PM 79-2959

E94X7/78AR2

DOE/ET/13046 --T18

PLAN FOR OBTAINING
DATA REQUIRED FOR RETROFITTING
BURNERS TO INDUSTRIAL FUEL GAS

Part I: TECHNICAL PLAN

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Submitted to
U.S. Department of Energy

by

Memphis Light, Gas and Water Division
P.O. Box 430
Memphis, Tennessee 38145

MASTER

Prepared by

Institute of Gas Technology
IIT Center
Chicago, Illinois 60616

for

Task IX-7. Distribution and Utilization
Characteristics of Gas Output

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ef

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1
2.0 OBJECTIVE	3
3.0 GENERAL INCENTIVES	4
4.0 STATEMENT OF PROBLEMS AND RESEARCH NEEDS	6
5.0 TECHNICAL BACKGROUND	8
6.0 SCOPE OF WORK	9
7.0 STATEMENT OF WORK	10
8.0 PROGRAM MANAGEMENT PLAN	12
APPENDIX A. Discussion of Technical Retrofitting Problems	A-1
APPENDIX B. IGT Qualifications and Facilities	B-1
APPENDIX C. Staff Biographies	C-1

1.0 INTRODUCTION

At the outset of Contract No. ET-77-C-01-2582, it was recognized that most but not all Memphis Light, Gas and Water (MLGW) industrial natural gas customers could use the product of the Industrial Fuel Gas Demonstration Plant. It was further recognized that, for some of the processes, retrofit information and performance data would have to be developed to make the change possible. Consequently, the program work plan includes "Task IX-7, Distribution and Utilization Characteristics of Gas Output." The purposes of this task are a) to determine which industrial customers and processes can use the output gas, b) to identify the required information and performance data necessary for the change, c) to develop the information and data not available from other sources, and d) to provide assistance to burner manufactures and current MLGW customers preparing to use the output gas.

The total scope of Task IX-7 and the level of effort required are a function of both the type and number of customers. This could not be determined prior to initiation of the contract; consequently, Task IX-7 was proposed as a two-part effort. Under the current contract, a preliminary evaluation of potential MLGW customers and their processes was funded and completed as the first step. This evaluation determined which customers and processes could use the output of the Industrial Fuel Gas Demonstration Plant. It also identified what information and performance data were needed to achieve the changeover.

The preliminary evaluation was based on the following:

1. All potential MLGW customers along the proposed distribution route were initially screened for feasibility of gas use, which was determined from MLGW records and limited customer contact. This initial screening determined which customers were most likely to utilize the product of the Industrial Fuel Gas Demonstration Plant. This determination was based on many factors, among which was the potential feasibility of technically retrofitting processes for necessary combustion performance.
2. The preliminary screening narrowed the utilization study to 21 "best" candidates. Each company was then visited and the processes in use were surveyed. This further survey provided the facts necessary for planning the required follow-up work. Each of the processes was categorized by IGT into one of three groups. The first group of processes was known to convert to a medium-Btu gas without the need for equipment changes, or with just small in-plant changes. The second group of processes required an analysis

of performance using available literature data. These processes would probably need some system change to achieve the required performance. The third group required experimental work to develop recommendations for necessary system changes to utilize the industrial fuel gas plant output.

The first evaluation step described above fully defines the total scope of the work needed under Task IX-7. We are now proposing to undertake the required, detailed evaluations as a further deliverable of Task IX-7.

2.0 OBJECTIVE

The overall objective of the gas utilization analysis proposed is to augment those activities leading to an "Industrial Fuel Gas (IFG) Demonstration Plant" as planned in MLGW-DOE Contract No. ET-77-C-01-2582.

The specific objectives of the work are -

- To identify what combustion-related problems will exist when using the product gas of an IFG Demonstration Plant to service proposed industrial customers and to provide information to equipment manufacturers needed to solve these problems by means of changes in process operating conditions or combustion equipment.
- To determine if process production rates and energy utilization efficiencies will change when retrofitting for a medium-Btu gas and to quantify the magnitude of such changes for the types of processes planned to be serviced by the demonstration plant
- To provide engineering information to assist the equipment manufacturers in determining what changes of combustion equipment must be made by the industrial customers in order to utilize the proposed medium-Btu gas
- To provide fuel utilization data and to assess the technical feasibility of supplying a standby or supplement gas that is compatible with the fuel gas product of the demonstration plant.

3.0 GENERAL INCENTIVES

Industry is caught between the requirements for cleaning up the environment and the need for decreasing (or eliminating) our current dependence on foreign sources of oil. Simultaneously, it is faced with a shortage of clean, environmentally acceptable fuels. For some industrial processes, coal can replace other fuels but environmental concerns make its use prohibitively expensive, if not impossible, because of the need to decrease sulfur emissions. For still other processes, technical combustion problems prevent the use of coal; only oil or natural gas can be used. However, much of this oil must be imported, which is against long-range Government policy. Natural gas is available to industry in limited quantities only, and these quantities are decreasing because of decreasing domestic production. (Coal still appears to be the only fossil fuel that is available in sufficient quantities to eliminate the necessity of importing oil and to augment the supply of natural gas.) Therefore, an environmentally acceptable and practical method of using coal must be developed and demonstrated. One method worthy of demonstration is conversion of coal to medium-Btu gases. This is the objective of the program being conducted by the Memphis Light, Gas, and Water Division cooperatively with the U.S. Department of Energy (DOE) and based on the U-Gas® Process developed by the Institute of Gas Technology.

The prime objective of the Industrial Fuel Gas Demonstration Plant Program is to demonstrate the feasibility of converting coal to fuel gas and utilizing the gas in commercial applications. Consequently, the acceptability of the fuel to the potential users is of major importance in the overall demonstration effort.

In addition to the price of a fuel, the industrial user is concerned with how much product can be produced with each Btu purchased. If more of an alternative fuel must be used (Btu consumed per unit of product produced) to produce industries' products than is necessary with their current fuel type, industries' energy costs will increase even if the alternative fuel is competitively priced. Consequently, the customer is concerned with such factors as combustion efficiency, process energy efficiency, and the "cost of use," which includes such items as changes in combustion equipment.

6/78

The work proposed herein will provide information to demonstrate utilization of the fuel gas process as a method to provide a fuel of acceptable cost and performance. In addition, this work will provide the technical information we believe will be requested by the customers.

4.0 STATEMENT OF PROBLEMS AND RESEARCH NEEDS

A considerable amount of technical information and experience is available on the utilization of low- and medium-Btu gases with compositions similar to that produced by the U-Gas Process. This information has been developed primarily by the steel industry over many years of using coke-oven gas (570 Btu/SCF) and blast furnace gas (95 Btu/SCF). This background enables designing furnace processes specifically for medium-Btu gas combustion which operate with similar performance and efficiency as obtained with a natural gas or oil-fired furnace. However, the available background data on the combustion of medium-Btu gases are not applicable for predicting performance changes when these gases are used in a furnace initially designed for natural gas or oil. In addition, background information is generally available for only those burner types used by the steel industry. Numerous industrial processes use completely different combustion conditions, flame shapes and sizes, and different heat release patterns. The overall result is that changes in the performance of many industrial processes cannot be predicted when these processes are retrofitted for operation using a medium-Btu gas. Accurate combustion and engineering data are needed to identify what performance changes will occur, to quantify the magnitude of potential changes and to solve problems associated with potential changes and potential decreases in performance or efficiency. The proposed program will provide the experimental information required to fill this data gap.

Some work is being conducted at IGT to fill this need. We are currently characterizing the combustion characteristics and performance of 8 burner types used for about 10 generic types of industrial processes using a range of low- and medium-Btu gases from 100 to about 300 Btu/SCF. This work is being sponsored by DOE under Contract EX-76-C-01-2489. Experimental work was started in April 1977 and spans a period of about 20 months. The data provided by this program will be useful in partially fulfilling the technical needs expressed in this proposal. Data will be available to predict performance changes and problems and to recommend solutions for such processes as rotary cement kilns, steel reheat furnaces, nonferrous metal melting, and large soaking pits for aluminum and steel. However, this program will not provide data for such processes as product drying ovens, process-oil heaters,

6/78

liquid heat exchangers, etc. The current DOE program also will not evaluate fuel performance for large commercial processes often classified as industrial, such as commercial bakeries, consumer food production, etc.

