Domestication of Anaerobic Decomposition

in

The People's Republic of China

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Preface

For people around the world interested in the decentralized development of sustainable agricultural and renewable energy systems, reports about the spread of biogas digesters that began to filter out of China in the late 1970's came as a great inspiration. Although later reports have clouded the original over-optimistic visions, the reality of the situation remains most impressive. Broad research, development and implementation efforts continue and it is still safe to say that over 95% of the world's active digesters are in China.

This author has followed the Chinese efforts in the literature since they began to become available. In the Summer of 1987, as part of a University of Pennsylvania research program, it was finally possible to visit and see some of the efforts in person. Although the area visited, Henan Province, is perhaps at the northern boundary of applicability for China's elegantly simple, unheated digesters, the efforts and facilities there may be seen as somewhat representative of the broader efforts. The following presentation, while founded upon the now large volume of literature on the Chinese biogas efforts, is composed primarily of information and impressions gained during the all too brief six week visit.

I. A Brief Intoduction to China with Emphasis on Energy and Agriculture

China is the world's third largest nation and has included more or less the same geographic area for the last 2000 years. The one billion plus human inhabitants is by far the world's highest national population. About 80% of the population lives in rural areas and about one half of the total comprises the labor force.(Hinrichsen, 1986) The annual per capita GDP is generally reported to be a bit under $300. This figure, however, gives a very poor representation of the relative standard of living because basic human needs are generally available at extremely low costs. Perhaps a better [statistical] idea of the quality of life can be extrapolated from the figures for life expectancy--67.4 years (up 26.7 years since 1950-55); infant mortality--38/1000 (down by two-thirds since 1960-65); and literacy--88% enrollment in primary and secondary schools.(Hinrichsen, 1986) Although a Gini Coefficient is not available, one definitly gets the impression of a very equal distribution of assets and income.

Since Liberation in 1949, China has followed a rather zig-zag path of development, varying between an emphasis on ideological purity during the early and late 1950's and the Cultural Revolution of 1966-76, and a more economically based practicality in the mid-1950's, early 1060's, and since the end of the Cultural Revolution. Emphasis on the development of the agricultural sector and lighter industry seems to correlate with the latter periods (Hsu, 1982), while heavy industry development was the major theme of the former.

Currently, emphasis is on the Four Modernizations--agriculture, industry, national defense, and science and technology. The principal themes for the 1980's are the rational integration of planned and market economies, administrative and economic controls, centralization and decentralization, state and collective sectors, new and existing facilities, domestic and foreign resources, and short- and long-term considerations.(Fingar, 1980) While the Communes, forcibly imposed in the late 1950's, were officially ended in 1986, many villages and production units (factories, research institutes, etc.) still maintain many communal aspects. [Party members head all production units and each village has its party secretary. Extensive yearly reports by these secretaries form the basis for the large amount of statistical information available in China] The primary national thrust at this time is overwhelmingly toward a personal and family responsibility "contract system." The key phrase from Chairman Deng is that "To Get Rich Is Glorious."

Having such a large land area, China is blessed with large quantities of natural resources which, relative to the U.S., they have only begun to exploit. China is now the world's fourth largest producer of fossil fuels (after the U.S., U.S.S.R. and Saudi Arabia) and is a net exporter.(World Bank, 1983) China is also the world's third largest consumer of fossil fuels (after the U.S. and U.S.S.R.) but the huge population results in a per capita usage of only about 18 gigajoules/year (as compared to the U.S. and Indian figures of 273 and 7 respectively).(Hinrichsen, 1986)

Fingar (1980) suggests that China's current leaders and economic theorists [brainwashed, this author would suggest, by short-term, neo-classical economics] extol the "economics of scale" and the need for construction of conventional, fossil fuel and nuclear [two plants under construction] energy systems. While many around the world may think of a "Chinese Model" of small, decentralized development, Fingar suggests that the current leaders are "bemused" by this outside representation and tend to be unreceptive or even hostile to suggestions that China follow a soft energy path. [Fortunately, or hopefully, the momentum of past, decentralized efforts and the appropriateness of many of the technologies developed will likely carry over until the true "economy of scale," with its exponentially increasing environmental and social costs curves, is more widely recognized.]

