Engineering, Science and Society

An Inaugural Lecture Given in the University of Rhodesia

by

J. Harris

UNIVERSITY OF RHODESIA

ENGINEERING, SCIENCE AND SOCIETY

An Inaugural Lecture
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by
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CONTENTS

ENGINEERING, SCIENCE AND SOCIETY.

J. HARRIS

Summary

As a background to the theme of this lecture, the nature of Universities is described and also the development of industry within Rhodesia over the last decade is outlined. It is upon the acknowledgement by the University of a concern in the human activity termed industry that the Faculty of Engineering within the University of Rhodesia is built, and also upon the acceptance that there exists a distinct and substantial corpus of knowledge called Engineering.

The work is essentially written around the idea that Mechanical Engineering is concerned with the social and technological aspects of the harvesting, transportation, conversion and ultilisation of information, materials and energy.

An outline comparative analysis is given of the Rhodesian industrial sector (both agricultural and non-agricultural) which forms part of the basis of studies in the Engineering Faculty of the University. Conclusions are drawn on four points:

1. Employment rate
2. Employment distribution
3. Efficiency of employment
4. Distribution of outputs.

The implications for the University are also noted.

Looking forward, new data from official sources are presented relating to skilled labour estimates for the 1975-1983 period. They show that the existing dominant position of Mechanical Engineering is expected to be maintained over at least the next decade.

A discussion is given which seeks to shed light on the relationship between science and technology. Mechanical Engineering is shown to be particularly concerned with construction and functioning of systems which are not necessarily of a mechanical or thermal nature; some of the technology may be applicable to community

development and the transfer of technology, also to the control aspects of these processes.

The subject of energy is treated in rather more detail than the related subject of materials. The global resources of various forms of energy are discussed and the requirements spanning the next century outlined. It is shown that there is little hope of spreading a uniformly high material living standard throughout the world in future, due to the energy required. Modern concepts of energy budgeting are outlined.

PREFACE

Vice-Chancellor, Deputy Vice-Chancellor, Distinguished and Honoured Guests, Ladies and Gentlemen, and I am also pleased that we have some children present, the world and the future, about which we shall talk more later, belongs to them.

As you know part of my roots are in Wales, from where we travelled in January of this year to reach Rhodesia. The major exports of Wales are preachers, teachers and coal, each a light to lighten the Gentiles. I would particularly like to welcome two visitors from Wales who arrived a few days ago to be with us, Croeso, cymru am byth.

Principal, a wedding has been arranged, the banns have long been published, the guests are here assembled, the bride and bridegroom stand ready to pledge their troth in wholesome union. The bridegroom is the University, I am not the bride, though I represent her.

I should mention that this is the third bride in engineering that the groom has taken. Is the union so wholesome then? We must refer to this matter later.

I would like to tell you a story of a certain country gentleman who aspired to the heights of respectability in his society, and had gathered to himself wealth, estates and influential friends until he was much admired.

However he was not content with his lot and determined that he would bring on himself some sort of Christian sign from the Church to seal his success. After giving the matter careful thought he decided upon a wedding to which he would invite many guests and dignitaries to join in the celebrations. Being a careful man, though not particularly well versed in Christianity, he started to dutifully and regularly visit the local priest to receive instruction.

The long awaited day appointed for the wedding finally came. The priest, guests and groom sat patiently waiting. Then the whisper went around the congregation that the bride had arrived. All turned to strain their eyes to catch a glimpse of the bride and there appeared at the doorway sixteen suitably adorned ladies.

Possibly the most shocked person there was the priest, who hurried to the bridegroom to demand an explanation. The bridegroom was equally surprised at the apparent agitation of the priest. "Well,' he said, "you told me in your instruction to particularly remember, that I would marry four richer, four poorer, four better and four worse."

Having spent my recent years in four very different Universities (five including the years as a student) I thought it may not be too presumptious, with your indulgence, to air some of my views on the subject at the outset. Universities are abiding features of our society, worthy of careful preservation and handing on to future generations and certainly able to accomplish more than just fathering a qualified human material.

ENGINEERING, SCIENCE AND SOCIETY

1. Introduction

Too often we are deceived by local plausibility and specious fashion which masquerades as reality. Much of our situation and thinking today would no doubt have appeared peculiar to our forefathers and may well seem absurd to our descendants.