In addition to the current DOE program, IGT has completed an evaluation of the performance of large boilers retrofit to use low- and medium-Btu gases. This work was undertaken for the Electric Power Research Institute (EPRI) and the Environmental Protection Agency (EPA) over a 24-month period. The results of this study are now being made publically available. This information will enable the prediction of performance changes for industrial boilers which may be serviced by the demonstration plant, but again will only partially fill the needs of the demonstration effort.

5.0 TECHNICAL BACKGROUND

Very little is known about the radiation characteristics, gas/air mixing rates, combustion stability, etc., of industrial burners when operated on medium-Btu gases. Although we do know that significant changes in all these parameters will occur, currently we can only infer the significance of these changes on process performance and production rates from general combustion knowledge.

We anticipate that three major problems may be encountered when an industrial process is converted to use a medium-Btu gas. The first is a change in the radiation characteristics of the flame, resulting in a change in heat flux in the furnace and a change in the temperature of the combustion products entering any flue-gas heat-recovery system. The second potential problem, which will be discussed later, is a lack of flame stability. The third potential problem is major changes in flame length and possibly incomplete combustion.

Many combustion parameters can be predicted from experience and from empirical rules which are used by furnace manufacturers in the initial design of industrial equipment. However, they generally do not apply to the large changes that will occur when a furnace is converted from coal, oil, or natural gas to low- and medium-Btu gases. The influence of combustion parameters on retrofit is discussed in detail in Appendix A.

6.0 SCOPE OF WORK

The scope of work of this program is specifically designed to give the information necessary for the potential users to make informed decisions regarding the suitability of the industrial fuel gas (IFG) for use with their burners. The program includes consultations with burner manufacturers and combustion trials to determine the modifications necessary to produce stable flames of a proper size for two types of boiler burners. In addition, measurements will be made to determine changes in process efficiency resulting from conversion to the industrial fuel gas. Previous studies by IGT for the Department of Energy have shown that simply enlarging the fuel inlets to allow for the increased fuel flow can result in a 10% or greater reduction in radiant section heat transfer due to changes in flame size and shape affecting combustion intensity. An additional task involves evaluating a fuel as a potential "short term" replacement fuel for use during planned or unplanned gasifier outages. The fuel will be evaluated with regards to flame stability, furnace (boiler) efficiency, flame temperature, and proper flame size.

The results of these experiments and others conducted by IGT will be used to determine the proper burner modifications and to predict the furnace (and boiler) performance changes among the potential IFG customers.

Task 1 of the proposed work will involve evaluating the performance of the industrial fuel gas on two boiler burners of the types at the Buckeye Cellulose Corporation in Memphis, in order to obtain the data needed to verify the results of the study by Combustion and Controls Co., Inc. Task 2 involves evaluation of natural gas-air as a potential back-up fuel for the industrial fuel gas. Task 3 involves a study of the combustion equipment among the potential industrial fuel gas customers, determination of the burner modifications required, and prediction of the changes in combustion system performance if the necessary data exists. If the data is lacking, the appropriate tests will be recommended.

7.0 STATEMENT OF WORK

Task 1. Boiler Burner Evaluations

During this task, discussions will be held with the burner manufacturer to insure that the experimental methods result in the determination of the proper modifications necessary to utilize IFG on the ring and spud type boiler burners installed at the Buckeye Cellulose Corporation. These types of burners with a capacity of about 3 to 5 million Btu/hr will be installed, in turn, on the IGT pilot scale furnace and baseline data with natural gas will be taken at the rated capacity with an unmodified burner. This data will include:

1. Flue gas temperature
2. Flue gas analysis
3. Furnace efficiency
4. Flame length
5. Heat absorption profile
6. Average furnace gas temperature at 6 axial and 10 radial positions.

Data items 1 - 4 will be collected at low-fire also.

The preliminary modifications suggested by the manufacturer will then be incorporated and flame stability with the IFG will be verified. Initial data collected with the IFG will be the flame length measurement to insure that the modifications give the appropriate flame size and shape. If the flame is stable and of proper size throughout the burner firing range, the remaining data will be collected similar to the baseline data. If not, additional modifications will be attempted in consultation with the manufacturers. After the IFG data has been collected, additional measurements will be made to evaluate the "low-fire burner overheating problem" sometimes associated with manufactured gases. The fuel injection parts subject to furnace radiation will be fitted with thermocouples to determine if burner overheating will effect the minimum fuel flow rate at which the burner can be operated.

The results of this task will be recommended burner modifications made in consultation with the manufacturer and verified by combustion trials at the IGT Combustion Research Facility. In addition, comparative furnace performance measurements will be made between natural gas and the IFG. Measurements will also be made to determine if burner overheating will be a problem.

5/79

The flue gas analysis will also determine if there are potential carbon monoxide emissions problems.

Task 2. IFG Back-UP Fuel Evaluations

The proposed natural gas-air alternate fuel will be fired on the two boiler burners and evaluated for flame stability. If it exhibits a stable flame, the burner and furnace will be set up on IFG and changed over to the back-up fuel. Data items 1 - 6 listed under Task 1 will be collected. This data will show changes in excess air, furnace thermal performance, flame size, and flame temperatures. The results of this task will include a recommendation of the suitability of the proposed back-up fuel including comparative furnace performance.

Task 3. Study of Burner Modifications for Potential IFG Customers

This task will involve a step by step analysis of each potential IFG customer to determine the burner modifications necessary to use IFG. The burner manufacturers represented at each potential customer's location will be consulted by IGT and burner modifications will be recommended for each device if sufficient information is available for that particular burner. The results of previous IGT studies plus those of Task 1 and 2 of this study will be used to determine these recommendations. If modification recommendations cannot be made due to lack of data, the tests and experiments necessary to provide the appropriate data will be recommended. The results of this study will be recommendations for burner modifications and predictions of furnace (boiler) performance changes for each potential customer if the information is available. If not, the lack of specific data will be noted.

8.0 PROGRAM MANAGEMENT PLAN

The following is a description of the management plan and lines of responsibility IGT believes necessary to complete the proposed program.

8.1 Overall IGT Organization Structure

IGT has a line-and-staff organizational structure with direct lines of authority and responsibility from its president down through the working research levels. Administrative personnel are interested in and maintain an awareness of technical and fiscal progress on individual programs.

IGT is organized into three technical divisions, each headed by a vice president:

1. Engineering Research Division, which conducts basic and applied research in energy systems, economics, utilization, conversion, and conservation. Solar energy research and energy markets are primary technical areas of activity in this division.
2. Process Research Division, which conducts basic and applied research in chemical and hydrocarbon processing and process analysis.
3. Education Division, which provides educational programs leading to B.S., M.S., and Ph.D. degrees in conjunction with the Illinois Institute of Technology, and provides special professional courses on various energy topics in Chicago, nationwide, and at overseas locations.

The two research divisions consist of sections, groups, and special project teams, each having a specific role relative to an overall discipline. The vice presidents have full management responsibility for their respective divisions and are assisted by technical and administrative staffs. Group research directors are responsible for disciplines within the division, with research program managers leading individual projects. A division is, therefore, a task group in its broad discipline with management at internal levels to conduct either specialized or multidisciplinary activities.

Multidisciplinary activities are developed under the direction of a division vice president and are coordinated by a member of the senior technical staff. Programs of virtually any scope and size can be accommodated because project teams can be constituted of entire functional groups or individuals from such units, either within or outside of the parent division. This organizational structure is also designed to handle subcontractors as

integral parts of the project team. Subcontractors are treated as basic functional elements in which project responsibilities, scope, contractual relationship to IGT, and work plan are prescribed prior to project initiation.

Services (editing, reproduction, drafting, library, computer, etc.) are combined under the direction of a vice president to ensure responsiveness to the needs of the technical divisions through administrative control. Actual day-to-day services are prompt and thorough at all levels in the organizational structure.

The "informal organizational structure," which is present in all organizations, is complementary to, rather than competitive with, the formal structure at IGT. Cooperative attitudes prevail throughout the organization which facilitate the performance of high-quality and timely work.

8.2 Project Organization

This proposed project is a modification to and intergral part of DOE Contract NO. ET-77-C-01-2582. The current contractual work is being performed and managed by the Process Research Division of IGT. The proposed additional work would also be managed by the Process Research Division under J. G. Patel-Project Manager but functionally carried out by the Engineering Research Division under the overall direction of Dr. G. G. Mannella. An overall organizational chart for the proposed effort is presented in Figure 8.1.