The State Energy Commission was established in 1980. Its general plan seems to be to use coal domestically while saving petroleum for export. (Fingar, 1980) Although this body has innumerable other responsibilities, a primary emphasis has gone toward energy conservation and improving the efficiency of all energy use.

While China is beginning to develop off-shore oil reserves, most of the fossil fuels are found toward the north and west of the country. Also, while China has the world's largest hydropower potential, most of this is in the south and west (and only 3% has been developed). Transportation is thus a problem. There is a very reliable and intensively used rail system, and many of the two-lane roads connecting major population centers are in the process of being expanded to four lanes. Still, distribution of commercial fuels to most rural areas continues to be problematic and biomass fuels are used extensively, providing 80-90% of rural household energy requirements. (National, [1985]; Mahin, 1986; Taylor, 1987)

While forests are generally reported to cover about 12% of the land area (Li, 1987), much of this is in inaccessable areas with lower population densities. Primary sources of wood fuel appear to be orchards, some small woodlots, trees planted in association with agriculture, and peripheral plantings around villages and along roads. If the areas visited in 1987 are at all representative, the number of tree plantings over the last ten to twenty years must be several times the current human population. In spite of these efforts, the fuelwood supply is far from sufficient and crop residues--

stalks and straw--currently provide over 50% of the biomass energy consumed in rural areas.(Taylor, 1987)

Total range and pasture lands cover about 58% of China's land area. Only about 15% of the total area is suitable for agriculture and about 45% of this land is irrigated.(Fingar, 1980) The arable land amounts to only about 7% of the world's total and yet China is now self-sufficient in food production. (Hinrichsen, 1986) This author's primary impression from several trips through he countryside is one of millions of hectares of intensively managed garden with extensive practice of agroforestry, inter- and over-cropping. Tractors appeared to be used almost entirely for transportation, all field work being done by animals and humans. [The latter certainly seems appropriate since there would be little emplowment available for such a huge population were it to be "released" from the land by industrialized agricultural methods.]

Average agricultural production has more than doubled since the mid-1960's and China is now the world's second largest food producer. Production continues to increase as state controls are relaxed and personal incentives increase. While organic fertilizers still provide the majority of plant nutrients, Chinese farmers, with just over one-half as much arable land as the U.S.(Hinrichsen, 1986), are now using nearly an equal amount of chemical fertilizers.(Brown, 1987) Given the water pollution caused by chemical fertilizer use in the U.S., one must wonder about the effects of these much higher rates of application.

Perhaps the most amazing thing about Chinese agriculture in general is that much of the land cultivated today has been cultivated almost continuously for many centuries. Given the effects of continuous agriculture on soil and the only recent advent of chemical fertilizer, the continuous productivity of these lands over many generations must be attributed to the careful husbandry and recycling of all residual organic matter [although they could just be lucky]. In the absence of anaerobic digestion systems, orgainc residues are still composted in piles or put in exposed pools to ferment before being taken to the fields.(Chen, [1981])

To properly appreciate the importance of the Chinese biogas program, it is useful to briefly review the benefits of organic matter in agricultural soil. While situations may vary, and increase in the level of soil organic material generally includes the following effects:(largely after Brady, 1984, and Parr, 1983)

-- Soil color is darkened.

-- Water infiltration, holding capacity and content are all increased. Concomitantly, drought susceptibility, erosion and resulting sedimentation, and nutrient runoff and leaching resulting in eutrification of water bodies are all decreased.

-- Aeration, permiability and pore size are increased and bulk density is decreased.

-- Soil structure is improved through encouragement of granulation and aggregation while crusting, plasticity and cohesion are reduced.

-- More plant nutrients are held in rooting zones. Cation exchange capacity is increased. More nutrients are held in organic forms and more mineral elements are released by the action of humic acids.

-- The pH buffering capacity is increased.

-- Soil biota increase in both number and variety, thus offering a greater opportunity for biological control of soil-borne pathogens.

-- Due largely to increased moisture retention, soil temperatures tend to decrease. This decrease is somewhat mitigated by increased absorption of solar energy through darkening color and increased metabolic activity in the soil.

China's large population has always provided the labor force necessary for this recycling system. However, the population has grown tremendously in the last few decades [due largely to declining death rate], and the associated increase in household energy requirements are taxing the traditional system. Although cases abound, the following two examples give some idea of the situation.

