Outlook

How close is the methane alternative?

Power your car with methane made from your household wastes. Use methane in your tractor or to supply your lighting, cooking, and heating needs on your farm. Make the gas by putting your crop wastes or animal manure in a digester. The idea has caught on so well that it's now a part of the folklore of the alternative technology.

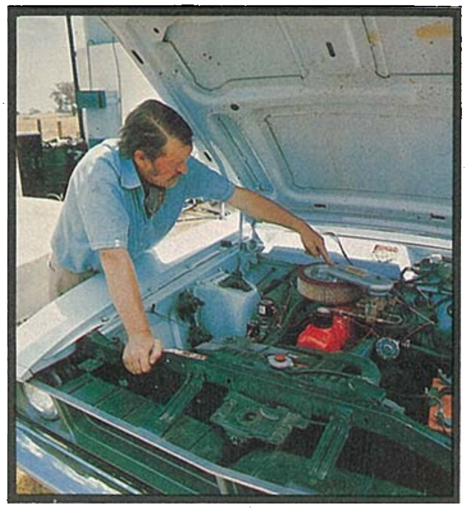
But wait a minute. The technique may seem marvellously simple; all you are doing is letting bacteria break down your wastes in an air-free tank. Carrying it out is another matter.

In spite of the enthusiasm with which the idea has been taken up, household digesters in our suburbs are still only things found in books, television series, magazines, and newspapers. Few people actually have a digester to get rid of their domestic wastes. Less than a dozen Australian farmers have installed larger-sized ones either — in spite of the obvious advantage of being able to cut down on fuel bills. Industry also has yet to successfully install one.

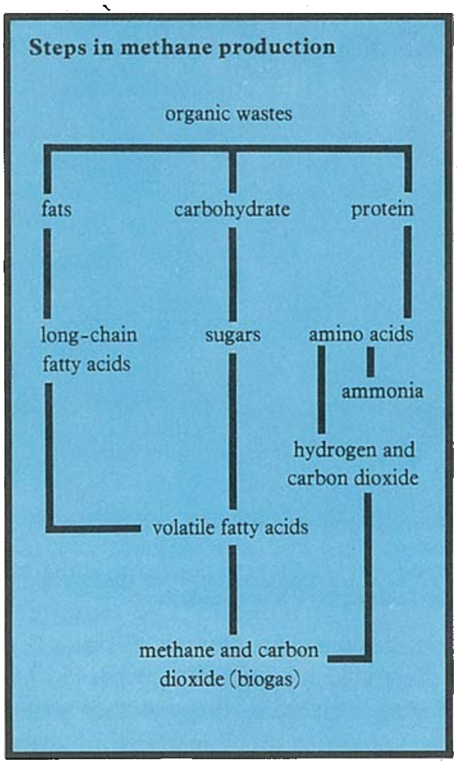
In fact there are good reasons why the apparently excellent idea of converting wastes to methane has been slow to take off in practice. For one thing, there's little reliable information available on how to build and run suitable digesters. They're usually costly, and urban councils and health authorities view them with suspicion. In addition, running a methane digester can be a tricky business. Since it contains living bacteria, it may easily be poisoned. For efficient gas production, the temperature of the contents must remain almost constant.

Oddly enough, we really don't know very much about the processes going on to give methane — even though the Italian scientist Volta discovered it in marsh gas from stagnant swamps during the Eighteenth Century.

Interest in making methane by digesting wastes in the absence of air (anaerobically) died in the middle of this century with the switch to oil as the major source of energy. It took the oil crisis of the early 1970s to rekindle that interest.



John Coulthard's methane-powered car. Cars run well on the gas, but storing enough is a major problem.



Step 1: Bacteria break down raw organic wastes. Step 2: Other bacteria produce fatty acids, hydrogen, and carbon dioxide. Step 3: Yet other bacteria complete the conversion to biogas.

Renewed interest

Today methane production is the subject of research in many countries, particularly in the United States, Japan, and the United Kingdom. In Australia several projects are now going on in CSIRO and the universities, and several companies are taking a lively interest.

Take Melbourne, for example. There, a mere 17 companies account for half of the organic matter in the sewage going to Werribee Sewage Farm. These companies — mainly breweries, or processors of food or pulp and paper — are obviously candidates for using anaerobic digestion for their wastes.

Recently the Board of Works changed its charging system, and these 17 companies now face large bills for waste treatment. Several are keen to build anaerobic digesters, but there are no consultants or contractors available with the necessary experience.