8.2.1 Person-Power Schedule

The total technical effort of this project is estimated to be 3116 person-hours. Table 8-1 presents a breakdown by task and staff assignment.

8.2.2 Personnel Qualifications

This section provides a brief description of the key IGT Engineering Research Division personnel to be involved in the proposed effort. Detailed biographies of the individual staff members with past experience and publications lists are included in Appendix C.

- Cognizant Engineering Research Division G. G. Mannella
Officer Vice President
 Engineering Research

Dr. Mannella has technical administrative responsibility for IGT's research in alternative energy systems, energy conservation, solar applications, unconventional natural gas, energy conversion and

A78061644

Figure 8-1. PROGRAM ORGANIZATION

Table 8-1. PERSONPOWER SCHEDULE

	5/79	6/79	7/79	8/79	9/79	10/79
Task 1. Boiler Burner Evaluation						
Assistant Director	20	20	20	20		
Research Manager	48	48	88	88		
Engineer	80	40	160	80		
Senior Technician	80	80	160	80		
Editing	4	4	4	12		
Task 2. IFG Back-Up Evaluation						
Assistant Director				20	20	
Research Manager				40	96	
Engineer	40	40		128	160	
Senior Technician	80	80		160	160	
Editing				4	4	
Task 3. Potential Customer Studies						
Assistant Director	20	20	20	20	20	20
Research Manager	64	64	48	24	24	120
Engineer	120	80	80	40	40	80
Editing	4	4	4	4	4	24

energy storage. Prior to joining IGT, he was acting Assistant Administrator for Conservation at the Energy Research and Development Administration (ERDA) in Washington, D.C. where he was responsible for the formulation and management of the Federal research program in energy conservation. Programs under his direction include transportation, industrial and building energy conservation, conversion and storage technology and electrical energy systems R&D.

- Cognizant Engineering Research Division Dennis H. Larson
Technical Administrator Director
Energy Conservation Research

Mr. Larson has the overall responsibility for IGT's research activities in the area of energy conservation. This includes R&D activities on appliance development, industrial utilization, fuel combustion properties, pollution control, energy conservation systems development, and heating and cooling system developments.

Mr. Larson's specific areas of responsibility are programs to develop fundamental aerodynamic information for large industrial combustion systems using natural or low-Btu gases, energy-demand surveys for industry, development of a solar-gas combustion space-conditioning system, development of fundamental kinetic data relative to combustion, and an appliance assessment and development program promoting greater efficiency and less pollutant emissions.

- Cognizant Technical Manager Richard T. Waibel
Manager
Applied Combustion Research

Dr. Waibel has responsibility for management of IGT's research activities related to the utilization of fuels on industrial furnaces and burner equipment. He has managed programs dealing with the utilization of and pollutant emissions from low-Btu gases and a fluid bed heat transfer application program. In addition he has worked on projects involving combustion of coal-oil mixtures, novel design of radiant recuperators, and industrial energy conservation.

- Project Manager E. S. Fleming
Supervisor
Applied Combustion Research

Dr. Fleming has responsibility for supervising the research activities at the furnace research facility. Since joining IGT in January of 1977 he has supervised projects related to the utilization of low-Btu gases on industrial burner equipment and evaluation of pollutant emissions from low-Btu gases.

Prior to joining IGT, Dr. Fleming was a post-doctoral fellow in the Fuel Science section of the Material Sciences Department at the Pennsylvania State University.

APPENDIX A. Discussion of Technical Retrofitting Problems

When switching a furnace from one fuel to another, the thermal radiating properties of the combustion products change. For the particular fuel change from natural to medium-Btu gas, the radiation from the medium-Btu gas could be more or less than that from natural gas, oil, or coal combustion because the radiant flux from hot gases to a heat sink is directly proportional to the partial pressures or the concentration of water and carbon dioxide formed by combustion. In turn, the partial pressures of water and carbon dioxide in the combustion gases are a function of the fuel gas composition. The concentrations of these two radiating species can be calculated readily for a fully reacted mixture of fuel and air; and, hence, changes in the radiant characteristics of the combustion can be predicted theoretically. For example, Table A-1 shows the ratio of the concentration of carbon dioxide from a natural gas flame to that of three low-Btu-gas compositions fully burned with a stoichiometric amount of air. The same concentration ratios also are shown for water vapor.

Table A-1. RATIO OF CARBON DIOXIDE AND
WATER FROM NATURAL GAS COMBUSTION
TO THAT FROM LOW-Btu GAS COMBUSTION

	$\frac{\text{CO}_2 \text{ Nat Gas/}}{\text{CO}_2 \text{ Low-Btu Gas}}$	$\frac{\text{H}_2\text{O Nat Gas/}}{\text{H}_2\text{O Low-Btu Gas}}$
Lurgi-Air/Fuel Composition	0.826	0.892
Lurgi-Oxygen/Fuel Composition	1.160	0.76
Koppers-Totzek Oxygen/Fuel Composition	0.562	1.02

If the above ratio is less than 1.0, the concentration of water or carbon dioxide is higher when burning low-Btu gas of the composition shown than when burning natural gas. If the ratio is greater than 1.0, the concentration is greater when burning natural gas.

With these relative concentration numbers, the relative change in radiant heat flux can now be calculated theoretically. For example, with an appropriate preheat to produce a 3500°F flame, the combustion products from the gas produced by the new molten iron process (about 150 Btu/SCF) will radiate about 45% less to an industrial furnace load than the combustion products from

natural gas. (This large a decrease is an extreme case.) This simplified approach is often used when the concentrations of water and carbon dioxide change in a natural gas flame because of air/fuel ratio changes. However, this method of estimating radiation assumes that a well-mixed, fully combusted fuel is used. This is the case only with certain premix burner systems. Most industrial flames are quite different and exhibit large gradients in the water and carbon dioxide concentrations. A furnace seldom contains only combustion products. The "real" heat flux from flame to load is a composite of the heat fluxes from many areas of the flame, each having different concentrations of carbon dioxide and water. Although the above simplified method of calculating changes in radiant heat flux works reasonably well for a natural gas flame when changing the air/fuel ratio, it has been shown by our DOE program that the same will not work as well when switching from natural to low-Btu gases. The changes in the species ratio and the combustion pattern are much greater when changing fuels.

Another change that must be considered when switching fuels is flame temperature. For gases with low heating values, the flame temperature can be as much as 800°F lower than that for natural gas. The lower flame temperature significantly affects radiation from the flame to the furnace product load. The lower flame temperatures of a medium-Btu gas will mean decreased heat transfer in the furnace which creates many of the problems mentioned earlier.

As previously mentioned, a second potential problem with retrofitting is burner instability. The mass flows of fuel in a burner will be significantly higher with a medium-Btu fuel than with oil, or natural gas. In the above mentioned example, we estimate that the mass flow would be 4-times higher with a medium-Btu gas than with natural gas for an equivalent heat input. These much higher flows, combined with the very different burning characteristics of a medium-Btu gas, have been shown to produce combustion instabilities for many burners that could lead to flame outages or destructive resonance in a furnace or burner. For some burners, this will be no problem. For other systems, the burner may have to be replaced completely.

The third potential problem with retrofitting for a medium-Btu gas is flame size. When an existing furnace-burner combination is switched to a low-Btu gas, major changes occur in the size of the flame. Without changing

the existing burner, the flame generally decreases in length for fuel momentum controlled burners. The length of a turbulent diffusion flame is approximately equal to the burner heat input (h_v) times the burner nozzle diameter (L), multiplied by a constant, and divided by the mass flow rate (d). Therefore, when switching from natural gas to medium- or low-Btu gas, as the mass flow rate through a burner is increased to hold the furnace heat input constant, the flame length decreases. This is a well-known effect of changing to a lower-heating-value gas. It has been observed and measured both in experimental furnaces and in actual furnaces burning carbon monoxide, coke-oven gas, producer gas, and blue water gas, as shown in Figure A-1.

Figure A-1. L/d AS A FUNCTION OF HEATING VALUE OF FUEL

This change in flame length as a function of fuel-gas heating value and mass flow rate is important to the potential performance of a furnace. As flame length changes, the rate of heat transfer from the flame to furnace product load changes because the "path length" for radiation changes.