The Yellow River is China's second largest and is "Yellow" because of its traditionally heavy silt load. This river's drainage area now experiences far the greatest erosions problems in the world.(Hinrichsen, 1986) The settling of suspended materials in slower moving areas over the centuries has resulted in a multitude of floods and has necessitated the construction of a tremondous system of dikes. At some points the current river bottom is thirty feet above the surrounding agricultural plains. The river's headwaters lie in a deep loess plateau where sod is now dug up and burnt for cooking energy needs. (Taylor, 1987)

On the plains, often from 70-80% of crop residues are now used for household fuel (Taylor, 1987), and soil organic matter content is generally less than 0.8%.(Li, 1987) In a three year study, it was found that the yearly addition of only 750 kg. of stalks per hectare increased production every year. Had the entire Provincial population followed this path, production in Henan would have been increased by five billion kg. over the time of the study.(Li, 1987)

All of the preceeding is to briefly make the point that two of China's [and many other countries'] most pressing needs are the supply of adequate household energy, especially for cooking in rural areas, and the build up and maintenance of organic matter levels in agricultural soils. Crop and animal residues could be recycled if external energy, largely coal, could be brought in but there are numerous environmental and other costs. Composting of residues allows recycling of organic materials but the energy released by the process, while potentially useful for space heating, is not appropriate for cooking.

The residues could be processed thermochemically or burnt directly to produce energy, but essentially nothing would be left for return to the soil. While specific situations may vary, one metric tonne of dry dung contains about 16,7 gigajoules of potential energy. Direct burning at 10-20% efficiency gives 1.67-3.34 gigajoules of useful energy and some ash for recycling. Biogasification of the same amount of dung at 55% efficiency results in a gas containing about 9.2 gigajoules plus much organic material and plant nutrients for recycling. A burner giving 50% efficiency [The widely used Beijing No.4 model burner gives about 55%.] results in about 4.6 gigajoules of useful energy.(Ramsey, 1986) Terminal energy utilization efficiency of stalks through bigasification is about 30-40% (National, [1985]), while direct burning would again be around 10-20% and there would be only ash left for recycling.

Very simply, the only way to meet both of the aforementioned needs in a systematic, integrated [allocatively efficient] manner is to make use of the anaerobic decomposition process! Although some application of technology is necessary to utilize the process, digesters are far more biological systems than they are technological constructs; far more like a cow than a car. Since humankind is now in the process of establishing a mutually beneficial relationship with digesters in general, the idea of domestication gives an excellent perspective on the situation.

II. The Domestication of Anaerobic Bacteria

A. Introduction

No attempt will be made here to describe the process of anaerobic decomposition in detail. The reader is directed to Stuckey (1983) and/or Gunnerson (1986) for excellent introductions. A few comments do, however, seem appropriate.

The decomposition of organic materials and their preperation for reuse can follow two, often intertwined, biological pathways. Through both pathways, organic materials are largely broken down by bacterial action and large amounts of carbon dioxide are released. The primary differences lie in: (A) the large oxygen requirements for the aerobic path and the requirement of the obligate anaerobes for no free oxygen; (B) the nitrogen transformations ending with mostly nitrates via the aerobic path and ammonia via the anaerobic path; and (C) solar energy, originally stored through photosynthesis, being released as heat through the aerobic path while it is largely contained in the combustible methane molecule formed through the anaerobic pathway. A concise view of some of the major considerations in the two processes is given on the following page.

Anaerobic microbes largely evolved during the very early history of the earth when there was little of no oxygen gas in the atmosphere. They continue to exist naturally today in nitches where similar conditions exist--in bogs and other stagnant water [The Chinese term zhaoqi, literally translates as marsh gas.], in the deeper layers of the soil, and in the guts of large animals.