In such a transient world we look for some reference points to focus upon, which we hope and trust will have more than usual durability and validity. These reference points are to be found in the form of institutions which are created as vessels, more durable than human beings, to voyage down the generations; the arks conveying the treasures of our civilizations. In our own context, the two with which we are most familiar and which are the most fundamental are, the Church and the Universities, whose joint special concern is the conscience, wisdom and knowledge of the civilization into which we have been born.

In the first place the University was derived from the Church.[1] This historical connection is still very visible today. In the earliest stages of development (12 century), the Chancellor of a cathedral, or some other authority, began to accord masters permission to open other schools than the cathedral school.

Academic mobility probably originated in a further stage of development when the licence to teach, granted after formal examination, empowered the master to carry on his vocation at *any* centre. Later, Universitas magistrorum et scholarium (equivalently = studium generale) could only be formed with the right of conferring degrees, which meant a licence to teach, if it had a licence from the Pope, Emperor or King. In effect the Head of State delegated the power to confer degrees to the Universities. This procedure is still followed, the University of Rhodesia functions under a Royal Charter,[2] granted to the University College of Rhodesia and Nyasaland on 10th February, 1955.

Students and teachers as clerici (i.e. members of the clergy) enjoyed certain privileges and immunities, such as protection against unjust arrest, trial before their peers and also "permission to dwell in security". These privileges were subsequently extended in various ways. The protection thus afforded was matured and mutated into "academic freedom", which in the hands of competent scholars means the right to question or criticise any intellectual concept or physical event in a creative manner. Indeed disputation was the common modus vivendi and rhetoric a cherished art.

The ultimate concern of universities is knowledge, and unless I am mistaken their role in Society is to distil the essence, to create and to propagate this entity. If this role does not belong to the universities, then I do not know to whom it does belong. This function will outlive any transient fashions of politics, customs or even science.

Universities have come under heavy pressure in recent times to help to satisfy particular material demands of society, just as all the resources of the globe have come under the same type of pressure. This is particularly true in the so-called developed countries. Here we must draw a distinction between the function of the training school within industry at one extreme, and a university at the other, as their roles are fundamentally different. Many will be familiar with the great strain on the university system in Britain as a result of the alternate stretching and compression exerted on it by society.

In order to be acceptable as a university subject, it must be satisfactorily proved that there exists a well-defined substantial corpus of corresponding knowledge. Engineering has been accepted by the University of Rhodesia, and I trust, Principal, that the proof will be found a posteriori.

This being the third Engineering Inaugural Lecture to be delivered within the very recent past and the second to be delivered this year, no doubt the reasonable question has crossed many peoples minds as to whether it is necessary to have three Chairs in Engineering.

It is true that the age prior to the period spanning what is now called the "industrial revolution", 1750-1850, engineering of two classes only was known, namely civil and military engineering.

Just prior to the industrial revolution period there had been a growing investment in roads and waterways, the former had fallen into neglect since the time of the Romans. This creation of an infra structure was due to civil engineers such as Metcalf (1717-1810), McAdam (1956-1836), Telford (1957-1834) and Brindley (1716-1772) (with the support of the Duke of Bridgewater). This transport revolution overlapped into the industrial revolution, which would have been much impaired without a suitable infra structure, and itself received a second impetus with the advent of mobile steam engines (locomotives).

However the industrial revolution proper rested upon the use of steam, coal and iron, the invention of manipulative machines to produce consumer goods, steam engines for driving the machines and finally to replace animal, wind and water power as prime movers.

It has been said that this period was one of immense achievement and also of immense suffering, for in human terms the change from a rural farming community to an industrialised society, was not cheaply purchased. Mankind has not yet fully come to terms with problems of living in a society based mainly on non-agricultural industry. Cash crop agriculture is itself now more of an industrial process and is included in the industrial sector statistics in Rhodesia as with many other countries.

During the industrial revolution mechanical engineering emerged as a clearly defined, vigorous and independent activity, which also gave birth to the illustrious first President of the Institution of Mechanical Engineers (U.K.) namely, George Stephenson (1781-1848).

There is some current thought about how far it may be feasible to fuse together the various branches of engineering, more particularly the three major branches, those of Civil, Electrical and Mechanical Engineering. However, a recent well-known President of the Institution of Mechanical Engineers, Professor Sir Hugh Ford, F.R.S. has expressed the opinion that Mechanical Engineering is a strong, distinct discipline at the present time and well able to stand on its own feet. I wholeheartedly concur with this opinion and would add the remark that it is likely to remain so in the foreseeable future. There is a certain amount of lip service paid to things such as inter-disciplinary engineering, having taught in both the fields of Mechanical and Chemical Engineering, which themselves overlap at a number of points, and been faced with the question, "Are you then mechanical or a chemical engineer?" It is no doubt natural to feel reservations on inter-disciplinary suggestions if it leads to no clearly defined under-graduate discipline.