When changing fuel gas, the length of a flame can be held constant by changing burner design. However, changing burners can be a very costly procedure, requiring furnace shutdown for a considerable time. Therefore, prior to conversion to a medium-Btu gas, the furnace performance change should be calculated and the economics of the performance change compared with the cost

of conversion. If the situation requires new burners, these must be designed properly to prevent a change in flame length.

Predicting the performance change based on the change in flame length and redesigning the burner to maintain a constant flame length is a problem. Equations and experimental data that indicate that flame length will decrease when switching from natural to low- and medium-Btu gases are accurate only for an axial gas injection nozzle with a coaxial air flow. Many industrial burners use a swirling air flow and often partially radial gas injection. Although the trend to a shorter flame for lower-heating-value gases still holds, the extent of the change in flame length cannot be calculated from existing data. Industry must now rely on its limited experience with such gases as coke oven, blast furnace, and producer, together with engineering estimates. This program will provide data specific to a wide range of generic industrial burner types and gas compositions.

Redesign of the burner to control flame length is further complicated by the fact that flame length can be changed by changing the amount of air swirl. As the ratio of the tangential to the axial momentum flow components (swirl) of the air decreases, the flame length increases. Consequently, it may be possible to hold a fixed flame length when switching from natural to low-Btu gas by changing the air register vanes or baffles to decrease air swirl. However, here again an accurate relationship between flame length changes and air swirl changes for low-Btu gases must be determined.

Table A-2 further illustrates some of the problems that can be encountered when attempting to retrofit existing burners. The data were obtained for a ported baffle burner fired on a furnace simulating a steel reheat furnace. Note that in this case the low- and medium-Btu flame lengths are longer than the natural gas flames. This is the case because this burner is meant to be air-momentum controlled and the high momentum of the substitute fuel negates this effect. Also the thermal efficiency for the medium-Btu Koppers-Totzek oxygen fuel gas is surprisingly low. It can be attributed to the long flame length causing an inordinately high flue loss. The low efficiencies for the low-Btu gases might be expected but the performance of all these fuels could not have been accurately predicted in advance.

Table A-2. FURNACE AND BURNER OPERATING CONDITIONS

<u>Fuel Type</u>	<u>Fuel Flow, SCF/hr</u>	<u>Air Flow, SCF/hr</u>	<u>Fuel Velocity, ft/s</u>	<u>Air Velocity, ft/s</u>	<u>Flue Gas Temperature, °F</u>	<u>Volume Flow Flue Gas, SCF/hr</u>	<u>Flame Length, cm</u>	<u>Furnace[†] Efficiency %</u>
Natural Gas	5,140	53,960	43	151	2433	59,000	180	35
Koppers-Totzek Oxygen	20,100	42,800	168	120	2676	54,800	342	26
Wellman-Galusha Air	34,200	44,300	286	124	2300	71,800	302	23
Winkler Air*	44,500	44,000	372	146	2328	80,900	240	22

* Air preheat 850° rather than 650°F as used with other gases.

† Efficiency based on load divided by fuel input times heating value.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Appendix B. IGT Qualifications and Facilities

1. General Qualifications

The staff of IGT's Engineering Research Division is highly qualified to conduct the proposed work. As already mentioned, IGT is experienced in evaluating the performance of boilers, industrial, and commercial processes retrofit to use low- and medium-Btu gases. In addition, IGT has been involved in fuels utilization and combustion work for industry throughout its 35 year history. We are experienced in a wide range of research and engineering service types: spanning from fundamental combustion research to redesigning whole plants for the use of alternative fuels. Many of our previous programs have been conducted in-the-field on full scale process systems. Consequently, we are acutely aware of the real-world problems which must be considered both by the energy supplier and industrial user.

The following are specific examples of IGT's abilities in this area:

Industrial Energy Demand

IGT has participated in many of the Federal programs to identify and evaluate the energy use patterns of numerous industries. In addition, many of these types of studies have been conducted specifically for companies within more than 20 industrial groups. IGT staff has also performed numerous energy conservation and fuel substitution studies for various industrial clients, A.G.A., and Government agencies.* The industries have included copper and zinc smelting, aluminum manufacturing, glass plants, paper mills, and food processing. Some of our more recent programs include:

- Study of Industrial Uses of Energy Relative to Environmental Effects

IGT identified where and how energy is being used by 14 selected major industries including the area of steam generation; determined the relationships between energy use and environmental impact; and assessed the environmental impact of emerging energy technology.

- Industrial Furnace Efficiency Field Survey

IGT measured actual furnace and process energy efficiencies on a real-time basis. This information was used to project the national impact of new energy conservation technologies for EPA.

* Older work was done for ERDA, current work is for the U.S. Department of Energy (DOE).

- Die Casting Industry Energy Use Patterns Evaluation

IGT mapped energy use patterns of specific processes in die casting as input to the evaluation of the technical and cost effectiveness of conservation technologies.

- Metal Heat-Treating Industry Energy Use Patterns Evaluation

Technical work on this program was the same as that for the die casting evaluation in the preceding citation except that it was for the Metal Heat-Treating Institute.

- Metal Industry Energy Conservation Potentials Evaluation

IGT determined what conservation methods including fuel changes could be cost-effectively used by the metals industries (forging, heat-treating, foundry, etc.) and the national impact of these measures on energy consumption by 1985 for the FEA.

- Direct Coal Combustion Retrofitting Industrial Furnaces Impact

An assessment was made for ERDA by IGT of industrial processes that could be retrofitted to use coal directly as a fuel in an environmentally acceptable way. This study then projected the potential impact of using coal on the demand for natural gas and fuel oil.

- Integrated Aluminum Plant Energy Use Patterns Evaluation

IGT identified how energy was used in a typical aluminum plant (from bauxite production to finished product), projected energy requirements, and determined the feasibility of switching energy forms for private industry.

IGT has conducted numerous programs to assess, experimentally verify, and field evaluate the effects of converting industrial processes from one energy form to another. Long-range studies have been undertaken for private companies and the A.G.A. to determine the compositions of future fuels and their impact on burner designs. Studies of the effect on emissions of the major transfer to industrial fuel loads from natural gas to oil or coal are now being carried out for the EPA. Frequently, we carry out task assignments for individual gas utilities on fuel interchangeability calculations. Some of the more recent programs in this area have been:

- Evaluation of Boiler Performance Retrofit to Use Low-Btu Gases

An experimental study, funded by EPRI, was conducted to determine the performance of various types of utility boiler burners retrofit to operate on low-Btu gases. This work included an assessment of the boiler efficiency changes that would result for various furnace operating conditions. The program also involved redesigning the boiler burners to correct for any observed decreases in energy efficiency resulting from retrofitting for low-Btu gas.

IGT received a favorable questionnaire response, completed questionnaires accounting for 40% of total U.S. ammonia production output. IGT received frank

answers regarding make-or-buy decisions, prices or costs, concern regarding feedstock continuity, service curtailments and interruptions, expansion plans, and interests in alternative processes or feedstocks.

- Furnace-Combustion Performance Model Development

IGT designed, constructed, operated, and modified as necessary a pilot-scale test furnace capable of simulating a wide range of industrial processes. This furnace was then operated as a tool for developing mathematical models to relate heat transfer and flame aerodynamics of industrial furnace systems as a function of fuel type. This research was a cooperative effort supported by the A.G.A., EPA, and ERDA.

- Characterization of Pollutant Emissions From Low-Btu Gases Used for Industrial Processes

An experimental study was conducted for EPA to determine the pollutant emissions characteristic of industrial burners operated on low-Btu gases over a range of gas preheat temperatures. This program involved determining the combustion characteristics that needed to be changed to reduce emissions consistent with maintaining process efficiency. The required combustion-characteristics changes were then translated into hardware modifications that could be implemented practically.

- Industrial Processes Improved Natural Gas Utilization

IGT prepared a series of four seminar reports providing information to improve gas utilization efficiency in industry. Reports were published in the following areas:

- Steel reheating operation
- Air/gas ratio adjustments of combustion systems
- Forging operations
- Aluminum melting and reheating.

- Improving Process Efficiency Using Oxygen-Enriched Air

This program, sponsored by the A.G.A. and by private utility industry, involved the development of a system and operating method to boost furnace production and to increase energy utilization efficiency by using oxygen-enriched air. Early development work on a 3 million Btu/hr test furnace evolved into a 2-year full-field trial on a production glass-melting furnace. A major goal of this program was to assess process performance using gas, oil, and coal.