In South Melbourne, the CSIRO Division of Chemical Technology has a number of projects looking into digesting wastes anaerobically, and it is doing what it can to assist those industries interested in building digesters. For instance, its scientists have recently advised two abattoirs on the subject.

The pig industry also has a waste-disposal problem, and the Division is currently carrying out trials with a digester designed to deal with these wastes. In addition, the CSIRO Division of Food Research in Sydney is studying how anaerobic digestion could be used to solve the waste-disposal problems of fruit and vegetable canneries.

What can you do with biogas, the gas coming out of a digester? It usually contains about 70% methane, 30% carbon dioxide, and a trace of hydrogen sulphide. This last is corrosive and needs to be removed by passing the biogas through iron oxide. The mixture of carbon dioxide and methane burns a little hotter than the old town gas supply used to.

If the carbon dioxide is scrubbed out by running the biogas through a lime slurry, then the pure methane behaves and burns with much the same heat as natural gas (which may itself be 99% methane). So scrubbed biogas may be used in domestic cookers designed for natural gas without modification. Unscrubbed biogas can be used directly in unmodified appliances designed to run on town gas.

Storing the stuff

Methane compresses fairly easily, but it won't liquify under pressures normally available, as do the propane and butane in LP gas. Normal car engines run well on it — methane burns with a little more heat than petrol — but two-stroke engines don't. Diesel engines will run on a blend of methane and distillate.

The major problem with using biogas in your car is storage. The higher the pressure, the smaller is the volume of a given quantity of gas. According to Mr Chris Mardon of the Division of Chemical Technology, it can be stored at about 1000, 3000, or 21 000 kilopascals (kPa) — that's 150, 500, and 3000 pounds per square inch — depending on whether you use a one-, two-, or three-stage compressor.

Commercial gas cylinders capable of withstanding 21 000 kPa pressure hold only about 55 litres (12 gallons) of gas. But one of these can only store scrubbed methane equivalent to 12½ litres of high-octane petrol. The same quantity of unscrubbed biogas (containing carbon dioxide) would only be the equivalent of about 9 litres of petrol. Because of the pressures they must withstand, the 55-litre gas cylinders are very heavy — a fact that has drawbacks in a car, but is less of a problem on a farm tractor. To store the amount of methane equivalent to 12½ litres of petrol at atmospheric pressure would require a 15-cubic-metre (540-cubic-ft) tank!

To date, running a methane digester has been more of an art than a science. In general, it's easier to run big ones than small ones, for the simple reason that the larger volume of the contents will buffer them better against quick changes in operating conditions. Sewage-disposal-authorities both in Australia and elsewhere have been running large ones successfully for many years, and indeed two new digesters have recently come on stream — at Malabar near Sydney, and at Carrum near Melbourne.

Several companies are keen to build anaerobic digesters.

Sewage engineers now know how to design effective digesters for sewage; but their main purpose is not to produce methane, it's to convert the solids in raw sewage into a suitable form so that they can be discharged into rivers or the sea.

Energy in wastes

Another article in this issue of *Ecos* looks at the energy theoretically available for our use in sewage, garbage, and farm and forestry wastes. According to the calculations of Dr Roger Gifford of the CSIRO Division of Plant Industry, all these wastes contain a total amount of energy equivalent to about 15% of Australian energy consumption in 1974 — that's a little more than double our current usage of energy as natural gas. So perhaps the quantity of methane produced by converting them could just about equal our present consumption of natural gas.

From the national point of view that isn't a great deal of energy, since only about 8% of our current supply comes from natural gas. (Moreover, it wouldn't be possible to convert all the wastes to methane.) Nevertheless, substantial amounts of gas could be made available to our cities by efficient conversion of all their cellulose-based garbage (cardboard, paper, vegetable matter) as well as all their sewage to methane. For example, Mr Mardon calculates, processing all the sewage and garbage from a city of two million people would each day yield gas equivalent in energy value to 545 000 litres (120 000 gallons) of petrol.

Again on individual farms, the farmer may well be able to greatly reduce his fuel bills or even eliminate them altogether by converting his farm wastes to methane — not something of national importance, but of immense importance to individuals.

At present, most of the farm digesters installed in Australia probably use pig manure as a feed. However, there is no reason why other wastes such as wheat straw should not be used, but some problems need ironing out. Even the problems of making methane from pig manure are by no means completely solved. In practice, large quantities of dry wastes can no doubt be better used in other ways. Producing methane is an effective way of

Mr Chris Mardon

Energy in various gas fuels

fuel gas	calorific value (×10⁶ joules per kg)
coal (town) gas	16·3–18·5
biogas	19·7–25·5
methane	35·3
natural gas (methane- or propane-based)	38·5–79·5
propane	89·2
butane	116·4
hydrogen	10·5

Remove the carbon dioxide from biogas and it burns very much like natural gas.