A DECADE OF INDUSTRY IN RHODESIA: 1965-1975

On taking up the Chair of Mechanical Engineering here in January of this year (1975) I felt moved to make a study of the industrial history of Rhodesia over the recent past; the earlier records are not so complete and and perhaps less important in plotting the growth of industry in this country. I would now like to report a summary of the findings of this study to date.

Some of the general trends to be looked for are:

1. The employment rate.
2. The employment distribution.
3. Efficiency of employment.
4. The distribution of the economic output.

Also the implications for the University are of interest.

During the decade, 1965-1975, there has been an average annual increase in the total population of $3\frac{3}{4}\%$ (approximately). There is nothing particularly remarkable about this figure at the present time except that this is virtually the rate of increase of that section of the population which is only partly within the cash economy and herefore not wholly economically active. The rate of increase of the economically active section of the community appears rather less at about 3% per annum and therefore if continued could pose a problem for the future. The methods by which the imbalance might be ameliorated are by:

1. Educational and material facilities to bring the economically inactive into the cash economy. (Such work is being currently undertaken by Tilcor).

2. Increasing industrial efficiency combined with a wealth distribution mechanim.

3. Expansion of the work force in increased employment opportunities. If this is by way of making industries more labour intensive, then it is counter productive to item 2 above.

The total population figures, based upon the Monthly Digest of Statistics data, are shown in Figure 1. The Gross Domestic Product in $millions over the same period is shown in Figure 2, giving an approximate rise of 16.2% per annum in the same decade.[3] The actual rise in the G.P.D. is somewhat lower at 8%. This allows for the decline in the purchasing power of the dollar (roughly 30%) over the same period.

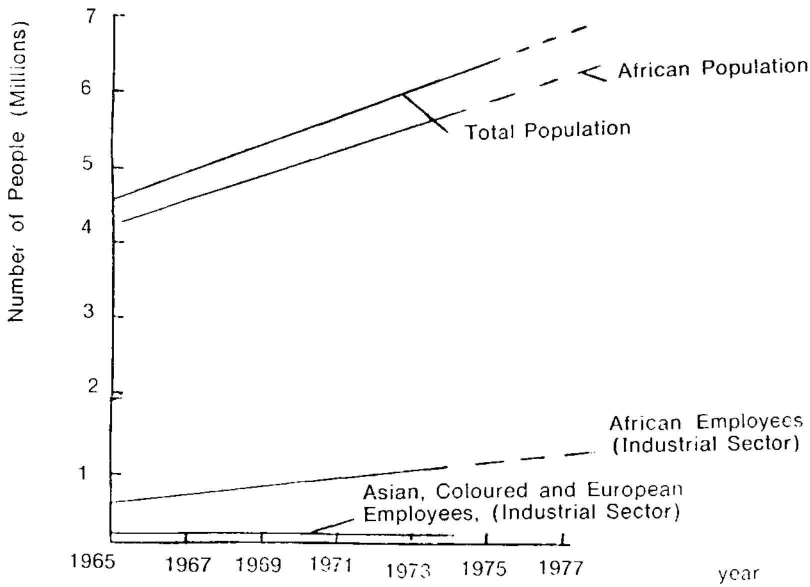

Figure 1. Population and Employment Statistics. (Rhodesia) (Ref. Monthly Digest of Statistics, Jan. 1975)

Before discussing any further statistics, reference must be made to the industrial classifications used by the Central Statistics