- Coal-Oil Fuels Retrofitability

This was a program to develop a burner capable of firing coal-oil slurries. This work involved a detailed evaluation of the combustion characteristics of coal-oil slurries and a formulation of recommendations for burner modifications to improve performance. The program was financed by Government funds from ERDA and by private industry.

- Industrial Burners and Prime Movers Combustion Products Analysis

Field and laboratory measurements were taken to evaluate literature data on pollutants from combustion processes and to provide new data where none existed, particularly for gas-fueled, total-energy systems, and turbines. Three types of systems were studied: industrial gas burners, gas engines, and gas turbines. Pollutant emissions measured included nitrogen oxides, hydrocarbons, high-molecular-weight hydrocarbons, carbon monoxide, aldehydes, and sulfur oxides. A major portion of this project consisted in collection, condensation, and critical review of published information on analysis of fossil-fuel combustion products.

- Large Industrial Non-Premix Burner Systems Scale Model

This theoretical and experimental project, sponsored by the A.G.A., has been in progress for the past several years. A mathematical design model has been developed for large diffusion gas combustion systems of the type used for high-temperature processes. To test the model experimentally and also to evaluate furnace design improvements suggested by use of the model, a scale model (8 million Btu/hr) of the combustion systems was constructed and operated at IGT.

- Glass-Melting Furnace Design

This project was conducted for an industrial sponsor to apply the above model to the redesign of an unusually large-capacity glass-melting furnace for which the empirical design based on prior experience failed to achieve the desired performance. This was accomplished; the performance of the furnace agreed well with that predicted by the model.

IGT has had a long-standing involvement in the analysis of stationary and mobile power units, particularly in fuel interchangeability.

- Community Advanced Coal Utilization Systems

In association with an engineering design subcontractor, IGT assessed the operating and economic characteristics of a wide variety of prime movers as part of the DOE study titled, "Advanced Coal-Using Community Systems." Operation of the following prime movers on coal-derived fuels was assessed:

- Diesel engines
- Gas engines (Otto cycle)
- Stirling-cycle engines
- Closed-Brayton-cycle turbines
- Open-Brayton-cycle turbines
- Steam turbines (including back-pressure and extraction)
- Alternative Rankine cycles (including organic compounds and liquid metals)
- Fuel cells
- Fluidized-bed boilers.

IGT conducted extensive technical and economic feasibility assessments of alternative fuels for automobile transportation, on the programs:

- Natural-Gas-Fueled Vehicles

IGT converted and operated one of the first automobiles to run on natural gas and gasoline interchangeably. Studies were performed on the safety of natural gas as an automobile fuel for a gas utility company and on the emissions and logistics involved in widespread use of natural-gas-fueled vehicles for the National Air Pollution Control Administration.

- Automotive Transportation Alternative Fuels Feasibility Study

Under contract from EPA, IGT conducted an extensive technical and economic feasibility assessment of alternative fuels for automotive transportation. IGT performed the following work:

Identification and characterization of potentially feasible and practical alternative fuels that can be derived from domestic, nonpetroleum energy resources

Technical and economic assessments of the most promising alternative fuels for three specific time frames

Identification of pertinent fuels and research data gaps and recommendations for alternative fuel(s) to best satisfy future U.S. automotive transportation requirements.

To apply the methodology of alternative fuel selection to a reasonable number of fuels, IGT studied 16 fuels and 12 potential domestic energy sources for fuel synthesis in this program:

<u>Energy Sources</u>	<u>Fuels</u>	
Nuclear fusion	Hydrogen	Carbon monoxide
Uranium and thorium	LPG (synthetic)	Coal
Coal	Methanol	Distillate oils
Shale oil	Methylamine	Ethanol
Tar sands	SNG	Gasolines (C ₅ -C ₁₀)
Solar radiation	Ammonia	Heavy oils
Solid wastes (garbage)	Naphthas	Vegetable oils
Animal wastes	Acetylene	Hydrazine
Wind power		
Tidal power		
Hydropower		
Geothermal heat		

- Hydrogen-Fueled Vehicles Survey/Assessment

IGT is currently conducting an ongoing study involving a survey and assessment of the progress on solving problems associated with the introduction of hydrogen-fueled vehicles. The work includes continual monitoring of work on hydrogen production and delivery systems, hydrogen-fueled engine development, vehicular on-board hydrogen storage and delivery, and the operational and safety aspects of hydrogen-powered vehicles. Both United States and overseas developments are monitored.

- LNG Aircraft Fuel Utilization

IGT's involvement with LNG in the early 1960's led to detailed LNG study as an aircraft fuel and for other potential markets, the technology and economics of the LNG industry, technical considerations pertaining to the use of LNG to fuel supersonic and subsonic aircraft in the commercial sector, and military potential for LNG in fixed-wing aircraft and helicopters. Aircraft storage and fueling problems, fuel supply infrastructure costs, and fuel standards were all analyzed. Additionally, the R&D programs for methane-fueled prime movers and a strategy for utility industry participation were documented.

IGT has been actively involved in developing means to reduce energy losses from industrial processes and to reuse currently wasted energy. Major programs in this area include the following:

- Improved Industrial Recuperator Development and Field Evaluation

This is an ongoing program involving the development of a new industrial heat-recovery system concept and associated redesign of industrial burners for preheated air operation. The program included the development of a mathematical model that enables designing full-scale hardware. The mathematical model was tested experimentally and was found valid through the use of a 20-foot prototype recuperator specially designed for this purpose. A full-scale field demonstration is now underway with Federal support from and in cooperation with a major aluminum producer.

- Improved Utilization Efficiencies

This was a 3-year study entitled "Improved Utilization Efficiencies for Industrial Processes - Implementation of New Technology." The program involved a detailed evaluation of a number of diverse technologies for conserving energy. Its purpose was to find technically and economically attractive methods that could be developed by further research. Areas considered included:

Improvements in insulation, specifically skid-rail insulation for a steel reheat furnace

Improving dual fuel burner designs, specifically gas/oil and natural gas/low-Btu-gas burners

Improving burner combustion efficiency by using electric fields

Evaluation of novel industrial radiant burners with high efficiency characteristics

Development of novel heat recovery and reuse techniques

Cogeneration opportunities.

- Industry-Government Cooperative Energy Conservation Program

The objective of this 3-year study is to identify opportunities to conserve fossil fuel and electric energy forms for selected energy-intensive industries and to conduct full-scale field evaluations of the most promising technologies.

- Utilization of Off-Peak Power to Produce Industrial Hydrogen

IGT developed and demonstrated an analytic methodology for use by electric utility companies in evaluating regional markets for off-peak-produced hydrogen. The project report, written as a guide for utility companies, included the following major sections:

Markets, which discussed current and projected uses of hydrogen and likely market price situations. This section also presented market opportunities for oxygen.

Economics of Hydrogen Production, Storage, and Transportation, which provided baseline data for regional utilities to calculate the cost of electrolytic hydrogen for a specific situation and to compare that with the cost of alternative hydrogen production. This section also addressed oxygen storage and transportation costs.

Methodology, which described, through specific examples, how to calculate a hydrogen production cost and matching that with a likely market price. The methodology emphasized the uniqueness of individual utility situations and the necessity of providing the individual utility with the ability to perform its own regional analysis.

A mail survey of ammonia producers, the principal users of hydrogen, was conducted to obtain information on requirements, make-or-buy, prices and costs, supply situations, and outlooks.

2. Available Technical Facilities

In addition to the above experience base, IGT also has most of the facilities required by the proposed effort. These include two existing test furnace facilities, a third furnace under design, and a facility to generate the medium-Btu gas needed. The existing furnace facilities have been previously used to model many different furnace types using fuels such as coal, natural gas, low-Btu gas, oil, and mixtures of coal and oil. These furnace facilities also have instrumentation systems capable of measuring a full range of combustion conditions and performance.

IGT's combustion facilities meet a necessary criterion of permitting an accurate scale-up of results to full-sized systems. One furnace has a 4.5 X 4.5 cross section and is 14 feet long. It can accommodate inputs up to 5 million Btu/hr and furnace temperatures of up to 3000°F. This facility has previously been used to model a variety of processes, including a utility boiler, an industrial cement kiln, and a production glass-melting furnace. In these cases, combustion data from IGT tests with natural gas were successfully correlated with the flow patterns of flame and combustion products as determined from tests of full-size units conducted later by others. The second furnace, the barrel furnace, is cylindrical, has a diameter of 4 feet, and is 20 feet long. This furnace can

accommodate fuel inputs of up to 6 million Btu/hr. This facility currently is also being used to model various industrial heating processes with a wide range of generic burner types. Combustion data for all types of fuels were collected and evaluated in much the same way that this program proposes to obtain data on low-Btu-gas fuels. IGT's new furnace will be similar in size and capacity to our current rectangular furnace except that it will have increased flexibility of operating to simulate various industrial processes.