Gas yields from digesting municipal wastes overseas

	gas yield (cubic metres per kg dry solids)	methane in gas (%)
sewage sludge	0·43	78
sewage skimmings	0·57	70
garbage	0·61	62
waste paper	0·23	63
combined refuse	0·28	66

Town garbage and wastes — a resource ready to be used?

using difficult wet wastes because they don't have to be dried first.

Interdependent bacteria

Why the difficulties? In a methane digester, bacteria convert solar energy trapped in plants during photosynthesis into a more usable form — methane. The process will only go ahead in the absence of oxygen (anaerobically). Although superficially simple, it is in fact very complicated. No individual type of bacterium can convert plant cellulose, sugars, and organic acids directly into methane. Instead, different bacteria carry out different parts of the process. So a digester contains a whole population of different bacteria, each using the products of others to carry out different steps.

Perhaps it's most convenient to regard the anaerobic digestion process as a three-step one. Some of the bacteria in the digester first break down the plant material (even pig manure contains some partly digested and some undigested feed) into simple sugars, glycerol, amino acids, and ammonia. Other bacteria then use these products to grow and multiply. In so doing, they convert them into volatile fatty acids, hydrogen, and carbon dioxide. Finally, yet other bacteria convert the fatty acids and hydrogen to methane and carbon dioxide.

The whole system of bacteria feeding on the products of others has to be kept in equilibrium. If one type produces its products too quickly, then other types may become inhibited, with a consequent shut-off of methane production.

Methane will be collected provided the temperature inside remains warm, the slurry feed has the right solids content, the carbon to nitrogen ratio is correct, and the feed is non-toxic.

Oddly enough, we really don't know very much about the processes going on to give methane.

Shocks to the system, like the addition of a lot of fresh manure, or a sudden change of temperature or pH, may put the whole system out of kilter — with the possible result that methane production temporarily stops, or, in more drastic cases, the whole digestion process breaks down altogether.

Except in tropical climates, where the temperature remains high enough for much of the time, it is necessary to heat the incoming feed to compensate for heat losses from the digester to the outside world. With a well-insulated digester operating on sufficiently strong feed and an efficient gas heater, it should be possible to use as little as one-fifth of the gas produced for heating the digester's contents during winter in southern Australia. The rest can be taken for other purposes.

It's necessary to mix the contents from time to time, too, to make sure that all the wastes and bacteria in the digester come in close contact and that the temperature distribution remains even. In addition, mixing breaks up a scum that often forms on the surface of the half-digested feed, and releases bubbles of gas.

So a reliable and efficient digester has to be a fairly sophisticated piece of equipment, especially if it is small, since it must be designed to keep the temperature from dropping. The feed must be preheated, and the contents stirred. Such features add proportionally more to the cost of small digesters than to that of their bigger brothers.

Best wastes for digesters

What can you put into a digester? Three factors determine the answer — the digestibility of the raw material, its water content, and the ratio of carbon to nitrogen and phosphorus within it.

That the bacteria must be able to digest the feed sounds obvious. But a major proportion of plant material cannot be digested.

Plants usually consist mainly of two substances — cellulose fibres and lignin. The cellulose fibres are made up of large sugar molecules strung together. A cement of lignin between the fibres gives the plants structural strength.

A methane digester is really just a large artificial version of the rumen of cattle or sheep. The bacteria found in the digester are in fact very similar to those in the gut of a cow. They can digest cellulose, but not lignin.

Unfortunately, in most plant materials (such as cereal straw or wood) the cellulose and lignin are so intimately mixed together that the bacteria cannot easily get at the cellulose. Hence, without treatment to open up the mixture of lignin and cellulose in some way, the bacteria cannot digest these materials.

Typical digestibilities range from 50–70% for pig and poultry wastes, and about 50% for sewage sludge, through to 40% for corn stalks, 30% for wheat straw, and 20–25% for newspapers. The digestibility of wood is considerably lower still.