The anaerobic decomposition process, its containers and products have all been referred to by numerous terms over the last couple decades of intensive development. Herein, the process will be referred to as "digestion," the

Some Selected Aspects of Aerobic and Anaerobic Decomposition.
(Based on Innumerable Sources)

CONSIDERATION	AEROBIC DECOMPOSITION	ANAEROBIC DECOMPOSITION
Moisture Levels	40-60%	99+% to less than 50% although less than ~75 % results in very slow activity
Particle Size	for both, generally speaking, the smaller the size, the quicker the process	
Oxygen (as O2)	large amounts necessary	fatal
Reduction in Carbon	for both, under controlled conditions, loss of dry-weight carbon can be over 60% of that in the original material	
Carbon Dioxide	all carbon lost is in this form	generally between 30-40% of the biogas
Nitrogen	likely loss of up to 50% [usually closer to 25%] as N2 or NH3 without close control; nitrates dominant in the final product	little control necessary for recovery of essentially all original; ammonia dominant in final porduct
Carbon/Nitrogen Ratio	both processes have optimums somewhere between 20-35:1 [The problem is that none of the usual laboratory tests give the biologically "decomposible" quantities of C or N. Thus the only way to really determine these levels is to check the losses after the processes have occurred.]	
Other Nutirents	potential leaching of soluable forms in uncovered piles	very well maintained
pH	final products from both processes are neutral to slightly alkaline	
Photosynthetic Energy	largely released as heat	largely contained in the methane produced
Time Required	both can be accomplished in days [or less for digestion of very dilute organic waters] under very controlled conditions--usually weeks or months, although years are required for complete decomposition	
Pathogen Destruction	complete destruction IF all materials reach >55 degrees C for a few hours	very significant, although a subsequent composting of the sludge is necessary for total destruction [espicially of Ascaris eggs]

container as a "digester," the gas produced as "biogas," and the liquid and solid remains of digestion as "supernatant" and "sludge" respectively.

B. A Summary of Events before 1970

The utilization of anaerobic microbes has an amazingly long history in China. In ancient literature, there are reports from 2-3000 years ago that indicate that use was made of naturally occurring biogas from swamps for drying salt.(Chen, G.Q., 1983) This author has also heard (as yet without undocumented) that some of the writings of Marco Polo mention the utilization of a gas from covered sewage tanks.

More recently, Luo Guorui investigated digestion in the 1920's and developed the water pressure design which is so widely used today.(Chen, R.C., 1983) In this design digestion and gas storage occur in one solid masonry tank and there are no moving parts. Digestion efforts were continued in the 1930's by Zhou Peiyuan. During this period, several commercial digesters were constructed to provide lighting in a few communities in the southeast. One digester, constructed in 1937 in Hubei Province, is still in operation. (National, [1985]) Costs at this point were far to high for any broad acceptance and by the end of World War II, there were only about 200 digesters throughout the country.(Chen, R.C., 1983)

While records are incomplete, it appears that some enthusiasts in various areas of the country must have continued at least some "backyard" efforts from those early days. In 1958 Mao Zedong met a farmer who had built and used a digester and he incorporated digestion into "The Great Leap."(Elligard, 1983) Thus during this brief period, there was considerablae government support for and propaganda about digester development. While tens of thousands of small rural digesters were built (over 40,000 in just one county), construction must have been quite poor and technical support was greatly lacking so that there is little left in rural areas today from this first push.(Chen, R.C., 1983)

There were, however, several larger-scale systems built during this period. As in many industrialized countries, digestion first approached practical usage at central sewage treatment facilities. The Sian Sewage Treatment Plant, constructed in 1958, has four digesters with a total volume of 5000 cubic meters and was the largest system in China until quite recently. (Chen, R.C., 1983)

Throughout the 1960's, one may assume that research and development efforts were continued at various research institutions, sewage treatment plants and other biomass based industries, and some innovative peasants' backyards. In 1967, two 2000 cubic meter digesters were installed at the Nanyang Distillery. This system was quite innovative at the time in that it is a plug-flow design and operates at thermophilic temperatures. [This system continues to function today, the 10,000 cubic meters of gas produced daily being used primarily for chemical production and process heat, but also providing household fuel for nearly 400 families in the "production unit."]

From these early efforts, it can be seen that there was a constant and growing effort toward the practical development of digestion systems. While the "Great Leap" push was largely a practical failure, it did increase general awareness and helped to direct research efforts. The lessons learned from this early push in regard to both construction and institutional support also layed the foundation for the massive efforts of the 1970's.