The proposed program would use primarily the rectangular furnace for testing, but will also use other furnaces for some specialized tests. All furnaces are equipped to preheat combustion air to about 1000°F, burn fuels with up to about 40% excess air, and the rectangular furnace can recirculate flue products. All furnaces have ports located along the length of the furnace in one sidewall so that the flames can be photographed or various probes can be inserted into almost any part of the furnace interior.

2.1 Description of Furnace Test Facility

IGT has a pilot-scale furnace which is 14 feet long and has a cross-sectional area of 21.3 sq ft. The facility can be used for firing burners rated up to 6 million Btu/hr. Combustion air temperatures up to 1000°F can be generated with a separately fired air preheater.

The furnace is also equipped with 58 water cooling tubes, each of which can be independently inserted through the roof, along the sidewalls. Varying the number of tubes, their location, and the depth of insertion allows control over the magnitude and character of the load that can be placed on the furnace. The amount of heat absorbed by each tube can be determined by measuring the water flow through each tube and the temperature difference between the inlet and outlet. The water temperature measurements are made with a Vertronix digital thermometer. The stated accuracy is 0.25°F. These measurements were checked with a mercury-in-glass thermometer, accurate to 0.1°F, and were found to agree within 0.2°F. A temperature difference of 25° to 60°F is maintained between the water inlet and outlet. This helps minimize the effect of temperature measurement error on the heat balance. The water flow rate from each tube is determined by measuring the time to fill a bucket of known capacity. The time is measured using a quartz digital stopwatch.

In addition to the combustion air preheater, a separately fired fuel preheater for gaseous fuels is available that can heat 12,000 SCF/hr of low-Btu gas to any desired temperature up to 800°F. Temperatures up to 1200°F are attainable with lower flow rates.

The overall system, shown in Figure B1, has the flexibility to independently vary —

- Fuel firing rate
- Air input
- Furnace load
- Air preheat temperature
- Fuel preheat temperature.

There are 33 panels or "sampling doors" along one sidewall that allows insertion of probes at any axial position from the burner wall to the rear wall.

2.2 Description of Instrumentation

On this furnace it is possible to measure temperature profiles, thermal radiation from the flame, flow direction profiles, and furnace-gas composition. Modified designs of the International Flame Research Foundation were used to construct probes that enable this type of data collection.

Temperature data are collected using a suction pyrometer; the design is illustrated in Figure B2. A Pt/Pt-13% Rh thermocouple is used. The efficiency of the pyrometer was monitored and was better than 95% with a 15-second response time.

The flow direction is measured using a water-cooled Hubbard probe, with the upstream and downstream pressure taps connected to a Datametrics Barocel transducer and Datametrics CGS electric manometer.

Figure B3 shows the assembly drawing of the gas-sampling probe used in the flame and the flue. To minimize NO_2 losses, the probe is water-cooled stainless steel joined to a Teflon sample line. At the end of the probe is a section of Teflon tube heated to 190°F , followed by a Millipore filter and a Permapure gas dryer. This dryer reduces the dewpoint to less than 32°F . In the dryer, water is the sample gas diffuses through a thin membrane into a stream of dry nitrogen. Tests have shown that only water is lost from the sample stream.

The analytic instrumentation equipment consists of the following items:

- Beckman 742 Polarographic Oxygen (O_2)
- Beckman Paramagnetic Oxygen (O_2)
- Beckman NDIR Methane (CH_4)
- Beckman NDIR Carbon Monoxide (CO)

078CF-897

Figure B1. OVERALL FURNACE SYSTEM

Figure B2. ASSEMBLY DRAWING OF THE SUCTION PYROMETER

A77071466

B-12

A77071508

Figure B3. ASSEMBLY DRAWING OF GAS SAMPLING PROBE

- Beckman NDIR Carbon Dioxide (CO₂)
- Varian 1200 Flame Ionization Chromatograph (Total HC and C₂ to C₉)
- Beckman NDIR Nitric Oxygen (NO)
- Beckman UV-Nitrogen Dioxide (NO₂)
- Thermo Electron Pulsed Fluorescent Sulfur Dioxide (SO₂)
- Hewlett-Packard Thermoconductivity Chromatography, Hydrogen (H), Nitrogen (N₂), Argon (A₂), CO, CO₂, CO₁ to C₅, Oxygen (O₂)
- Beckman Chemiluminescent NO-NO₂
- RAC Model 2414 Staksamplr, EPA Method 5 for flue gas particulate loading
- Anderson 2000 High Temperature Cascade Impactor for particle size distribution.

To evaluate radiation intensity, which is needed for determination of radiant flux and flame emissivity, we use either a Hycal thermopile type radiometer or Pyroelectric radiometer, manufactured by Molelectron Corp. in Sunnyvale, California. The PR-200 radiometer uses a permanently poled lithium tantalate detector that is capable of resolving radiant power in the nanowatt range while maintaining a continuous spectral response from the vacuum UV to 500 μ m. A built-in optical calibration system, in the form of a highly stable LED (light-emitting diode) that is calibrated against an NBS traceable standard of total irradiance, permits a direct correlation of experimental data from different trials.

A unique system to supply a range of low- and medium-Btu gases is also available at the IGT facilities. This facility has been used to evaluate the performance characteristics of utility power boiler burners with low-Btu gases and is currently being used for the DOE program on industrial burners. The unit currently has the capacity to deliver about 3.5 million Btu/hr of gases of various compositions and heating values.

The current availability of IGT staff members with the requisite expertise, our large, proven experimental furnace and instrumental capabilities, and our low-Btu gas generator are a unique combination of qualifications.

APPENDIX C. Staff Biographies

G. G. Mannella
D. H. Larson
R. T. Waibel
E. S. Fleming

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

GENE G. MANNELLA, Vice President, Engineering ResearchPresent Duties

Dr. Mannella is responsible for the management of the engineering research division, which includes major programs in alternative energy systems, energy conservation, solar applications, unconventional natural gas, energy conversion, and energy storage.

Professional Experience

Dr. Mannella joined the staff of IGT in 1977. Prior to coming to IGT, he worked for 1-1/2 years as acting Assistant Administrator for Conservation at the Energy Research and Development Administration (ERDA) in Washington, D.C. There he was responsible for the formulation and management of the Federal research program in energy conservation. Programs under his direction included transportation, industrial and buildings energy conservation, conversion and storage technology, and electrical energy systems research and development.

Prior to working with ERDA, Dr. Mannella was Associate Administrator for research and development at the National Highway Traffic Safety Administration of the U.S. Department of Transportation (DOT). From September 1971 to December 1972, he was Dean of the School of Engineering and Architecture at the Catholic University of America.

Dr. Mannella joined the staff of the National Aeronautics and Space Administration (NASA) at the Electronics Research Center (ERC) in Cambridge, Massachusetts, in 1964. There he participated in the task force which established ERC and eventually became Director of Advanced Technology. When that facility became the Transportation Systems Center of the DOT, he held the position of Director of Technology until 1971.

Education and Professional Activities

Dr. Mannella received a B.S. in chemical engineering from Case Institute of Technology in 1953, and an M.S. and Ph.D. in chemical engineering from Rensselaer Polytechnic Institute (RPI) in 1956. He performed post-doctoral research at RPI for 4 years in the field of reaction kinetics and upper atmosphere chemistry under the direction of Professor Paul Harteck.

Dr. Mannella has been a member of numerous professional societies and the Cosmos Club of Washington, D.C. He was the head of the U.S. section on automobile

transport of the joint U.S. - USSR working group on transportation. He has appeared as a witness at numerous Congressional hearings, published extensively, and has appeared on a number of television programs, most recently the MacNeil-Lehrer Report broadcast on electric vehicles. Dr. Mannella holds the NASA Apollo Achievement Award, the NASA Certificate of Appreciation, the DOT award and medal for Distinguished Service, and the ERDA award for Superior Performance. He also received the W. O. Jump award for contributions to the education of retarded children.