According to Mr Mardon, the ratio of carbon to nitrogen should be between 20 : 1 and 30 : 1; it certainly shouldn't

Volumes of excrement and urine produced by different animals

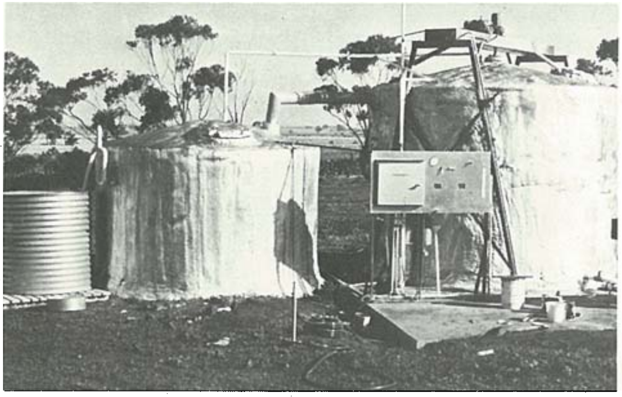
	animal's body weight (kg)	amount (litres per day)
dairy cow (silage and concentrates)	454	32–45
pigs (dry meal)	45	4·5
pigs (whey)	45	9–13·5
horses (grass)	380	23
sheep (grass)	30	2·3
humans	70	1·4

It would not be feasible to run small household digesters on human excrement alone.

Carbon to nitrogen ratios in some plant wastes

	C : N
grass clippings	12 : 1
vegetables (non-legumes)	11–19 : 1
hay	15–20 : 1
straw	50–150 : 1
sawdust	200–500 : 1

Straw and sawdust are too high in carbon to be used alone in a digester — a nitrogen source is needed.



Mr Kirby's experimental methane digester at Deer Park near Melbourne.

Mr Kevin Kirby.

exceed this, since nitrogen is an important component in the process of digestion. Too much nitrogen will cause excessive ammonia formation, which inhibits the system. Typical carbon : nitrogen ratios are 0·8 : 1 for cow urine, 12 : 1 for grass clippings and cabbage wastes, 25 : 1 for cow manure, and 128 : 1 for wheat straw (which consequently can't be used on its own). Phosphorus is also needed in smaller amounts than nitrogen.

Pig and poultry manures contain higher proportions of nitrogen and phosphorus than cow manure, so if you are running a farm digester on pig or poultry manure there seems to be no reason why you shouldn't add in straw and other low-nitrogen wastes, provided they are reasonably digestible.

Recently, a team of scientists from the Bendigo Institute of Technology carried out a study for CSIRO on the 'Sanamatic' methane digester system of Mr John Coulthard, one of the leading proponents of anaerobic digestion in Australia. The investigation indicated problems caused by overproduction of ammonia.

During the test, the system ran exclusively on pig manure. Perhaps addition of other wastes that increased the carbon to nitrogen ratio would have helped prevent this overproduction.

Pig problems

To date, the pig industry is the one showing most interest in installing digesters. Mr Kevin Kirby of the Division of Chemical Technology is currently investigating efficient ways to do this.

Disposing of the wastes from a large piggery, which may contain 30 000 pigs, is a major problem. Most piggeries presently dispose of the wastes in one of three ways: by spraying them onto pastures, by leaving them to decompose in ponds, or by decomposing them in 'oxidation ditches'.

The first method needs a lot of land — about 1000 ha for 30 000 pigs. With all of them, the effluent may also seep into streams, or into the groundwater. They may be smelly and create problems with flies and weeds too. State environmental protection authorities are putting increasing pressure onto pig farmers to find more-acceptable ways of disposing of their wastes.

Mr Kirby is collaborating with Mr Tony Dunkin of the University of Melbourne to check how anaerobic digestion really does compare with existing ways of disposing of piggery wastes. To date, he has successfully carried out laboratory studies, and he has now built a pilot digester for treating the waste from about 300 pigs at the University's field station at Deer Park. By eliminating hosing down as a way of clearing the excrement from the animal houses, he will obtain more concentrated feed than normal. This should increase the efficiency of the digestion process considerably.

