Education in Fuels and Combustion: Needs for the Future and the Pennsylvania State University Program

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INTRODUCTION

Fuels Science and Engineering is a wide ranging topic that has been described as the interdisciplinary subject par excellance. The total scope is often divided into three prime topics: Production of fuels; Fuel preparation and Benefication; and Utilization. Production covers mining of coal, and petroleum and natural gas reservoir engineering. Preparation covers cleaning, crushing, grinding, and related aspects of coal benefication, with refinery engineering and related operations for oil and gas. Utilization is the facet that fuels education most commonly focuses on, and is primarily concerned with combustion and related uses of all fuels in all applications. The proper content of fuels education is discussed in more detail below: the broad scope of the study of fuels from the scientific to the engineering aspects is often titled Fuel Technology*.

PERSPECTIVE

To the outsider viewing Fuel Technology in the context of todays energy famine it must surely appear to be the subject of greatest technical importance in the curriculum of any university or similar training institute. Such a view is not supported by the facts, however. Fuels education is in a curiously anomalous position. Although fuel technology has been a rewarding subject for study and application for many decades -- one might even say, centuries -- it has still never had the academic prominence or even recognition of other technologies such as chemical engineering, metallurgy, ceramics, and so forth. There are believed to be less than half a dozen universities or institutes in the world with formal academic programs leading to degrees in Fuel Technology. Fuel Science, or Fuels Engineering, and the numbers, in fact, have been declining. There is likewise no central recognized platform or journal for the total range of the topics of concern in Fuel Technology. Interest is scattered over many semi-specialized Society divisions and journals. In a word, Fuel Technology does not, at present, have the recognition of being a formal academic discipline with a formal body of knowledge (even though this exists) that practitioners should know if they are to claim the authority of speaking as fuel technologists. Only in specialized cases such as power and propulsion systems (a minority branch of fuel technology) does something like a formal training exist. Industrial principles and applications, which represent over 40% of national energy use, are mostly unknown and untouched. Industry has therefore had the habit in the past, partly by default, of appointing fuel engineers, managers, supervisors, or controllers, from those in the ranks of other engineering professions such as chemical, metallurgical, ceramic, and mechanical engineering.

The problem has been that since fuels was everyone's business, it was no-one's business. In each individual segment of industry the topic of fuel use was essentially an appendage, with individual solutions to very similar problems being developed in the different process sectors -- ferrous and non-ferrous operations, glass, ceramics, refinery stills, cement manufacture, and so forth.

*"Technology" is used here in the same sense as in M.I. of Technology, or C.I. of Technology, etc.

In university curricula, where process metallury and ceramics, and the like, are still thought to be important, fuels are discussed mostly in the context of the single industry. In the other engineering areas, emphasis tends to be solely on power systems and, as observed by Smith and Stinson (1) 25 years ago: "It has been (our) observation that the general treatment of fuels and combustion is many times slighted in engineering curricula, even though the combustion process is a vital link in power cycles. Frequently the topics of fuels and combustion are presented, in part, through courses in steam power, internal-combustion engines, heating and ventillating, and laboratory, with little coordination or continuty of the material presented in the various courses. The result many times is an incomplete coverage of either fuel technology or combustion, and usually a meager concept is obtained of the actual chemical processes of burning." This observation would still seem to be substantially true. Only in the propulsion specialties (gas turbines and rockets) would there seem to have been any significant change.

This fragmentation of fuel technology, however, does not seem to have been too significant in the past; it would be hard to say that industrial development has really been hindered by this. So does it matter for the future? The answer would seem to be a decided: Yes! The pattern of the distant industrial past was a generally accelerating use of fuel, initially of wood and charcoal and subsequently of coal, during which there was ample time (decades) for the most part to develop necessary techniques by essentially untrained inventors and developers (who often became highly skillful by on-the-job training). The pattern of the more recent past (the last 50 years) was then a process of further industrial development based, first, on oil, then on gas. The trend was to more easily used and proportionately cheaper fuels. A return to coal or coal-based fuels means reversing that trend. The fuels will be more expensive and more difficult to use. It is not simply a matter of reverting to past technologies. The use of oil, and particularly gas allowed (largely ad-hoc) improvements in precision of firing furnaces: temperature control, metering, burner cycling, and so forth; and operators will continue to expect, or demand as essential, similar precision and ease of firing. The scale of the problem, in terms of fuel tonnages consumed has also increased: total energy consumption has almost quadrupled in the last half century. There are also environmental constraints that makes return to coal so much more difficult.

