** 895 Joslyn Avenue Mail Code 2K41 Pontiac, MI 48340-2920 USA	313-857-1162

Participants List - 1993 Windsor Workshop on Alternative Fuels

Garth Schultz Corporate Office	**Beacon Power Systems, Inc.** 447 East Elmwood Troy, MI 48083 USA	**313-589-7888**
Clive Sedgwick Marketing Eng.	**Taylor Forge of Canada Corp.** P.O. Box 2511 1675 Burlington Street E. Hamilton, ON L8N 3R5 Canada	**416-549-3051**
Norman R. Sefer Consultant	**Consultant** 6223 Forest Bend San Antonio, TX 78240 USA	**210-684-4282**
Robert Siewert Sr. Staff Research Engineer	**General Motors** **R & D Center** Thermosciences Dept., Box 9055 30500 Mound Road Warren, MI 48090-9055 USA	**313-986-0014**
Don Singleton Research Officer	**National Research Council** Ottawa, ON K1A OR6 Canada	**613-993-2500**
Raymond Skinner Project Engineer	**ORTECH International** Engine Technologies 2395 Speakman Drive Mississauga, Ontario L5K 1B3 Canada	**416-822-4111 X440**
Malcolm Smith	**Consultant** 3072 West King Edward Avenue Vancouver, BC V6L 1V5 Canada	**604-739-7324**
Kenneth D. Smith Policy Director, Clean Fuels Program	**Sacramento Metropolitan AQMD** 8475 Jackson Road, Suite 215 Sacramento, CA 95826 USA	**916 386-7023**
Ry Smith	**Union Gas** 50 Keil Drive N. Chatham, ON N7M 5M1 Canada	**519-436-5250**
Tom Smyth Manager, Vehicle Technologies	**Energy, Mines & Resources Canada** **AED - CANMET** 580 Booth Street Ottawa, ON K1A OE4 Canada	**613-992-7598**
Michael Snodgrass Regional Fleet Manager	**U.S. General Services Administration** 525 Market Street San Francisco, CA 94105 USA	**415-744-6067**

Participants List - 1993 Windsor Workshop on Alternative Fuels

Matthew D. Solomon	**Consolidated Diesel Company** U.S. Highway 301 Box 670 Whitakers, NC 27891 USA	**919-437-6611**
John Spacek Mgr. & Director, Methanol Fuel Develop.	**Canadian Oxygenated Fuels Association** 190 Bronson Avenue Ottawa, ON K1R 6H4 Canada	**613-232-9729**
Alex Spataru	**The Adept Group** 10920 Wilshire Blvd. Suite 1203 Los Angeles, CA 90024 USA	**310-208-8074**
N.H. Speller Chief Engineer	**Navistar International Corp.** 508 Richmond Street Chatham, ON N7M 5M4 Canada	**519-436-4060**
Mario Sposini R & D Manager	**Ecofuel** Viale Brenta 15 Milano, 20139 Italy	**39-2-520-21932**
Ken Stamper Manager, Fuels Utilization Program	**National Renewable Energy Laboratory** 1617 Cole Blvd. Golden, CO 80401-3393 USA	**303-231-7669**
Laura Stennett	**Consumers Gas** 400 Coventry Road Ottawa, ON K1K 2C7 Canada	**613-748-6787**
Perry Stover Director, NGV Business Development	**Consumers Gas Company** 500 Consumers Road, P.O. Box 650 Scarborough, ON M1K 5E3 Canada	**416-495-6112**
Alexander Stuart President	**The Electrolyser Corporation Ltd.** 122 The West Mall Etobicoke, Ontario M9C 1B9 Canada	**416-621-9410**
Michael Sulatisky Research Engineer	**Saskatchewan Research Council** 15 Innovation Boulevard Saskatoon, Sask. S7N 2X8 Canada	**306-933-5468**
Cindy Sullivan Program Supervisor	**South Coast Air Quality Management District** 21865 E. Copley Drive Diamond Bar, CA 91765-4182 USA	**909-396-3249**