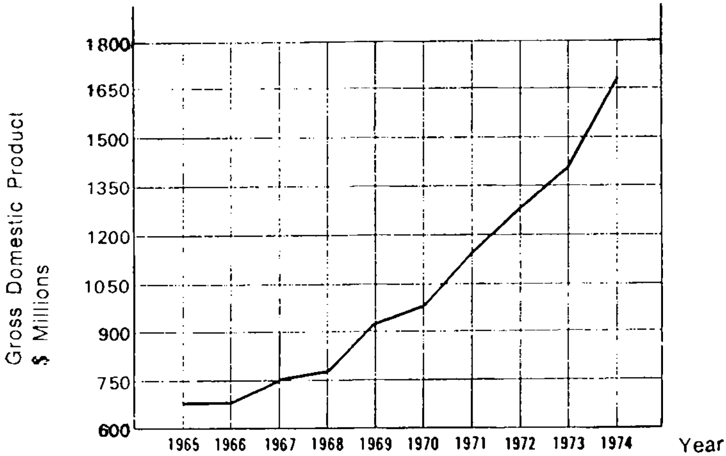

Figure 2. Gross Domestic Product for Rhodesia 1965-1974[14]

Office in Rhodesia. This is based upon the United Nations' *International Standard of Industrial Classification of all Economic Activities (1968 Revision)*, modified to suit local conditions. The major group in this classification is as follows:

Agriculture and Forestry (including Agricultural Services)
Mining and Quarrying
Manufacturing (including Printing and Publishing)
Electricity and Water Supplies
Construction (Building and Civil Engineering)
Finance, Insurance and Real Estate
Distribution, Restaurants and Hotels (including Motor Vehicle Service Stations not primarily engaged in repair work)
Transport and Communications
Services:

(i) Public Administration

(ii) Social and related community services such as education, health, research institutions and religious organisations

(iii) Business services such as legal and accounting services, advertising and leasing of machinery and equipment
(iv) Recreation and cultural services
(v) Personal and household services including repair of footwear, household equipment and motor vehicles, domestic services, dry cleaning, barber and beauty shops
(vi) International and extra-territorial bodies.

Additional notes on the classification system are given in the Monthly Digest of Statistics.[3]

The above list is lumped together under the heading "Industrial Sector". It is clear that the Engineering Faculty in the University of Rhodesia is more closely related with some of the sectors in the above classification list than others and is not related at all to some.

For the present purposes it is interesting to compare the outputs from the Agricultural, Mining, Manufacturing and Construction sectors of the industrial group. This comparison is shown in Figure 3.

The data illustrated in Figure 3. shows that the manufacturing sector output, to which the Department of Mechanical Engineering is most strongly related, is by far the largest contributor to the economy at the present time. (The electricity and water sector combined is smaller than the construction sector output).

From our point of view, the number of people engaged in a certain industrial sector is also of interest. Comparative figures are given in Table 1. Agriculture has by far the largest number of employees, but is, of course, much more labour intensive than the other sectors. After this comes the Manufacturing sector, which is clearly larger than any of the others.

The state of development of a country is very often viewed on a national or international scale by the relative size of the work force in agriculture to that in the rest of the industrial sector. In Rhodesia there is, of course, a relatively large work force engaged in Agriculture, the main interest is how rapidly there is a movement towards the rest of the industrial sector and away from