As a result of this pattern, there is indeed evidence now of an increasing demand for fuels specialists with a much higher level of education. The past practice of on-the-job training (which led to many re-inventions of the wheel) can be expected to disappear. It takes too long; it can leave too many gaps in knowledge; it is likely to be too specilized which makes for inflexibility; and there is usually time only to attain a relatively elementary level of understanding that can be far short of what is required today.

The demand must increasingly be met by training at the university level, but this presents several problems. There are too few schools at present with even a pretence at a reasonable coverage of the field of knowledge that can be called Fuel Technology, and these schools are almost unknown to large sections of industry, to other universities, and to virtually all prospective students. There is even ignorance in some academic quarters of what academic or formal training coverage can be provided in the field of fuel technology so that plans to expand course coverage can be held up or will be incomplete on account of that lack of knowledge, and lack of necessary teaching manpower. (This, further, ignores the present constraints on university funding that makes curriculum enlargement difficult to impossible in may cases.)

It is understood that this Meeting (on Fuels Science and Engineering Education) at which this paper is presented is designed to develop solutions to these problems. In this paper, contributions to three aspects are presented.

WHAT IS FUEL TECHNOLOGY?

The broad scope of fuel technology (or science and engineering) is outlined in the Introduction. It can be summarized as: the study of fuel in science and practice. For the development of curricula, something with greater precision and more detail is required for setting the boundaries to the field and for identifying individual subject or topics.

Fuel technology is broadly concerned with the utilization of fossil fuels and of their manufactured and related dervatives, including the process of manufacture of the secondary fuels (by gasification and liquefaction). It should also include some degree of study of the sources and reserves of coal, oil, gas, and other potential fuels (including shales, tar sands, solid waste, etc.). Also significant are the physical and chemical properties, methods of analysis, chemical structure, and methods of preparation (cleaning, drying, grinding, distillation, screening, etc.).

Utilization is still the core of fuel technology. This means: producation of power; use for processing; and secondary fuel manufacture for ultimate use as gas, liquid, or solid, in power and processing. Utilization depends on knowledge of fuels reactivity -- Reaction Kinetics applied to solid, liquid, or gaseous fuels. It also requires applied knowledge of fluid mechanics (combustion aerodynamics) and heat transfer (mainly radiative). Specific technological subjects of importance that represent application of fundamentals include, in particular: flame chemistry; flame propagation theory; carbon and coal reactions; reactor and flame holding theory; furnace analysis; radiative properties of flames; and scale-up methods for pilot plants.

These topics are set in schematic perspective in Figs. 1 and 2. Figure 1 illustrates the overall process of utilizing fuel to deliver a useful end product. Input includes knowledge of fuel and raw material sources, preparation, and supply to the reactor. Output lists power, process use, manufactured fuels, and effluents. Reactor operation, or requirements for understanding their operation, is illustrated in Fig. 2, which shows the relationship between the basic sciences and their engineering application.

Supplementary to the above, training in fuel technology must also include such sufficient understanding of the power and process operations themselves that the mechanical and other aspects of the furnaces and engines makes sense. This brings in such additional topics as: heat engine thermodynamics; furnace thermodynamics; refractory behavior and selection; heat treatment principles (with emphasis on the iron/carbon diagram); and effluent control (such as, air pollution from combustion sources).

Fuels Education at Penn State

In spite of the wide ranging scope of Fuel Technology, at the Pennsylvania State University all aspects are covered in one Department or another. Relevant Departments or Sections include Chemical Engineering, Mineral Processing, Petroleum and Natural Gas, Mining, Mineral Economics, and the Fuels Science Section of Materials Science and Engineering with some combustion and power aspects in Mechanical Engineering. In addition, the Coal Research Section is a research and administrative unit that ties together a number of closely related research activities on coal and carbons.

Most of the teaching and research activities, however, are centered in the Fuel Science Section of the Materials Science and Engineering Department. The original program started nearly 50 years ago in the Department of Fuel Technology, essentially as an outgrowth of graduate courses in coal carbonization and fuel utilization in the Department of Metallurgy. Over the period 1921-1931 these original courses developed into an Option in Fuel Technology, in that Department, with undergraduate instruction in fuel testing and calorimetry, coking, classification of coals, liquid and gaseous fuels, carbonization and processing of coals, and combustion and utilization of solid, liquid, and gaseous fuels. The strength of this option was such that, in 1932, a separate Department of Fuel Technology was created, granting simultaneously both undergraduate and graduate degrees (B.S., M.S. and Ph.D.). In the years since then, a total of 180 students have graduated with the bachelors degree, 83 with the masters degree, and 115 with the Ph.D.