C. The Big Push of the 1970's

Extensive interest in small-scale digestion systems began again in 1970 based on the experiences of peasant enthusiasts in Sichuan Province and researchers in the provincial capital of Chengdu. Digester development during this period was dominated by events in Sichuan with over 70% of construction occurring there. While it is possible that the emphasis on Sichuan may have been decided upon from a national level, the effort there may be traced to the Provincial Party Secretary becoming especially convinced of the appropiateness of digestion and taking an active part in developments.(Elligard, 1983) The effort also obtained the support of the State Planning Commission and the Chinese Academy of Sciences with its branch institutes in each province. The Ministry of Agriculture and Forestry and and the national State Council assumed overall responsibility and digestion was again included in national plans.

It appears that the primary motivations for digestion in the early portions of this period came from the process' nutrient conservation and sanitation aspects while the biogas itself was seen as more of a fortunate coincidence. Considerable effort went into demonstration of increased yields obtained with digester effluent as opposed to traditionally treated residues. Increases were generally reported to average around 10% but many higher figures were reported in certain situations.

With schistosomiasis and other enteric diseases being such a widespread problem, the sanitation aspect was perhaps even more highly stresse.. While most disease vectors are destroyed due to the anaerobic environment, some parasite ova, especially those of Ascaris, do remain viable even through the long digestion deriods generally recommended. Designs were developed to maximize the settling out of ova so as to obtain the most pathogen-free supernatant. A final sludge composting was included in sanitation recommendations/regulations which were established for pathogen levels in effluents used on fields.(UNEP, 1981)

Because only a couple family digesters in a village could not provide the full sanitation benefits, a cluster development scheme was established.(Chen,

1981) In this system, whole villages would [opt or be coerced to] put in family digesters. Village level surveys were then conducted over several years to show the differences in levels of infection and presence of flys in villages with and without digesters.

Since gas production and storage was not of primary interest, some leakage was accepted even in new digesters. As gas production began to be seen as more valuable and excessively leaky digesters began to sicken, the original box-shaped tank design with its hard-to-seal corners evolved into various rounded configurations including full spheres, ovals and domes.

One of the primary emphases at this time was in keeping material costs extremely low no matter how much labor was involved. Very little concrete was used and the emphasis was on making use of traditional techniques and whatever construction materials that were locally available. Technical literature from the period shows how designs may be adapted to various available materials and environmental conditions. Gas burners and lights were often locally produced ceramics and even lotus pods were utilized as light fixtures.(Van Buren, 1979)

To overcome the lack of technical extension experienced in the 1958 effort, a hierarchical system of training was established. One or two volunteers from a village were taken to central training facilities where 50-100 persons at a time would undergo a 2-4 week intensive session which included both the theoretical and practical aspects of digestion as well as the construction of several units. Upon return to their production units, these people were expected to train others.(Elligard, 1983) Over 100,000 technicians were trained in Sichuan alone.(Smil, 1976)

Subsidies were provided at both state and collective levels.(Gunnerson, 1986) While local materials were stresses, the state made loans available at 0.18% interest for the small amounts of cement which was recommended.

(Elligard, 1983) [One problem that certainly causes some general confusion is that the Chinese seem to naturally quote interest rates on a per-month basis while visitors are often used to per-year figures. Realization of this generally gives much more comprehensible figures.] State level support may be seen, however, as primarily consisting of the support for training sessions, the establishment and support of research centers in many areas of the country, diffusion of information through publication of technical information, and the popularization of the idea through the various forms of mass media, i.e. from wall posters to film and television.

Collective level support may be seen as the arrangement of time schedules and the development of construction teams. Although far the majority of digesters at this time were household systems, the production unit owned all digester feedstocks and effluents and planned digester operation and residue usage.(Chen, R.C., 1983)

While the primary emphasis was on household digesters of 6-12 cubic meters, there were also many larger systems constructed. One may fairly assume that a very large portion of the 50,000 medium-scale (50-100 cubic meters) and large-scale (over 100 cubic meters) digesters and the 1000 biogas power stations having a total capacity of 8000 kW reported by Chen Ruchen in 1983 were installed during this period. There was also musch interest in development of chemical production from the carbon dioxide and methane which generally compose around 99% of the gas.(Chen, R.C., 1983)

In the mid-1970's, digesters were being built at a rate of almost one million a year. In 1978, a total of 5.67 million digesters were reported with 4.3 million in Sichuan.(Chen, R.C., 1983) Chen (R.C., 1983) suggests that figures as high as 7 million from this period included many systems that were only in the planning stage. National plans at this time called for 20 million systems by 1980 and 70 million by 1985. It was expected that the latter figure would supply about 70% of rural households.(Smil, 1976)

By the late 1970's, it was becoming generally recognized that adaption of digestion to household use was not quite as easy as it at first had appeared. Adequate digester functioning required a bit more attention to feed materials and practices than had first been generally recognized and publicized.