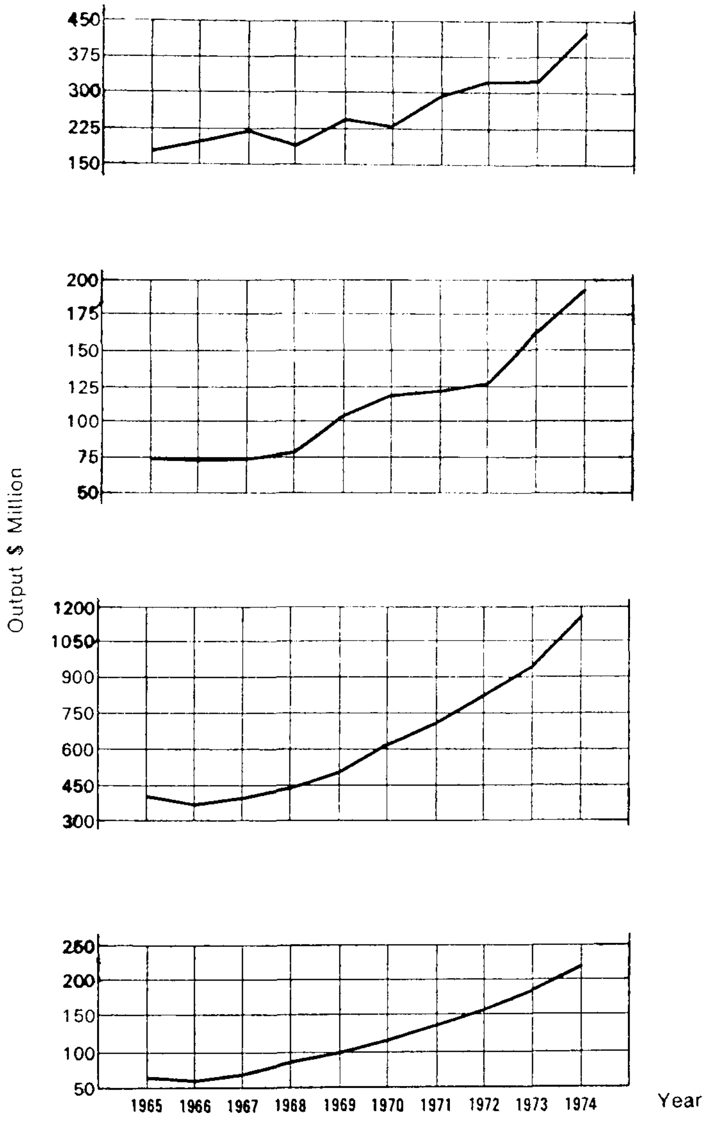

Figure 3. A comparison of the outputs of four groups of the Industrial Sector

a) Agricultural
b) Mining
c) Manufacturing
d) Construction

agriculture. This data is shown in Table II, which shows that the ratio of Rest: Agricultural employees increased slowly from 1965 to 1971 and reached a peak of 1.8981. By way of comparison the ratio would be of the order of 100 to 500 in what is known as a developed country. Rhodesia cannot be said to be developing much in this sense.

It is interesting to note that there has been a small, but steady, increase in the percentage of the total population employed from 15.85% in 1966 to an estimated 18.25% in 1975.

The other important aspect is that of industrial efficiency, (productivity) as measured by the dollar per capita product. This is shown in Table III. As expected, the per capita output is three to four times as great for the rest as compared with agriculture. What is perhaps less expected is that the ratio fluctuates about a mean value of 3.304, with no obvious trend with time.

Finally, on this data, I make the observation that there appears to be a marked imbalance in the proportions of undergraduate students in the Faculty of Engineering in the University of Rhodesia. The mechanical engineering students are in the minority, whereas there is good evidence to suggest that they should in fact be in the majority. I would expect the Mechanical Department to become rather larger than the other two of Civil and Power and Electronics unless prevented from doing so by constraints, and I shall endeavour to see that the balance is redressed in this respect.

It may be argued that the above conclusion cannot be drawn from data in Table I since industry in Rhodesia, and indeed within Africa generally, is more labour intensive and contains a much larger element of unskilled labour, rather unrelated to the number of graduates employed. However, if one considers the skilled manpower data[4], the conclusions are reinforced as there should certainly be a strong correlation between skilled worker numbers and those for graduate engineers. The data are shown in Table IV and Figure 4.

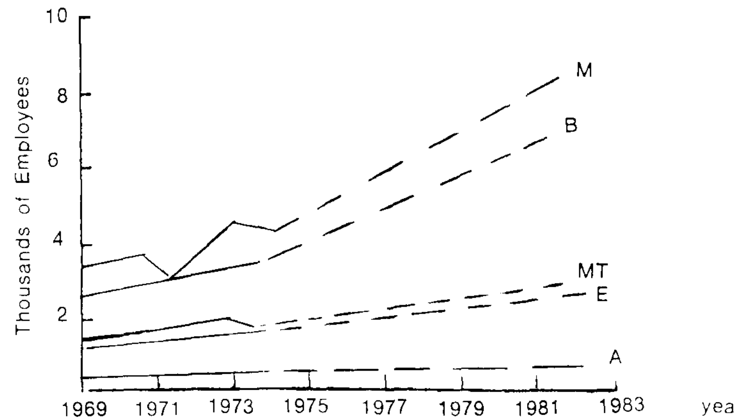

Figure 4. Skilled Manpower Statistics and Forecasts to 1982. (Ref. Private Communication from the Apprenticeship Training and Skilled Manpower Development Authority, dated 8th July, 1975. Ref. D/2/16/452)

KEY A Aircraft

B Building

E Electrical Engineering

M Mechanical Engineering

MT Motor Industries

The ratio of skilled workers in Table IV to the total number of employees in the engineering sector of the industrial group in Table II is very low and certainly as an important step in any desired industrialisation, requires revising by a massive training programme. The importance of this lies in also creating able consumers who can absorb the industrial output. It is pertinent to point out that the chemical process industry, an essential ingredient in an industrial society, is intrinsically a large scale operation requiring a large scale consumer market. This should naturally evolve in Rhodesia over the next one or two decades if the familiar growth pattern of civil engineering infra-structure, mechanical engineering manufacturing followed by chemical engineering manufacturing is followed.