About 10 years ago the undergraduate curriculum was closed because of very low enrollment. It was then obvious to everyone, except for the faculty in the Fuel Technology Department, that there was no further future in coal, and little further need for fuel technologists dealing with utilization of oil and gas. Reflecting that view, the State Legislature dropped support of a special coal research funding program. In industry, fuel was so easy to burn and so cheap that no special knowledge was required for its (inefficient) use. It is symptomatic of those times that, as remarked above, fuel engineers in industry were almost universally drawn from the ranks of the other engineering professions, without training in fuels, and with little awareness of the body of knowledge that did exist in fuel technology; and this, to some extent, is still the case today.

In 1969, the first (predicted) shortages in interstate pipeline gas supply showed up. In 1970-1971, the (predicted) peaking of native oil supplies from the lower 48 states also occurred. The timing on contraction of support for fuels education was clearly superb. Since then, the well-known controversy has been raging whether the fuel shortages are real or the result of some conspiracy. Wtih the understanding that this is a real problem, the question of what is needed in fuels education is reopened with dramatic force. The central significance of the problem derives from the central significance of energy in driving the industrial machine and modern civilization, and the awareness that without fuel you are out of business.

In spite of the dropping of the undergraduate program, in time for the start of the fuel shortages, (more accurately, the program dropped us), senior level and graduate programs nevertheless continued. In the early years, all the work the Department, both undergraduate and graduate, was focussed almost entirely upon coal and coal-related topics -- what might be called, without prejudice, coal technics. Following World War II, however, the scope of all programs was enlarged to cover the classical range of fuel technology topics: focussing on utilization, but with coverage increased to include gaseous and liquid fuels, and on materials derived from fuels, notably carbons and graphites. Coal preparation and beneficiation that were part of the original Fuel Technology Department program were moved about that time into a new Department of Mineral Preparation.

About the time of the demise of the undergraduate curriculum, the original Department of Fuel Technology ceased to be a Department, and was absorbed (with a small name change) as the Fuel Science Section in the (new) Department of Materials Science and Engineering.

The current scope of the teaching activities in the Fuel Science Section is illustrated by Table 1 which lists, with brief descriptions, the present course offerings of the Section. (The 400 numbers are senior-graduate courses, and the 500 numbers are graduate courses). There are presently 7 faculty in, or associated with the Fuel Science Section (several of whom also have additional teaching reqirements in materials and related subjects). There is also a related course in coal petrography (Geol. 421). There are also other closely related courses on combustion, gas turbines, and more conventional mechanical engineering courses on power plants, thermodynamics, and so forth, in other departments. Including aspects of petroleum production and refining, mineral economic aspects and related topics, there is a total of some 15 to 20 courses available at the senior and graduate levels that can be properly defined as part of Fuel Technology.

The research interests are of even wider scope. These include studies of gas/carbon reactions, gasification of carbon and coal, liquefaction of coal, fuel cells, and solar energy converters. The research has been described in about 450 research papers in the past 20 years.

Fuels Education in the Future

If Fuel Technology is sufficiently important for the future, the pattern of the past would suggest that new programs can be expected to come into being, with courses covering part or all of the material outlined in the Section defining Fuel Technology. A decade ago this would already have happened and new Departments would have come into existence. That this has not yet happened is almost certainly due to a number of factors. The most obvious has been lack of funds. There has also been uncertainly as to the real nature and scope of the fuels problem, and uncertainly over the real Federal commitment towards fuels. The topic has lacked activists in the manner of the Environmental Spokesmen of a decade ago -- after all, fuels have been with us a long time: isn't it really a simple problem, and don't we already know all we need to know? Energy activists have tended to promote nuclear electric (which must always be a minor energy source) or new developments in solar, geothermal, and the like. Also, there has not been a recognized combustion engineering community or Institute to speak for the fuels area as a whole.

A more suble problem derives from the current small size of the fuels community. A program that will attract students, and supporters, must be visible, credible, and viable. Without the existence of a widely-recognized academic discipline a single Department of Fuels lacks visibility, which makes recruiting difficult. The program can also lack credibility: "If it's as important as that, why aren't there more Departments?" is a good question. Without more Departments, the subject is barely viable. It was on these grounds that M.W. Thring on becoming Professor of Fuel Technology at Sheffield University (England) in 1950 immediately entered (successful) negotiations to have the Department recognized as a joint Department of Chemical Engineering.