Construction had perhaps become a bit shoddy and many digesters were built so poorly as to never be used. Simple, locally available, traditional materials were proving inadequate for very long-term operation. Gas leakage was not the only problem. Water leaking out of the tanks was another, but more important was leakage into the tanks from the surrounding water table. The average digester lifetime was turning out to be only 3-4 years and systems were going out of operation nearly as quickly as they were built.

The energy crises had also stimulated interest in making greater utilization of the biogas. More cement use for better gas sealing began to be recommended. With the progression of economic reforms begun in the later 1970's more efficient burners and lamps began to become commercially available.(Chen, R.C., 1983) Researchers also began more intensive investigation of other designs such as the Indian floating drum, higher-technology systems for faster digestion such as up-flow configurations, and more secure gas storage such as red mud plastic systems developed in Taiwan.

While developments in this period do stand out as quite amazing when taken by themselves, they are more appropriately seen as a more gradual, natural progression into broad experimentation with a biotechnology whose time had come in a society with a long history of the careful husbandry of organic residues for utilization on agricultural lands.

D. The Re-evaluation of the 1980's

The re-evaluation of the national approach to diffusion of digestion systems actually began in the late 1970's, but it has continued and become more crystallized in the 1980's. Representatives from the various departments of the State Council compose the State Leading Group on Biogas Construction. (Gunnerson, 1986) In 1979, the National Office of Biogas was firmly established within the Ministry of Agriculture and Forestry.(Kharbanda, 1985) The provincial, regional, county, and city levels of this ministry generally include a biogas component in their respective Rural Energy and Conservation Units.

Although there was a significant slowdown in construction of small-scale digesters in the late 1970's, the Sixth Five Year Plan for 1981-85 called for about 3.5 million new digesters nationwide. Also included were preliminary targets for 1990 of 20 million family digesters plus 10,000 larger systems for electrical generation supplying a total of about 5% of rural household energy. (Kharbanda, 1985) Actual construction during the period fell a bit short of expectations, averaging a mere 500,000 new systems per year.(Li, 1987)

The leakage problems and other happenings of the big push of the 1970's were accepted as a learning experience. Where possible, these older digesters have been repaired and upgraded, but many hundreds of thousands have simply been crossed off. (Kharbanda, 1985) The reported number of digesters went down from over 7 million in the late 1970's to less than 5 million.

Emphasis has shifted from extremely rapid diffusion using all locally available construction materials to slower, more careful diffusion with quality, concrete construction and systematic, scientific operation.(Li, 1987) National standards and designs have been established for concrete construction of systems from six to nearly sixty cubic meters.(State, 1984) Interestingly, there appear to de decreasing "economies of scale" for these systems.(Li, 1987)

Well designed digester construction tools and steel concrete forms and biogas appliances have become commercially available. Hanging gas mantle lamps equivalent to about a thirty watt electric bulb cost around $5 and the widely distributed Beijing No. 4 cooking burner cost about $6, and are available throughout the country. Ultra-violet resistant, long-lasting red mud plastic tubing has become available for gas lines at a cost of less than two Yuan (about $0.60) for thirty meters.

With the improved quality, family-scale digestion system costs, now including labor, rose to around 200 Yuan (about $55). [Slightly more than the cost of a bicycle.] Although digesters still recieved some priority in the allocation of materials and loan funds, direct subsidies have been largely phased out.(Li, 1987) With the economic reforms giving more individual and family freedom in financial matters, the continued spread of digesters has required emphasis to be placed on documentation of the financial benefits that accrue from digestion. Considering only the values of the biogas, the effluents, labor saved, and yield improvements, researchers can still show a pay-back period of less than two years.(Li, 1987)

The cluster development approach has continued but villages must now be convinced rather than coerced. Also, as the peasants have become better off financially, they have also become more interested in convenience. Therefore it was necessary to address some of the operational difficulties such as the emptying of digesters. Once this problem was addressed by the very large research and engineering community, numerous tools, pumps, and other devices have become available and continued to be refined.(eg. Liaoning, 1986)

The training program for village volunteer biogas technicians has been refined and continued to receive government support. There were well over 200,000 of these trained extension workers by 1985.(Kharbanda, 1985)

While small-scale systems continued to spread, perhaps more emphasis has been going toward the development of large-scale systems for more industrial, food processing residue, and sewage applications. The Nanyang Distillery, mentioned in Section II.A., constructed two new 5000 cubic meter digesters which will soon supply gas to about 20,000 households in the surrounding city.