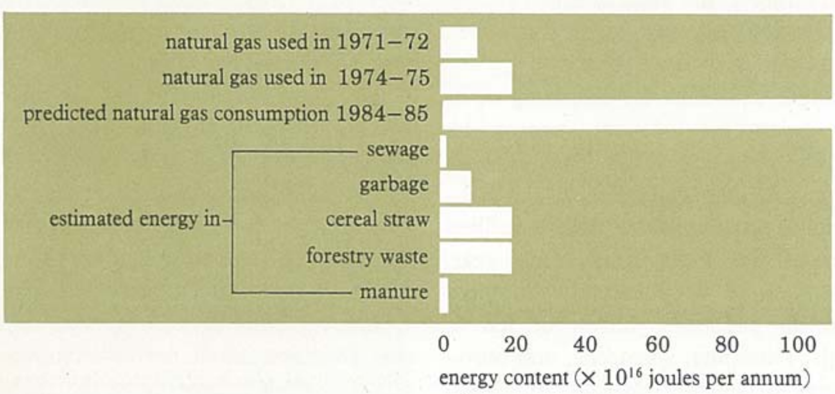
Anaerobic advantages

Anaerobic digestion seems to have several advantages over existing disposal methods. It produces a sweeter-smelling and less-polluting brown liquid, and a relatively small amount of sludge that settles on the bottom. The sludge has the consistency of mud, but very little smell. It consists mainly of lignin, and won't break down further with unpleasant side effects. Being humus-like, it may have some value as a soil conditioner, although the copper added to pig feed may cause problems. Its phosphorus and nitrogen contents are too low for it to have much value as a fertilizer. The Bendigo study of the 'Sanamatic' system showed that the sludge contained about 7% protein — not enough to make it a useful stock feed.

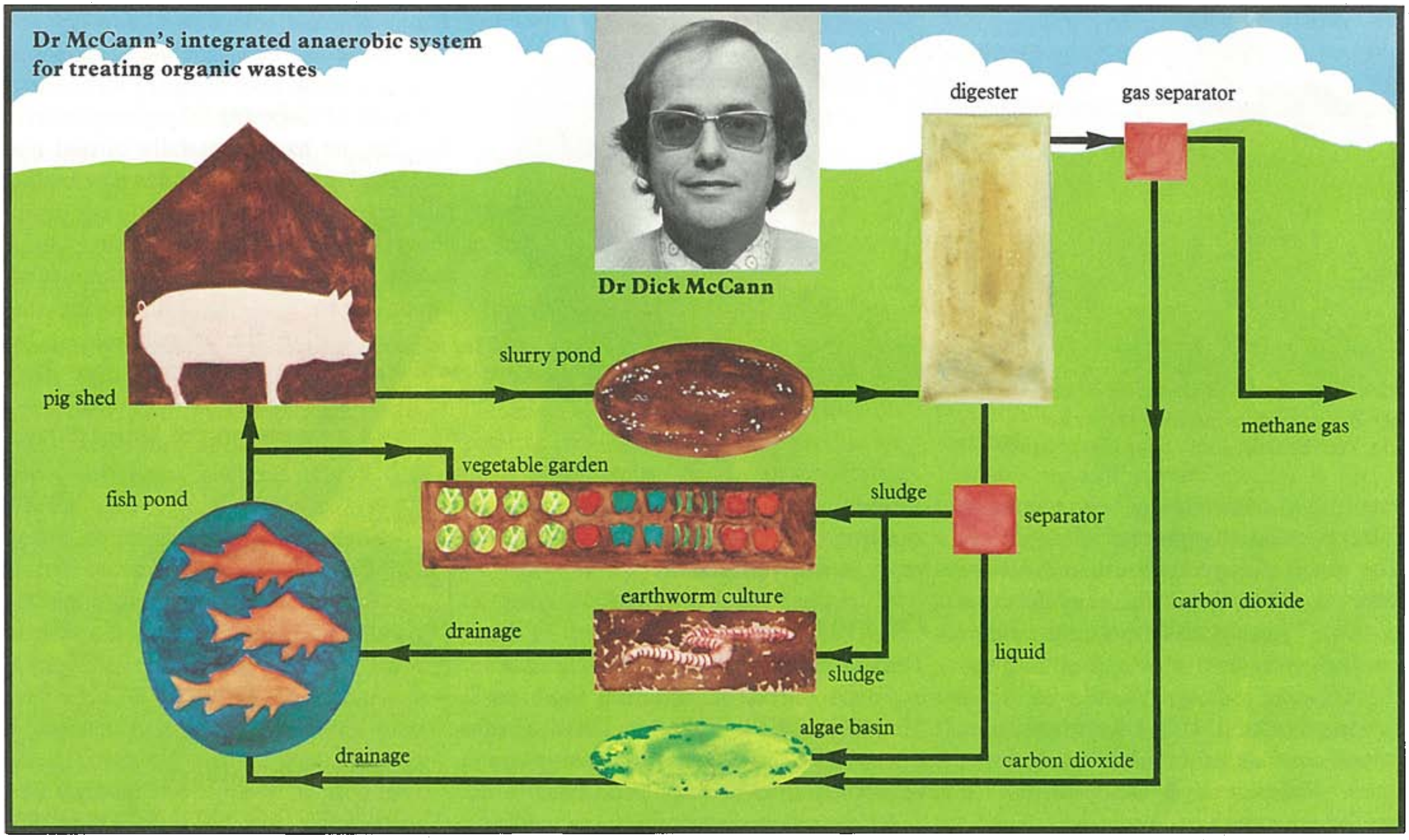
On the other hand, the overlying liquid contains most of the nitrogen and some of the phosphorus from the original manure in a dissolved form that plants can use. So it can be a valuable, albeit unbalanced, fertilizer. Having little smell and a much lower organic content, it can be sprayed onto pasture without complaint. Mr Kirby hopes to look into using the waste water from his digester on pastures.