Counters to these three problems are now forthcoming. The problem of visibility (and significance) was partly solved by the belated recognition by the Network News Anchor men that an energy problem of some sort really did exist. Credibility will appear when a number of fuels departments, options, centers, programs, or sections come into being: this will also confer the necessary viability to the academic programs.

The necessary centers would already appear to be in embryonic existence. This has been established in the following way. We have carried out a search of

the listings on fuels and fuel-related courses in the Course Catalogs of Universities in North America. We have identified a total of about 500 such courses offered in about 120 Universities. Although this averages 4 courses per University about half only offer 3 courses or less. About 1/3 of the courses are offered by only 14 institutions, each offering 9 or more such courses. These Universities are identified in Table 2 together with the total number of courses they offer. Table 2 also shows two other columns. In the Course indentification, all conventional (though necessary) courses in transport phenomena, heat transfer, reaction or chemical kinetics, power systems thermodynamics of heat engines, and the like, were omitted. Topics on industrial combustion engineering, flames, propulsion, combustion aerodynamics, pollution from combustion, and so forth, were included. In a first breakdown of the total, the established engine, gas turbine, propulsion, and related power and aerospace topics were designated as a Group II. Subtracting from the total leaves Group I (listed in Table 2), which are mostly the more industrially oriented combustion, pollution, and fundamental flames courses. Inspection of these then shows that fuels and combustion was evidently the major topic in some courses, but was of minor or secondary interest in the rest. Group IA in Table 2 is the number of courses identified as having fuels and combustion as the major topic (within what could be identified by the course descriptions).

Before discussing the breakdown, some caveats and disclaimers are in order. Course offerings of most universities were examined, but not all (we were unable to obtain the Harvard University Catalog, for example). The discrepancy between course description and course content is well known and requires no comment. Selection of the courses (or their omission) involved a value judgement that was difficult to exercise in quite a number of cases, particularly where course descriptions were vague, wide ranging and cut across several topics; members of individual universities may well make a somewhat different selection. The breakdown does not differentiate between senior level courses (that can indicate strength in teaching) from graduate level courses (that can indicate strength in reasearch). A clear pattern nevertheless exists. There is evidently a core of about a dozen Universities with strength in fuels or fuel-related activities. About half are more engine or propulsion oriented (Cal Tech, Michigan, Purdue, Wayne State in particular). The other half are more fundamentally/industrially oriented, or showing equal weight with engine/propulsion aspects (notably Penn State, Georgia Tech, IIT, MIT).

It would appear, then, that a Fuel Technology and Combustion Engineering community and constituency does exist. There can be a question as to how it should grow. There are constraints: funding or the lack of it is the most important, but there is also a shortage of manpower. What else could happen if the subject has been short-changed for so long? It is also not clear whether the center of gravity of Fuel Technology properly lies in the mining, mechanical, chemical, or even metallurgical or some other engineering area. Perhaps the best means of expanding Fuels programs would be by creating Options or Minors in Fuel Technology inside existing Departments of different disciplines. This would not overload the available manpower, and would either provide time for an evaluation of the subject matter to see where it best lies or it would solve the problem by having a different bias -- mechnaical, or chemical, or some other -- in different institutions. This may prove indeed to be the only feasible method of providing adequate coverage of the whole area of Fuel Technology. In course of time, such Options and Minors might expand into Sections inside the parent Department, and ultimately the Sections could become Departments. An organic growth based on real need rather than a forced growth based on expectations is obviously a preferred behavior. It is probably not necessary or even desirable for this to be accompanied by the development of the usual paraphanalia of Departments, rigid

curricula, Institutes, Journals, and the like, so long as there are sufficient centers of Fuel Technology that recognize each other and whose standing is acknowledged and made use of. The criteria of visibility, credibility, and viability must be met.

CONCLUSIONS

A coherent, significant, and important body of knowledge representing Fuel Technology does exist, together with a practical reason for its existence. Between half a dozen and a dozen Fuel Technology centers also exist already, at least embryonically. An academic framework for the necessary instruction and research also exists. It would seem that Fuel Technology is ready to come of age and to be recognized as a significant academic and practical discipline in its own right.