While many institutions of higher education seem to include some digestion investigation, the primary research and development institutions are the provincial Academies of Science. While some work is going on in most of the provinces, the major site is the Asian-Pacific Centre for Biogas Research and Training in Chengdu, Sichuan. Annual meetings are held around the country to give researchers an opportunity to share information and exchange ideas.

Zhongguozhaoqi [China Marsh Gas] began publication in 1983. This quarterly periodical includes reports from all over China and offers another means for information exchange among researchers. Glancing through the diagrams in several of the 1986 issues of Zhongguozhaoqi [unfortunately written in Chinese characters with only an English "Table of Contents" to tease] and numerous reports in the Proceedings of the International Symposium on Anaerobic Digestion held in Guangzhou in 1985, one can see that Chinese researchers, while still being concerned with simple, small-scale systems, are also right at the cutting edge of the development of elegant, high-technology, innovative designs, biologically integrated systems, and gas utilization in internal combustion engines.(China, 1985)

The Chinese biogas program can thus be seen as having evolved pragmatically over the last two decades. As Gunnerson (1986) suggests, the program is now quite "sophisticated and integrates research and develoment, implementation, finance and extension within a cohesive national biogas policy."(p.99)

E. The View from the Summer of 1987

The over-optimistic euphoria of the mid-1970's is now gone from the Chinese biogas program. It has, however, been very well replaced by a more practical, systematic and scientific approach. Biogas development has become part of the national plan. While digestion is not seen as a major energy source in the nation's future [such as coal or oil], its overall potential in energy and other aspects is recognized and it is often mentioned first in discussions of alternatives to conventional fuels for rural areas.

At all levels of government, from the State Council to extension services, a well developed institutional structure has already evolved. There is also in place a very highly developed and broadly spread research establishment with very good facilities working in this field. Very good communication links among the different groups have also been established. Thus, while various problems still exist with various aspects of digestion, the amount of attention that is being directed toward solutions is, this author would suggest, at least equal to that of the rest of the world combined.

The current rate of small-scale digester construction, while less than the mid-1970's, is higher than the late 1970's and has remained fairly constant throughout the 1980's. The 500,000 new digesters per year dwarfs efforts in the rest of the world combined. That this rate of construction has continued throughout the economic reforms with families now paying the entire cost of more expensive systems is a testament of a very broad appreciation of the appropriateness of the systems.

Mr. Xie Zhihen, Deputy Director General of the China Biogas Association, currently quotes a figure of about 4 million digesters in China, of which 30% are in Sichuan. From this one may assume that most of the digesters built with inadequate, locally available materials in the mid-1970's have now been written off, and that the figure for total digesters should begin to rise again soon. [If not, there will certainly be another period of re-evaluation.]

Robert Taylor, a World Bank expert on China, has suggested that, since one of the major complaints in areas with high livestock populations is of insufficient digester feedstock, the installation of family digesters in areas with less livestock was an "inefficient allocation of resources."(1987) The University of Pennsylvania Summer Program group spent its time in Henan Province which lies near the northern limit for unheated digesters. While the swine population in this area is less than half of that in Sichuan, there appeared to be no problem with insufficient feedstock since digesters were largely batch loaded about three times a year with high ratios of stalks and straw--up to a ratio of 15 stalk to 1 manure. While higher proportions of manure do give higher gas yields, production from the aforementioned regimen was found to be adequate for cooking three meals a day for six months, one to two meals a day for about four months, and lighting throughout the year. When one considers the various health aspects of digestion and the conservation of organic materials, nutrients and soil that utilization of the process makes possible, this author would suggest that direction of resources toward digestion can hardly be called "inefficient." One must wonder what sort of resources would have to be directed toward energy supply, sanitation, and nutrient/soil conservation to accomplish in other ways all that digestion alone makes possible.