DENNIS H. LARSON, Director, Energy Conservation ResearchPresent Duties

Mr. Larson has the overall responsibility for IGT's research activities in the area of energy conservation. This includes R&D activities on appliance development, industrial utilization, fuel combustion properties, pollution control, energy conservation systems development, and heating and cooling system developments.

Mr. Larson's specific areas of responsibility are programs to develop fundamental aerodynamic information for large industrial combustion and conservation systems using natural or low-Btu gases, energy-demand surveys for industry, development of a solar-gas combustion space-conditioning system, development of fundamental kinetic data relative to combustion, and an appliance assessment and development program promoting greater efficiency and less pollutant emissions.

Experience at IGT

Mr. Larson joined the staff of IGT in 1966 as a chemical engineer. In this position, he was responsible for research programs involving the formation of oxides of nitrogen in gas flames, the development of the Eternal Flame at the John F. Kennedy gravesite, appliance research to develop new concepts in oven design, and the development of safe practices for handling liquefied natural gas.

From 1968 to 1971, Mr. Larson was supervisor of applied combustion research. In this capacity, he was responsible for programs to develop new methods of melting glass and new high-speed cooking concepts, to control oxides of nitrogen emissions from commercial heating equipment, and to control flames and increase heat transfer in cement and lime kilns. He also conducted fundamental studies on gas combustion properties.

From 1971 to 1974, Mr. Larson was responsible for research activities to aerodynamically control nitrogen oxides emissions from industrial combustion systems, to utilize low-Btu gas in industrial processes, to relate current national energy demands to future demands, and to develop a wide range of new systems to conserve energy in industrial and commercial applications.

Education and Professional Activities

Mr. Larson received a B.S. in chemical engineering from Illinois Institute of Technology in 1965.

Mr. Larson is a member of the American Institute of Chemical Engineers, The Combustion Institute, the American Institute of Ceramic Engineers, and the Industrial Gas Council.

Publications and Patents

"Industrial Energy Conservation - Overview/National Objectives," D. H. Larson. Paper presented at the Energy Action Symposium - Engineers Week Committee, Chattanooga, Tennessee, February 23, 1978.

"Supply and Utilization of Alternate Fuels for Industry," D. H. Larson and D. P. Gregory. Paper presented at the Eastern Section 1977 Fall Meeting of The Combustion Institute, Hartford, Connecticut, November 10-11, 1977.

"New Development in Gas Technology," D. H. Larson. Paper presented at Consumers' Gas Company/Sales Marketing Conference, Toronto, Canada, May 15-16, 1977.

"Interchangeability Index: Calculation and Application Limitations," D. H. Larson. Paper presented at the American Gas Association Distribution Conference, New Orleans, Louisiana, May 2-4, 1977.

"Direct Combustion of Coal for Glass Melting," D. H. Larson. Paper presented at the Peoples Gas Company Glass Roundtable, Greentree, Pa., April 13-14, 1977.

"Association Role in Energy - Alternate Energy Resources," D. H. Larson. Paper presented at the Annual Meeting of the American Die Casting Institute, Chicago, October 9, 1975.

"How to Melt More Metal With Less Energy," D. H. Larson, Mod. Met. 31, 55-71 (1975) June.

"Monitoring Stack and Other Emissions," D. H. Larson and M. E. Fejer. Paper presented at the 1975 Plant Engineers and Maintenance Conference, Chicago, May 7, 1975.

"Problems of Industrial Utilization of Low- and Intermediate-Energy Gas," D. H. Larson. Paper presented at the Conference on Industrial Utilization of Gas From Ohio Coal, Battelle Memorial Laboratories, Columbus, May 6, 1975.

"Methods to Reduce Gas Consumption in Forging Operations," D. H. Larson. Paper presented at Seminar No. 5 of the East Ohio Gas Energy Management Conference, Cleveland, May 1975.

"Interchangeability of Natural and Substitute Gases," D. H. Larson and M. Scott. Paper presented at the Gas Appliance Engineers Society Meeting, Chicago, April 9, 1975.

"Conserving Energy in the Manufacture of Container Glass," D. H. Larson. Paper presented at the Canadian Glass Association Meeting, Toronto, January 22, 1975.

"Improving Natural Gas Utilization in a Continuous End Port Glass-Melting Furnace," D. H. Larson and M. E. Fejer, J. Can. Ceram. Soc. 43, 87-94 (1974).

"Improving Efficiency in Reheating, Forging, Annealing, and Melting," D. H. Larson, M. Fejer and J. D. Nesbitt. Paper presented at the Industrial Efficiency Seminar, A.G.A. Marketing Conference, Atlanta, March 5-7, 1975.

"Combustion and Heat Transfer in the Aluminum Industry," D. H. Larson. Paper presented at the Combustion and Flame Management Workshop sponsored by The Aluminum Association, Inc., Cleveland, March 4, 1975.

"Industrial Fuels of the Future," D. H. Larson. Paper presented at the Symposium on Efficient Use of Fuels in the Metallurgical Industries, Chicago, December 9-13, 1974.

"Study of Industrial Uses of Energy Relative to Environmental Effects," D. H. Larson and M. E. Fejer, Publ. No. EPA-45013-74-044. Durham, N. C.: Environmental Protection Agency, July 1974.

"Recuperative Waste Heat Recovery," D. H. Larson, Precis. Met. 32, 28-31 (1974) June.

"Low-Btu Gases as Industrial Process Fuels," D. H. Larson. Paper No. 17 in Efficient Use of Fuels in Process and Manufacturing Industries. Chicago: Institute of Gas Technology, April 1974.

"Direct Combustion of Coal for Glass Melting," D. H. Larson and M. Fejer. Paper presented at the Peoples Natural Gas Glass Round Table, Greentree, Pa., April 13-14, 1974.

"Industrial Utilization Research - Its Importance and What Is Being Done," D. H. Larson. Paper No. 4, Session VII, in Proc. Third Conf. Nat. Gas Res. Technol. Chicago: Institute of Gas Technology, March 1974.

"Aerodynamic Characteristics and Pollution Emissions From Scaled Industrial Burners," D. H. Larson and D. R. Shoffstall. Paper presented at the 66th Annual Meeting of the American Institute of Chemical Engineers, Philadelphia, November 14, 1973.

"Energy Conservation Possibilities for the Glass Industry," D. H. Larson. Paper presented at the American Gas Association Industrial Marketing Conference, Tulsa, November 12-14, 1973.

"The Combustion Interchangeability of Natural and Substitute Gases," D. H. Larson and M. Scott. Paper SPE 4716 presented at the Eastern Regional Meeting Society of Petroleum Engineers, Pittsburgh, November 5-9, 1973.

"Improved Utilization of Industrial Natural Gas - Improving the Utilization of Existing Technology and Development of New Technology," D. H. Larson. Paper presented at the 1973 Industrial Marketing Conference - Consolidated Natural Gas Service Co., Inc., Youngs West Sheraton Inn, Youngstown, Ohio, October 4-5, 1973.

"The Application of Oxygen Enrichment and Precise Burner Positioning to Glass Furnaces," D. H. Larson and M. Fejer. Paper presented at the Leone Industries Applications Seminar, Bridgeton, N.J., September 25, 1973.

"Improving Glass-Melting-Furnace Operation Using Improved Combustion Control Methods," D. H. Larson and M. Fejer. Paper Am. Gas Assoc. Cat. No. L10373 presented at the Energy Action Today Seminar, Chicago, August 27, 1973.

"Projections of Energy Demand by the Iron and Steel Industry," D. H. Larson. Paper presented at the Energy Conservation Through Effective Utilization Conference, New England College, Henniker, N.H., August 19-24, 1973.

"Aerodynamic Control of Combustion Processes to Control the Formation of Oxides of Nitrogen," D. H. Larson and D. R. Shoffstall. Paper presented at the Central States Section of The Combustion Institute, Urbana, Ill., 1973.

"Gas Applications in Glass," D. H. Larson. Paper presented at the Chartered Industrial Gas Consultant - Phase III Meeting, Chicago, October 9-20, 1972.

"Improved Fuel Efficiency in Glass Melting" D. H. Larson. Paper presented at the Ford Motor Co. Technical Conference, Nashville, October 12, 1972.