As well as cutting down on the noisomeness and bulk of the sludge, anaerobic digestion also, of course, produces the usable methane fuel. On the farm this gas certainly does have value since it can save the cost of buying electricity, petrol, or diesel oil. So the anaerobic system not only provides a more-acceptable way of disposing of wastes, it should go a long way towards

Natural gas consumption compared with energy from wastes (Australia only)



In the unlikely event that we could use all the energy in our organic wastes, they would provide us with only a fraction of our total needs.



paying for itself. Mr Kirby intends to examine possible applications for the spare gas coming from his digester.

The big snag with the anaerobic system is that it proceeds slowly, so the digesters have to be large. Also it's sensitive. Antibiotics put in pig feed or disinfectants, for example, may stop the process if used in large quantities. Chlorinated hydrocarbon insecticides also will unbalance the system.

Ambitious project

Another research project into using piggery wastes is going on in the University of Sydney's Chemical Engineering Department under the leadership of Dr Dick McCann.

Dr McCann and his colleagues have an ambitious program for making use of every part of the wastes coming from a commercial piggery. Not only are they looking at efficient ways of digesting the pig manure to give enough methane to make the farming operation self-supporting, but they are trying to use all the nutrients in the spent digester sludge and in the large quantity of clear liquid that goes with it as well.

They will use the nutrients in the liquid by piping it into ponds and growing algae on it. They'll separate the carbon dioxide out of the gas coming from the digester, and pump this in to boost growth of the algae, which will then be used as food for fish. Any nutrients left in the fish ponds will be used by spraying the pond water onto a vegetable garden.

Meanwhile, the sludge will be used for growing earthworms. These also will be fed to fish.

The idea of growing earthworms on the sludge may sound far out, but it isn't, really. Scientists at the Waite Agricultural Institute in Adelaide have been successfully growing tiger worms on sludge from a sewage digester for some years. Dr McCann and his colleagues also plan to use tiger worms.

The scientists have successfully carried out laboratory tests with a novel design of digester. They are now constructing a scaled-up version on a commercial piggery at Berrima, south-west of Sydney. This digester is designed to process the excrement from between 200 and 400 pigs. Putting in the algae and fish ponds, earthworm-production beds, and vegetable garden will come later.

Another candidate for disposing of its large quantities of wet wastes by anaerobic digestion is the fruit-canning industry. All the canneries in Australia combined produce about half a million tonnes of wet-waste solids each year. Most of these are currently dumped, spread on paddocks, burnt, or fed to animals. Dumping, spreading, and burning are expensive disposal methods; moreover, vermin, smoke from burning off, and smell often cause serious local pollution problems.

Digesting fruit wastes

Unfortunately for the fruit-processors, nobody knows for certain how to successfully install an anaerobic digester that can deal with their wastes. While a fair amount of research has been done overseas into methane production from sewage, and to a lesser extent from garbage, nobody seems to have investigated using any form of agricultural wastes other than manure, straw, or bagasse.

At the CSIRO Division of Food Research in Sydney, Dr Alan Lane is currently specifically studying the problem of digesting fruit- and vegetable-processing wastes.

He began by trying to digest either apple pomace or citrus peel in very small digesters in the laboratory.

Once the bacterial culture had adapted itself to the two wastes, the process went very well. In all cases more than 90% of the solids were converted to gas.

Dr Lane has now scaled the process up. He has successfully run a 4500-litre (1000-gallon) pilot-scale digester for 4 months. Unfortunately, he couldn't obtain large enough quantities of fruit- or vegetable-processing waste in Sydney, so he had to use pelleted citrus peel instead.

The digestion process worked so well that Dr Lane didn't have to remove any digested sludge throughout the duration of his 4-month trial. The only snag was that, without being scrubbed, the biogas

continued on page 20

What about those small-scale digesters we have heard so much about?

Simple small-scale family digesters are most likely to work well in a tropical climate. There, they don't have to be heated or insulated. So the digester can be cheap. But, except in India, the experience hasn't been too promising so far.

