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Vienna, Austria, 8 - 12 October 1973

THE ROLE OF FEEDSTOCKS IN SINGLE CELL PROTEIN PRODUCTION 1/

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SUMMARY

THE ROLE OF FEEDSTOCKS IN SINGLE CELL PROTEIN PRODUCTION 1/

J. H. Harwood* and A. Gabriel**

The paper considers the role of existing and potential hydrocarbon feedstocks in single cell protein (SCP) production and compares the potential viability of the various conversion routes from hydrocarbon substrates.

The conversion of natural gas (Methane) and liquid petroleum gas fractions (LPG), using defined mixed bacterial cultures is discussed in some detail and the importance of feedstock values on end product costs is demonstrated.

Alternative routes via Methanol and the technical implications of using defined mixed bacterial cultures in the context of the probable future availability of "Energy Methanol" (Methyl Fuel) is considered. Comparisons are made of feedstock costs for other hydrocarbon conversion processes including the yeast/gas oil and yeast/n-paraffin routes.

The likely current and future economics of SCP production are shown to be feedstock and also location dependant.

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I. RANGE OF POTENTIAL FEEDSTOCKS

The potential range of feedstocks which can and are used as substrates for conversion to Single Cell Protein (SCP) is extremely large. There is no ideal general feedstock, rather it is a case of assessing the most suitable feedstock/substrate for a particular situation.

Of the greatest potential interest are the hydrocarbon sources ranging from natural gas (methane), liquified petroleum gas fractions (LPG) and also various first stage chemical derivatives such as methanol. Indeed the whole of the hydrocarbon series can be used including the long chain normal paraffins. The latter category is already being used as a chemical feedstock on an industrial scale, not simply for SCP production. Hydrocarbons derived from coal, lignite, shale and tar sands are also potential longer term candidates.

In addition to the fossil hydrocarbons, there are a variety of carbohydrate and cellulosic sources and various waste liquors and even carbon dioxide which can be fixed photosynthetically or chemolithotrophically by organisms capable of oxidising molecular hydrogen with oxygen as the hydrogen acceptor.

In practice, however, waste liquors containing carbohydrates, cellulosic and similar materials are usually linked to specific techno-economic situations and are closely related to the questions of pollution prevention and waste disposal. For this category of feedstock, no general assesement is possible since each case has to be taken on its own merits. It should be noted, however, that there are already many successful and efficient enterprises based on these "special" situations. Perhaps the yeast plants utilizing sulphite waste liquors from paper pulp mills are the best developed examples. Other waste disposal situations are also under development, for example the handling of cattle feed lot effluent and other agricultural waste.

(Slide 1. LIST OF POTENTIAL SCP FEEDSTOCKS AND SUBSTRATES)

II. HYDROCARBON FEEDSTOCKS AND CONVERSION ROUTES

The use of liquid and gaseous hydrocarbons falls into a different category from the carbohydrate and cellulosic substrates in that their scale and universality of availability make them general feedstock candidates for large scale plants in a wide variety of locations.

In view of the fact that fossil hydrocarbons are a finite and diminishing resource, it has been suggested that renewable raw materials, such as carbohydrates and cellulose, must be preferable as carbon substrates for SCP production rather than the essentially non-renewable hydrocarbon or hydrocarbon derived substrates. In reality, however, energy is employed simply to improve the overall quality of life and the burning of hydrocarbons only achieves this indirectly, whereas utilization for protein production represents a much more direct contribution by our limited fossil fuel resources to an improved quality of life.

In view of probable increasingly stringent product quality regulations, it could well be that cheap cellulose in the form of waste materials will not be permitted at least for some categories of SCP production, because of the potential carry-over of undersirable and/or dangerous contaminants from the substrate to the product. Furthermore, the availability of carbohydrate substrates for fermentations is highly dependent on local and climatic conditions and subject to intermittent harvest failure and other variations.

For large scale continuous production on a multi-location basis, hydrocarbon substrates offer the most universally available and standardized raw material substrates for SCP production.