Reference

1. Smith, M.L. and Stinson, K.W., "Fuels and Combustion", McGraw Hill, 1962.

Acknowledgements

Preparation of this paper was made possible by support of the Combustion Laboratory Cooperative Fund (Contributors: ALCOA, Combustion Engineering, General Electric, General Motors, Gulf, Mobil, Pittsburgh Plate Glass, Phillips). The selection and compilation of the Fuel Technology courses offerings used as the basis for Table 2 was carried out by Dr. E. Gootzait.

Table 1

Courses in Fuel Science

F.Sc. 421 Flames. Fundamentals of premixed and diffusional combustion.

F.Sc. 422 Combustion Engineering. Principles of industrial combustion and gasification engineering.

F.Sc. 424 Energy and Fuels in Technological Perspective. Critical examination of present-day energy technology.

F.Sc. 430 Air Pollutants from Combustion. Pollutant-forming processes; pollutant potential of various fuels and combustors; combustion modification and pollution control.

F.Sc. 431 The Chemistry of Fuels. Origins and properties of the fossil fuels: coals, oils, gas. Coal liquefaction and gasification.

F.Sc. 506 Carbon Reactions. Heterogeneous reactions of carbons. The scientific base for coal gasification.

F.Sc. 512 High Temperature Kinetics and Flame Propagation. Equilibria and rate processes in hot gases; flames; detonations.

F.Sc. 520 Thermodynamics and Kinetics of Fuel Efficiency. Thermodynamic and kinetic constraints on efficiencies of thermal systems; efficiency ratios; furnace analysis; radiation in furnaces, applications and examples.

F.Sc. 522 Flame Dynamics in Combustors. Analysis of mixing and reaction in high intensity combustion chambers.

Table 2

Number of Course offerings in Fuel Technology at Different Institutions

T - total Course offerings in Fuel Technology

I - Courses on flames, combustion, pollution, etc., and non-engine or propulsion topics

IA - as the major subject

	T	I	IA
Cal Tech	12	5	3
Cincinnati	9	8	8
Georgia Tech	16	13	11
IIT	10	8	7
MIT	13	9	7
Michigan	12	6	3
Minnesota	9	4	4
N. Carolina State	9	4	3
Penn State	20	17	16
Princeton	10	7	7
Purdue	10	4	1
Stevens	8	7	4
Utah	14	14	12
Wayne State	10	7	5
Totals	162	113	91

Note: A total of 500 courses in Fuel Technology were identified offered at 120 different universities and similar teaching institutions. About half offer only 3 courses or less. The 14 institutions listed above offer about 1/3 of all the courses.