Early in 1976, Mr Mardon toured eight countries in south-east Asia from India to Japan. Most of these countries had not-so-long ago begun large government-financed programs of installing family methane digesters to be run on household and stock wastes. Yet almost everywhere except in India these programs had ground to a halt, and many of the completed digesters were no longer operating.

A major reason seemed to be that individual families didn't possess enough domestic stock to produce the manure to enable their digester to provide enough gas for cooking all the year round. Others included a lack of local know-how, high construction costs, and a lack of suitable materials. In such countries, communal village digesters may look a better bet, but running them and distributing the gas will present difficulties.

And what about setting up the family digester in our suburbs? Again this doesn't look too promising. According to Mr Mardon, the average (rather wasteful) gas cooker uses about 8500 megajoules each year. This usage requires a daily input of about 0·9 cubic metres of biogas containing methane and carbon dioxide, or 0·65 cubic metres if the carbon dioxide is removed. You will probably get about 0·03 cubic metres of gas per day from the wastes of each human being in the family, another 0·1 cubic metres per person from garbage, and about 0·2 cubic metres per day from each pig. So a family of four would need to keep at least two pigs or the equivalent in other animals just to keep the gas cooker going.

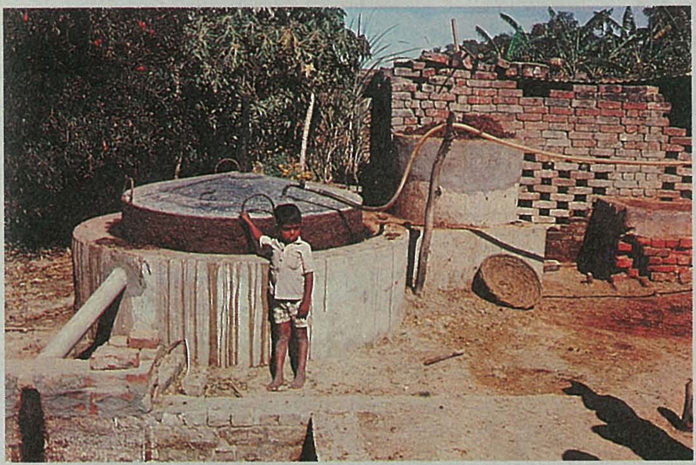
The gas would be quite suitable for burning in any gas lamp of the mantle type. A single-mantle gas lamp consumes between 0·05 and 0·08 cubic metres of gas per hour. So it would need eight or nine pigs to keep it going for 24 hours per day, or six or seven pigs if the family wastes were added in.

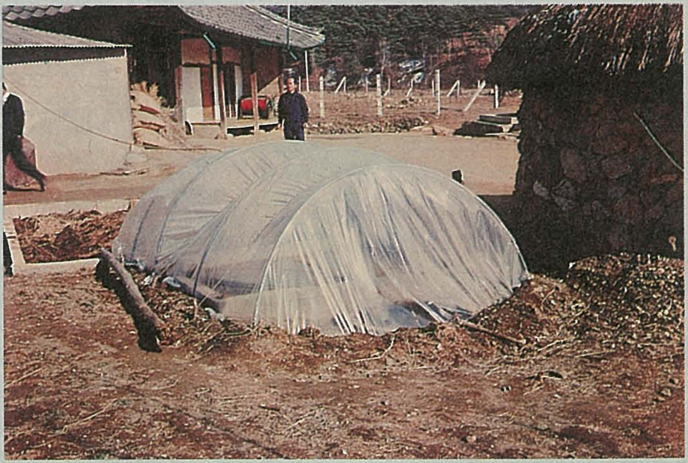
Obviously the gas lamp wouldn't be burning for 24 hours each day. Nevertheless, if it burnt only one lamp for an average of 5 hours each night, the self-supporting family of four would still need three or four pigs just to provide this minimum of light and cooking heat. Heating the house, of course, would be extra.

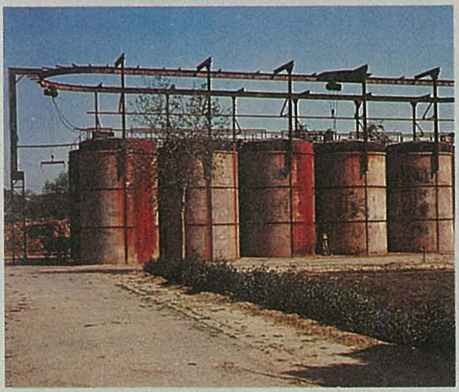
Somehow the prospect of each suburban household possessing half a dozen pigs, or a couple of cows, doesn't seem too likely, not while we cling to our present urban life-style anyway. But, Mr Mardon points out, with a change of life-style and social organization, energy self-sufficiency could be achieved. If people live communally in groups of two or three families, combine their digestible kitchen wastes with their toilet wastes, and minimize water flushing when disposing of these wastes, then they should be able to produce enough methane to cater for their domestic needs.