III. NATURAL GAS

Methane is the first member and the simplest of the paraffin series. It is available as natural gas in many parts of the world and has the great merit of low transport costs for moderate distances over land. However, in many of the more remote parts of the world, pipeline transport is not feasible - at least at present for low pressure gas - so that flared gas situations exist and will continue to exist for some time to come. In the context of this situation the conversion of natural gas - essentially methane - directly to a high value protein concentrate, was considered to be a legitimate techno-economic target.

Unfortunately methane from a microbiological view is a relatively inert molecule. Nevertheless a process has now been developed using defined mixed bacterial cultures which will enable the conversion step to be made economically under non-aseptic industrial conditions.

The oxidation of methane with attendant biomass production follows the route:-

$$CH_4 \rightarrow CH_3OH \rightarrow H.CHO \rightarrow H.COOH \rightarrow CO_2$$

The most difficult step and one which produces essentially no energy for growth, is the first step to methanol. On the other hand the heat generation at this stage is considerable and demands the removal of large quantities of low grade heat.

For SCP production, the yield coefficient, i.e. the weight of cells produced per unit weight of carbon substrate utilized, is one key biological factor in the process. Another factor is the protein content of the cells produced which in the case of this type of bacterial conversion is in the 70-80% range.

In the ideal fermentation for biomass production, the products will be carbon dioxide, water and cell mass, the latter with a maximum protein content. These targets can best be achieved in continous culture under carbon substrate limited conditions. In order to maximize cell mass production, certain defined mixed cultures of bacteria have been selected which are capable of achieving yield coefficients of around 1.0 under certain continuous methane culture conditons.

IV. METHANOL ROUTE

It has long been known that the bacteriological conversion of methane goes via methanol and it was an obvious st p to consider the use of methanol as an alternative feedstock to methane. The methanol itself can be produced either from methane, naphtha or other carbonaceous feedstock.

There are considerable merits to the use of methanol. In a sense the process is helped by the fact that methanol is a liquid. This simplifies the plant and avoids some of the mass-transfer complexities of working with multiple gaseous substrates. Thus for a given size of fermenter, product through-put is greater and significantly less cooling is required compared to the direct methane route.

Against this, one has to consider that methanol at least in European terms, is a relatively expensive feed material as compared to methane in a flared gas situation. Furthermore, in an integrated chemical methanol plus SCP production unit, the effect of the extra capital related to the methanol plant has also to be taken into consideration.

However, the advent of "energy methanol" (methyl fuel) on a 5-10 million tons per annum scale, could have a dramatic effect on the economics of the methanol route and it has already been established that mixed bacterial cultures can grow on this potential feedstock without subsequent refining.

For the production of SCP from methanol, it is essential that carbon substrate utilization should be as complete as possible, particularly from the point of view of ensuring that the product does not contain more than residual traces of methanol. The steady-state level of methanol present in a continuous culture of methanol utilizing organisms wil be a function of the affinity of the organisms for the substrate. With defined mixed bacterial cultures, the affinity for methanol was found to be 20 micro molar. At half the maximum growth rate, this would be the approximate steady-state concentration in a methanol limited continuous culture. Thus the residual methanol concentration in a chemostat fed with 1 volume % methanol would be less than 0.005% of the methanol supplied.

V. PROCESS TECHNOLOGY FOR SCP PRODUCTION FROM C_1 COMPOUNDS

Our own research programmes have been very largely concerned with the production of SCP from C_1 compounds, although parts of the programme are equally applicable to other routes for SCP production.

Key factors around which the process research programme has been based have been the questions of yield and productivity.

Yield - the weight of biomass produced per unit weight of substrate utilized.

Productivity - the weight of biomass produced per unit fermenter volume per unit time.

In the case of yield, performance has essentially been optimized, whilst in respect of productivity, the overall programme has included cell density and dilution rate studies, mass-transfer studies and particularly questions of multiple gaseous substrates with potential double substrate limitations. Conversion efficiencies of gaseous substrates, heat transfer problems and culture stability aspects have also been closely studied.