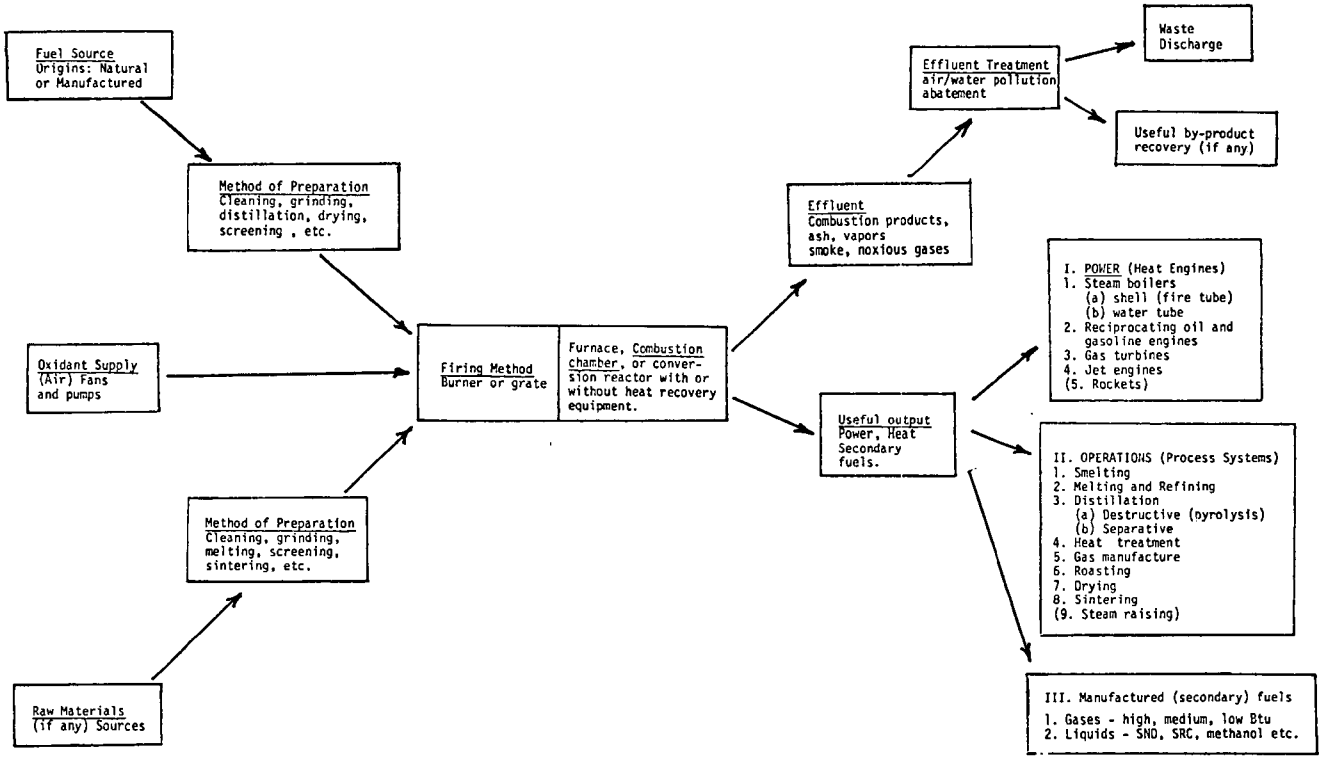

Fig. 1 - Schematic Representation of a Combustion Engineering Operation with Principal Applications (Useful Output)

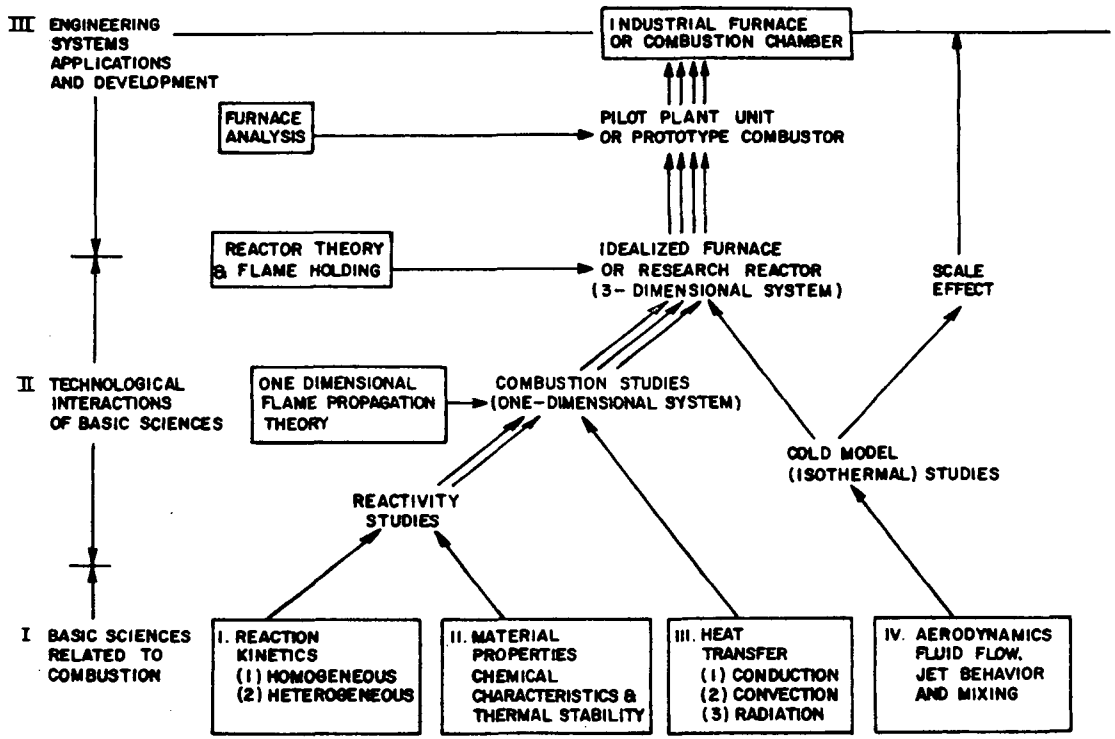

Fig. 2 - Schematic breakdown to illustrate the information flow required for a complete understanding of industrial furnace or combustion chamber behavior. Understanding rests on the four basic sciences: I, Reaction Kinetics; II, Materials Properties; III, Heat Transfer; IV, Aerodynamics. The diagram also illustrates the general relationship between science, technology, and engineering.