Indoor air pollution caused by the direct burning of biomass fuels has begun to receive more attention recently (De Koning, 1985; Smith, 1986), and the University of Pennsylvania group also addressed this problem. Although there is generally small amounts of highly poisonous hydrogen sulfide contained in biogas, none was ever recorded on testing instruments placed for eight hours within a meter above biogas burners in several villages' homes [some with very high concentrations of hydrogen sulfide in the biogas] and other situations. While varying levels of sulfur dioxide, the combustion product of hydrogen sulfide, were recorded in biogas burning kitchens, the levels averaged about one-quarter of that recorded in both coal and stalk burning kitchens. One would also expect particulate and hydrocarbon levels from biogas burning to be around [most likely less than] that of natural gas, the cleanest burning of conventional fuels. While this is just another aspect of health and is thus generally "external" to narrow, conventional economic methodology, this author would contend that the effects of biogas combustion in control of indoor, and indeed general, air pollution is a significant benefit which has not even been considered by most proponents of the systems.

While construction of and research into family-scale systems continues, larger systems are being increasingly emphasized. While this is largely for the convenience it affords convenience-seeking gas users, it is also a result of the need to comply economically with industrial environmental pollution regulations which began to be implemented in 1981. Large amounts of expensive electricity are generally required for air circulation to maintain aerobic decomposition of potentially polluting organic materials of all types and digestion appears to be a very competitive alternative.

It was suggested by Li Junde (1987), chief biogas researcher at the Henan Academy of Science's Energy Institute, that the weakest link in the biogas program today is that between researchers and village users. In other words, all of the potential yields and benefits from digestion which may be obtained in laboratory-scale and even full, family-scale digester operation at the Institute are diffucult to obtain in the villages. Such problems are common in the transition from highly controlled settings to field conditions and are certainly not unique to digester development in China. Considering the needs of such a huge rural population and the effects that would occur from the urban industrialization of the masses, the age-old, societal commitment to the recycling of organic materials, and the pragmatic reaction to events over the past two decades as well as the evolution of digestion development policy, one may expect that the researcher-user link too will be strengthened in the near future. [During the stay in China, this author heard nothing of "in-service" training of the village volunteers, and the institution of such a program would go far toward the spread of the most current information and recommendations.]

III. Conclusion and Potential for Broader Applicability

It may have occurred to the reader by now that this author is absolutely biased in favor of the maximum, worldwide development and utilization of this bio-technology in which China has very well assumed the burden of showing the way. Considering that the human establishment of a symbiotic relationship with the microbes of the anaerobic decomposition process would allow for:

-- a renewable, environmentally benign [in terms of effects on both worldwide carbon dioxide levels and indoor pollution levels] source of energy, potentially available to most of the world's population, especially those in the tropics, in a form which can directly fulfill all or a large part of one of their primary energy needs--the high heat requirements required for cooking food;

-- greater control of human and livestock enteric diseases and their insect vectors, agricultural pests, and organic and chemical pollutants; and

-- the transformation of a problem into the resource for the recycling of a maximum of non-polluting organic materials and plant nutrients to agricultural land thus inhibiting the entropy involved in the flow of agriculturally productive soil to river bottoms where it increases the potential for the flooding of other agricultural plains which, if it occurs, decreases food production [no matter how much chemical fertilizer is applied] which, perhaps, causes some starvation which . . . which somewhere along the line even has some economic effect,

it is rather amazing that maximum utilization of the process has not occurred before now. Assuming control of the bottom of the cycle of return is, perhaps, one of the ways to reverse the downward spiral which many ecosystems around the world, and indeed the biosphere in general, seem to be following at the moment. Perhaps a sustainable, long-term bio-economic methodology will be developed or perhaps short-term "finances" will lose its current predominance in so much of human endeavor.

The applications for digestion around the world are fairly infinite and, as long as animals must eat and the sun shines, never-ending. While constructing a functional digester does require a certain level of skill, operating [or raising] a digester is very little harder than raising any other type of livestock. It is appropriate anywhere that population growth has necessitated abandonment of a sustainable swidden agricultural system and now requires constant agricultural use of the land. Once economics gets the prices right for health and the environment and governments assume their rightful responsibility for maintenance of public welfare [admittedly unlikely], one may expect a very broadly spread domestication effort to begin.

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