Participants List - 1993 Windsor Workshop on Alternative Fuels

Mehboob Sumar Project Engineer, Emissions	**ORTECH International** Engine Technologies 2395 Speakman Drive Mississauga, Ontario L5K 1B3 Canada	416-822-4111 X654
Dale Swift Coach Project Manager	**Chance Operations Inc.** P.O. Box 12328 4219 Irving Wichita, KS 67277 USA	316-941-1616
Satya P. Syngal General Manager	**Grantech Manufacturing** 100 Hollinger Crescent Kitchener, ON N2K 2Z3 Canada	519-576-4270
Michio Takita Senior Manager	**Nippon Steel Corp.** 2-6-3 Ote-machi Chiyoda-ku Tokyo, 100 Japan	81-3-3242-4111
Ray Tate President	**American Gas & Technology** 23382 Deerfield Road Los Gatos, CA 95030 USA	408 353-3464
Anthony C. Taylor Director, Transportation Energy	**Energy, Mines & Resources Canada** 580 Booth Street 15th Floor, Room 1562 Ottawa, ON K1A E4 Canada	613-995-7300
John A. Taylor Sr. Coordinator - Fuels	**Petro Canada Products** 111 - 5th Avenue S.W. P.O. Box 2844 Calgary, AB T2P 3E3 Canada	403-296-4931
David Thompson President	**Northern Cross Pipelines Ltd.** 700 4th Avenue S.W. Suite 430 Calgary, AB T2P 3S4 Canada	403-237-0055
Bob Thompson	**Thompson Management Services** 1203 Greenoaks Drive Mississauga, ON L5J 3A1 Canada	416-823-0599
Toros Topaloglu Head, Automotive Energy Section	**Ministry of Transportation of Ontario** 1201 Wilson Avenue Downsview, Ontario M3M 1J8 Canada	416-235-5017
Jerry Tostevin Consultant	**Consultant** 30 Roxborough Street W. Toronto, ON M5R 1T8 Canada	416-961-8460

Participants List - 1993 Windsor Workshop on Alternative Fuels

Michael Tremayne Acting Mgr. NGV Engineering & Oper.	**Consumers Gas** P.O. Box 650 Scarborough, ON M1K 5E3 Canada	416-495-5989
Jerry L, Trotter Director of Bus Technology	**American Public Transit Association** 1201 New York Avenue N.W. Washington, DC 20005 USA	202-898-4087
Vera Jean Trueblood	**Cummins Engine Co. Inc.** P.O. Box 3005 Mail Code 60108 Columbus, IN 47202 USA	812-377-4938
Vasso Tsatsami Project Engineer	**BP Oil Company** 3092 Broadway Avenue Cleveland, OH 44115 USA	216-441-8118
Vlad Ulmet Mechanical Engineer	**Engine Control Systems Ltd.** 165 Pony Drive Newmarket, ON L3Y 7V1 Canada	416-853-5500
John Unsworth President	**Petro-Tire Inc.** 14 Duke Street Hamilton, ON L8P 1X1 Canada	519-529-0019
Seiichi Ushioda Director, Alcohol & Biomass Energy	**NEDO** Sunshine 60, 29F, 1-1, 3-Chome Higashi-ikebukuro, Toshima ku Tokyo, 170 Japan	81-3-3987-9481
Sheldon E. Vedlitz Mgr. Alternative Fuels Marketing	**Conoco Inc.** P.O. Box 4784 TR3024 Houston, TX 77210 USA	713-293-2942
Charles Villeneuve Programs Manager	**Energy, Mines & Resources Canada** Transportation Energy Division 580 Booth Street, 15th Floor Ottawa, ON K1A OE4 Canada	613-996-5957
Robert Waddell President	**Motion Concept Vehicles Inc.** 1980 Boylen Road, Units 5 & 6 Mississauga, ON L5S 1O5 Canada	416-672-0332
Joseph R. Wagner Project Manager	**NYSERDA** 2 Rockefeller Plaza Albany, NY 12223 USA	518-465-6251 X228