VI. OTHER GASEOUS SUBSTRATES

Comparatively little attention has been paid to the cultivation, for SCP production, of organisms which utilize other gaseous hydrocarbons, particularly the constituents of liquified petroleum gases (LPG). However, under certain conditions, especially where natural gas is fed into long distance pipeline transmission systems, substantial quantities of both propane and n-butane may be available and these are potentially useful fermentation substrates.

Part of the technology developed for the commercial cultivation of methane utilizing bacteria is also applicable to all systems where multiple gaseous substrates are used.

VII. GAS OIL/NORMAL PARAFFIN ROUTE

The gas oil/normal paraffin route is historically the best established industrial route and its greatest merit is that it already exists as a proven piece of technology. Yeasts can convert both the normal paraffin content of gas oil or separately extracted normal paraffins into products with protein concentrations in the 60-70% range. There is, however, a potential problem. The gas oil route is very attractive in that it does two jobs at the same time, producing protein and by effectively consuming the normal paraffin content, also dewaxing the oil. However, carry-over problems when using this route are intrinsic, although clean up processes have been developed to a very high level of effectiveness.

When using normal paraffins as the substrate, they must first of all be specifically extracted using an urea wax process or perhaps preferentially a molecular sieve process. These extraction processes are expensive and high purity normal paraffins are unlikely to become a really low cost feedstock in the foreseeable future, especially as they are also in much demand as chemical feedstocks. Much discussion has taken place about "n-paraffins of pharmaceutical standards". At the 100,000 t/a plus scale, this is a misuse of terminology and if they were produced to British Pharmacopoeia standards, the cost would be quite prohibitive. Nevertheless given an adequate supply of low cost n-paraffins the yeast-n-paraffin route is practical and economically viable at the animal feed protein prices which will probably prevail in the mid-1970s.

(Slide 2. DIAGRAMATIC COMPARISONS OF HYDROCARBON PROCESS ROUTES)

VIII. COMPARISON OF HYDROCARBON PROTEIN PROCESS ROUTES

All the processes described can produce animal feed protein which is at least comparable to soya bean meal and in some cases even with fish meal in respect of concentration and nutritive values. When allowance is made for variations in the percentage protein content, other differences are relatively minor and all the products would be acceptable wholly or at least in part replacement formulations for currently imported high cost conventional protein meals.

By the mid-1970s, the price of soya bean and other vegetable meals will come down from the very high levels of this year due to more plentiful supply conditions, but this is unlikely to apply to the same extent to fish meal which will probably remain in short supply and at premium prices relative to soya bean meal (on a protein content basis). Although the recent extreme prices are unlikely to be sustained, they will nevertheless not return to the near steady state levels of the late 1960s and including the 1970/71 season.

In this changing context, the yeast/normal paraffin route may not be able to retain in the longer term its present position as a front runner, bearing in mind the likely limited availability and high costs of normal paraffin feedstocks of suitable quality. However, given early investment and the added margin of various capital grants, from governmental and community funds, current projects could remain competitive.

As far as can be projected at this time, the lowest cost feedstock, under normal fiscal conditions, is likely to be methane in a flared gas situation and to derive the fullest cost benefit, a direct methane to SCP plant would have to be sited in a flared gas producing area or at least at the end of a gas pipeline from such an area.

If, however, energy methanol (methyl fuel) became available and this was used directly as an SCP feedstock material, the location constraint is minimized since the transport of a chemical liquid such as methanol over long distances could be made in near conventional tankers at a fraction of the cost of cryogenic LNG tankers. Thus the actual SCP plant could be sited near major consuming areas which could, in practice, be at or near most of the existing European and Japanese coastal refineries.

IX. SUMMARY

(Slide 3. HYDROCARBON FEEDSTOCK RELATIVE COST LEVELS AND PROCESS FACTORS)

(Slide 4. COMPARISON OF ALTERNATIVE PROCESSES AGAINST LIKELY FUTURE PROTEIN PRICE LEVELS)

X. CONCLUSION

Thus it may be concluded that in the long run, feedstock availability and prices are the major constraints in deciding on the type of process as well as location of an SCP plant and since there are more potential flared gas/energy methanol situations available, then it is highly likely that the methane direct to SCP process or methane via methanol process will become the main processes for SCP production for animal feeds during the 1980s.

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