"Emission of Pollutants From Natural Gas and Oil-Fired End-Port Glass Melter," D. H. Larson, J. D. Nesbitt and M. E. Fejer. Paper presented at the First American Flame Days Conference, Chicago, September 6-7, 1972.

"Improving Natural Gas Utilization in a Continuous End-Port Glass-Melting Furnace," D. H. Larson, J. D. Nesbitt and M. E. Fejer. Paper presented at the Second American Gas Association-Institute of Gas Technology Conference on Natural Gas Research and Technology, Atlanta, June 5-7, 1972.

"Muffle-Type, Gas-Fired, Self-Cleaning Oven," E. R. Kweiler, R. B. Rosenberg and D. H. Larson (assigned to the Institute of Gas Technology), U.S. Patent 3,612,032 (1972) October 12.

"Burner," R. B. Rosenberg and D. H. Larson, U.S. Patent 3,516,773 (1970) June 23.

"Fundamental Studies of Furnace Systems Using Preheated Air and Non-Premix Burners," D. H. Larson, R. B. Rosenberg and A. Kardas. Paper presented at the Gas Symposium for Ohio Industry, Columbus, May 14-15, 1969; published in Gas Heat Int. 18, 449-59 (1969) December.

"The Different Effects of Flame Chemistry on the Formation of Ethylene and the Oxides of Nitrogen in Flames," R. B. Rosenberg, S. A. Weil and D. H. Larson, Am. Chem. Soc. Div. Fuel Chem. Prepr. 13, No. 1, 137-51 (1969) April.

Fundamental Studies of Furnaces Using Non-Premix Burner Systems," R. B. Rosenberg and D. H. Larson. Paper presented at the American Gas Association Research, Utilization, and Marketing Conference, Washington, D.C., February 23-26, 1969.

"Instrumentation for Measurement of High-Temperature Natural Gas Fired Furnace Parameters," D. H. Larson and A. K. Mitra, Special A.G.A. Report, Am. Gas Assoc. Cat. No. M54569. Arlington, Va.: American Gas Association, 1969.

"Environment Control," R. B. Rosenberg, M. Y. Longley and D. H. Larson, Spec. Inst. Gas Technol. Chicago Rep. Am. Gas Assoc. Project HC-4-14, (1968) May.

"New Knowledge of the Flame," R. B. Rosenberg, R. V. Serauskas and D. H. Larson. Paper presented at the American Gas Association Research, Utilization, and Marketing Conference, Washington, D.C., February 25-28, 1968.

"New Ideas for Weatherproof Torches," R. B. Rosenberg, D. H. Larson and W. Degran. Paper A.G.A. Cat. No. M32573 presented at the American Gas Association Research, Utilization, and Marketing Conference, Denver, July 17-19, 1967.

"Results of A.G.A. Study Yield Faster, More Uniform Glass Melting," R. B. Rosenberg, D. H. Larson and A. Kardas. Paper A.G.A. Cat. No. M32571 presented at the American Gas Association Research, Utilization, and Marketing Conference, Denver, July 17-19, 1967.

"Formation of Nitrogen Oxides in Aerated Methane Flames," R. B. Rosenberg and D. H. Larson. Paper presented at the American Gas Association Basic Research Symposium, Chicago, March 14, 1967.

6/78

RICHARD T. WAIBEL, Manager, Applied Combustion Research

Present Duties

Dr. Waibel has responsibility for management of IGT's research activities related to the utilization of fuels on industrial furnaces and burner equipment. He has managed programs dealing with the utilization of and pollutant emissions from low-Btu gases and a fluid bed heat transfer application program. In addition he has worked on projects involving combustion of coal-oil-mixtures, novel design of radiant recuperators and industrial energy conservation.

Professional Experience

Dr. Waibel joined the staff of IGT in 1975 and was appointed supervisor of the furnace research facility. In 1977 he was appointed Manager of Applied Combustion Research.

Prior to coming to IGT, Dr. Waibel was a senior research engineer at the Melting and Forming Division, Glass Research Center, PPG, Industries, Creighton, Pennsylvania. There he was a member of the Furnace Models Group and the glass forming process development team. He had primary responsibility for developing and evaluating waste heat recovery methods for glass melting furnaces. In addition, he evaluated alternative fuels and assisted in trouble-shooting problems related to combustion and heat transfer at PPG's glass plants.

Dr. Waibel had previously been a post-doctoral fellow at the Fire Science Centre, University of New Brunswick. There he studied fire spread through natural and simulated fuel beds in addition to radiative heat transfer in furnaces.

Education and Professional Activities

Dr. Waibel received a B.S. and a Ph.D. in fuel science from The Pennsylvania State University.

Dr. Waibel is a member of The Combustion Institute and is IGT's representative on the American Flame Research Committee.

Publications

"Development of Combustion Data to Utilize Low-Btu Gases as Industrial Process Fuels - Special Report No. 1, Forward-Flow Burner Type," R. T. Waibel, for U.S. D.O.E. Contract No. EX-76-C-01-2489, March 1978.

"Burner Design Criteria for NO_x Control from Low-Btu Gas Combustion: Vol. II, Elevated Fuel Temperature," D. R. Shoffstall and R. T. Waibel, EPA-600/7-77-0946, December 1977.

"Some Characteristics of Fires Within Uniform Fuel Matrices," F. R. Steward, L. J. Wuest and R. T. Waibel. Paper presented at the A.I.Ch.E.-ASME Heat Transfer Conference, Salt Lake City, August 15-17, 1977.

"Boiler Burner Design Criteria for Retrofit with Low-Btu Gases," D. R. Shoffstall and R. T. Waibel. Proceedings of the Second Stationary Source Combustion Symposium, EPA-600/7-77-073C, July 1977.

"Burner Design Criteria for Control of NO_x From Natural Gas Combustion," D. R. Shoffstall and R. T. Waibel. Paper presented at the Central States Section of The Combustion Institute, NASA Lewis Research Center, Cleveland, March 28-30, 1977.

"Some Observations on Fire Spread Through Uniform Fuel Matrices," R. T. Waibel and F. R. Steward. Paper presented at the 1974 Fall Meeting of the Eastern Section of The Combustion Institute, Silver Springs, Maryland, November 1974.

"Combustion of Thermoplastic Polymer Particles in Various Oxygen Atmospheres: Comparison of Theory and Experiment," R. T. Waibel and R. H. Essenhigh. Paper presented at the 14th Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, 1973.

"Fire Spread Through Uniform Fuel Matrices," F. R. Steward and R. T. Waibel. Western States Section Meeting of The Combustion Institute, WSCI 73-3, Tempe, Arizona, 1973.

"Requirements for the Characterization of Coal Chars for Combustion," R. T. Waibel and R. H. Essenhigh. Paper presented at the Pennsylvania State University Seminar on Characterization and Characteristics of U.S. Coals for Practical Use, Pennsylvania, October 25-28, 1971.

"Combustion of Polymers at High Oxygen Concentrations," R. T. Waibel and R. H. Essenhigh. Paper presented at the 161st American Chemical Society National Meeting, Los Angeles, March-April 1971.

EDWARD S. FLEMING, Supervisor, Applied Combustion Research

Present Duties

Dr. Fleming joined the Applied Combustion Group of IGT in January 1977. His responsibilities include supervision of low-Btu gas combustion research and kinetic studies of combustion systems with emphasis on NO_x .

Professional Experience

Prior to joining the staff of IGT, Dr. Fleming had been a post-doctoral fellow at the Department of Mineral Industries, Fuel Science Section, Pennsylvania State University. There, he studied the chemiluminescent emissions from low-pressure diffusion flames of barium metal vapor with various oxidizers.

Education and Professional Activities

Dr. Fleming received a B.S. in chemistry from the University of Scranton and a Ph.D. in physical chemistry from Boston College.

Dr. Fleming is a member of the American Chemical Society.

Publications

"Electronic Transition Photon Yields From Reactions of $\text{Ba}_{(g)}$ with O_2 , O_3 , N_2O , and NO_2 ," E. S. Fleming and H. B. Palmer. Electronic Transition Lasers, J. I. Steinfeld, ed., 70-74, Cambridge, Mass.: MIT Press, 1976.

"Kinetics of Low Pressure Hydrocarbon/Fluorine and Hydrogen/Chlorotrifluoride Flames," E. S. Fleming, J. M. Smist, and D. I. MacLean. Paper presented at 169th National American Chemical Society Meeting, Philadelphia, April 1975.