Below left:
Small methane digester in a village in Uttar Pradesh, India. This one, and many others like it, run very well on cattle dung.

Below right:
This small rural digester in a village in South Korea is protected by a plastic greenhouse to prevent it from freezing in the bitterly cold winter winds.







Left:
A large bagasse digester at the Sugar Research Institute, Kampur, India. It converts crop wastes to biogas for use in the Institute's laboratories.

Right:
A 2¼-million-litre high-temperature digester at the Oriental Yeast factory in Tokyo. The factory's waste water is treated for 7 days at 54°C.

given off wouldn't burn, since it consisted of 47% carbon dioxide and only 53% methane.

Dr Lane would now like to transport his pilot-scale digester to a fruit-processing plant and try it out on real wastes. He thinks that Shepparton in Victoria may be a particularly suitable location, since preserving companies in that district produce about 50 000 tonnes of wet wastes each year.

High-temperature digestion

The projects of Dr Lane, Mr Kirby, and Dr McCann, and indeed Mr Coulthard's 'Sanamatic' system and all sewage digesters, are designed to run at around about 35°C. However, this is really at the lower end of the temperature range at which anaerobic digestion can take place. As the temperature rises the process speeds up, which increases both the gas production in a given time and the proportion of the organic waste digested.

As it happens, the rate of digestion doesn't increase uniformly with an increase in temperature. The graph has a kink in the 40's, where the rate is increasing more slowly. Consequently, it's best to run the digester either at around 35° or at about 60°C. The reason for the kink in the graph is that different methane-producing bacteria operate at 60° from those operating at 35°. At temperatures in between, neither type is at its best.

To date nobody in Australia has taken much interest in the high-temperature digestion process. Investigators have felt that the amount of energy needed to keep the digester contents at 60° will be more than the gas output of the system. However, Mr Mardon questions this. It may be true when digesting watery sewage sludge, but, he points out, crop wastes and garbage can be made available with much higher concentrations of solids. Also the hot digester liquid can be recycled to save heating energy and nutrients. The incoming feed can also be heated by the hot effluent using a heat exchanger, which will also help achieve the required high temperature economically.

Producing methane is an effective way of using difficult wet wastes.

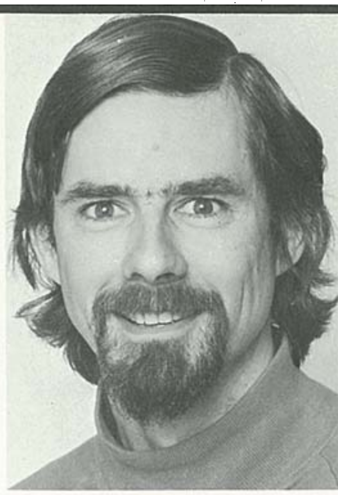
Mr Mardon is currently examining the possible advantages of digesting a number of agricultural crop residues at high temperatures. Dr Lane also intends to investigate higher-temperature digestion.

Canning peaches at Shepparton, Vic. Canneries in the district produce about 50 000 tonnes of wet wastes each year, which could be converted to methane.

To date, successful digesters have been developed by trial and error, but nobody really has much idea as to the details of what's going on inside them. Yet without this knowledge it won't be possible to make the process more efficient. For example, is it really best to start up a digester by using the usual procedure of seeding it with sewage sludge, and then leaving the bacteria to sort themselves out on the new waste material? This process may take several weeks, during which time little gas is produced. Would it be better to tailor bacterial cultures to the particular waste to be digested?

Again, is there anything that one can do to lignin-containing wastes so that bacteria can break them down quickly? Also, is it possible to speed up the rather slow rate at which the bacterial enzymes actually break down cellulose fibres? Research into these topics has been carried out for some years at the Biochemistry Department at the University of Sydney. At the CSIRO Division of Chemical Engineering, Mr Gerard Vaughan is also just starting a new project looking into the processes going on during anaerobic digestion.

Dr Lane's pilot digester for fruit- and vegetable-canning wastes. It has worked well when fed citrus peel.



Dr Alan Lane

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