Participants List - 1993 Windsor Workshop on Alternative Fuels

Syed Ah Wahiduzzaman Staff Engineer	**Ricardo North America** 7850 Grant Street Burr Ridge, IL 60521-5852 USA	708-789-0003
David W.T. Walker	**Robert Hay Incorporated** 405-1215 Cameron Ave. S.W. Calgary, AB T2T 0K8 Canada	403-228-0519
Gregory Walker Engineering Analyst	**American Automobile Manufacturers** 7430 Second Ave. Suite 300 Detroit, MI 48202 USA	313-872-4311
James S. Wallace Professor	**University of Toronto** **Dept. of Mechanical Engineering** 5 King's College Road Toronto, ON M5S 1A4 Canada	416-978-5736
Murray Walsh Director, Fleet & Auto Tech. Services	**Superior Propane Inc.** 75 Tiverton Court Unionville, ON L3R 9S3 Canada	416-475-9200
Howard L. Walton Director	**U.S. Department of Energy** 1000 Independence Ave. S.W. EI-52 Washington, DC 20585 USA	202-254-5500
Gary Webster President	**Advanced Engine Technology Ltd.** 17 Fitzgerald Road Suite 102 Nepean, ON K2H 9G1 Canada	613-721-1234
Martin Whicher	**Ontario Ministry of Environment and Energy** 56 Wellesley Street West 14th Floor Toronto, ON M7A 2B7 Canada	416-327-1476
Nicholas P. White NGV R&D Program Administrator	**Canadian Gas Association** 950 Burnhamthorpe Road West Mississauga, ON L5C 3B4 Canada	416-897-1691
Ray Willey Powertrain Devel. Engr.	**Ford Motor Company** 21500 Oakwood Blvd. EEE Bldg., Mail Drop 19 Dearborn, MI 48121-2053 USA	313-323-0568
Martin L. Willi Sr. Research Engineer	**Caterpillar Inc.** 100 N.E. Adams Peoria, IL 61629 USA	309-578-6978

Participants List - 1993 Windsor Workshop on Alternative Fuels

Peter Williams	**Energy, Mines & Resources Canada** **CANMET** 580 Booth Street Ottawa, ON K1A OE4 Canada	613-996-9760
Craig L. Willis Project Manager	**Ministry of Transportation of Ontario** 1201 Wilson Avenue, 3rd Floor, Central Building Downsview, ON M3M 1J8 Canada	416-235-5033
Bryan Wilson	**Colorado State University** **Dept. of Mechanical Engineering** Fort Collins, CO 80523 USA	303-490-1418
William Woolam Director	**Southwest Research Institute** 1235 Jefferson Davis Hwy #1104 Arlington, VA 22202 USA	703-979-0500
Robert Wooley Manager, AFDC	**National Renewable Energy Laboratory** 1617 Cole Boulevard Golden, CO 80401-3393 USA	303-231-7191
Paul Wuebben Manager, Clean Fuels Program	**South Coast Air Quality Management District** 21865 E. Copley Drive Diamond Bar, CA 91765-4182 USA	909-396-3247
Charles Wyman Director, Alternative Fuels Div.	**National Renewable Energy Laboratory** 1617 Cole Boulevard Golden, CO 80401-3393 USA	303-231-1753
Teruo Yamauchi Sr. Manager	**Hitachi America, Ltd.** 34500 Grand River Ave. Farmington Hills, MI 48335 USA	313-474-2800
Akio Yasuda Senior Coordinator	**Toyota Technical Center, USA** 1588 Woodridge R.R. #7 Ann Arbor, MI 48105 USA	313-995-2600

END

DATE FILMED

3/11/94