(1) African
(2) Asian + Coloured + European
(3) Total

TABLE I

Thousands of Employees

Year	Agriculture	Mining	Manufacturing	Electricity and Water	Construction	Ind. Total Less Agric.	Gross Population
1965 (1)	289	43.6	68.8	3.7	29.4	367	
(2)	4.36	2.95	15.10	1.22	5.67	85.4	4490
(3)	293.36	46.55	83.9	4.92	35.07	452.4	
1966 (1)	272	45.7	68.5	3.8	30.1	372	
(2)	4.37	3.14	15.11	1.26	5.9	85.7	4630
(3)	276.37	48.84	83.61	5.06	36.0	457.7	
1967 (1)	271	47.3	74.7	3.8	30.6	387	
(2)	4.09	3.23	15.7	1.31	6.0	87.6	4790
(3)	275.09	50.53	90.4	5.11	36.6	474.6	
1968 (1)	282	48.4	82.0	4.1	36.1	411	
(2)	4.06	3.34	16.89	1.38	6.61	91.7	4960
(3)	286.06	51.74	98.89	5.48	42.71	502.7	
1969 (1)	300.5	50.4	90.2	4.0	40.3	435	
(2)	4.54	3.45	17.48	1.41	7.12	95	5130
(3)	305.04	53.85	107.68	5.41	47.42	520	
1970 (1)	290.5	53.3	99.5	4.2	42.5	457	
(2)	4.59	3.74	18.49	1.44	7.49	99.1	5310
(3)	295.09	57.04	117.99	5.64	49.99	556.1	
1971 (1)	303.4	53.9	105.3	4.2	47.0	481	
(2)	4.64	3.67	19.72	1.59	7.89	103.71	5500
(3)	308.04	57.57	125.02	5.79	54.89	584.71	
1972 (1)	334.2	54.2	112.6	4.4	51.2	510	
(2)	4.68	3.65	21.34	1.68	7.83	108.2	5690
(3)	338.88	57.85	133.94	6.08	59.03	618.2	
1973 (1)	348.1	54.4	120.1	4.8	58.2	541.1	
(2)	4.8	3.56	22.05	1.75	8.07	111.54	5900
(3)	352.8	57.96	142.15	6.55	66.27	652.64	
(June,) (1)	379.7	58.1	129.9	5.5	64.8	575	
1974 (2)	4.76	3.59	22.99	1.78	8.67	114.04	6100
(3)	384.46	61.69	152.89	7.28	73.47	689.04	

Ref. Monthly Digest of Statistics, January, 1975.[3]

Issued by the Central Statistics Office, Salisbury, Rhodesia.

TABLE II

Thousands of Employees

	Agriculture & Forestry			Rest			Ratio	
Year	African	Asian Coloured and European	Sub-Total	African	African Coloured and European	Sub-Total	Rest/Agric.	% of Population Employed
1965	289	4.36	293.36	367	85.4	452.4	1.5421	16.609
1966	272	4.37	276.37	372	85.7	457.7	1.6561	15.854
1967	271	4.09	275.09	387	87.6	474.6	1.7252	15.651
1968	282	4.06	286.06	411	91.7	502.7	1.7573	15.902
1969	300.5	4.54	305.04	435	95.0	530.0	1.7374	16.081
1970	290.5	4.59	295.09	457	99.1	556.1	1.8845	16.029
1971	303.4	4.64	308.04	481	103.71	584.71	1.8981	16.231
1972	334.2	4.68	338.88	510	108.2	618.2	1.8242	16.819
1973	348.1	4.8	352.8	541.1	111.54	652.64	1.8498	17.040
1974	379.7	4.76	384.46	575	114.04	689.04	1.7922	17.597
1975								18.25 (estimated)

At the present rate – take 150 – 200 years to reach 95% employment level.
In the above Table REST = TOTAL INDUSTRIAL EMPLOYEES-AGRICULTURAL + FORESTRY EMPLOYEES
Ref. Monthly Digest of Statistics, January, 1975.[3]

Issued by the Central Statistics Office, Salisbury, Rhodesia.

TABLE III

Year	Worker Ratio % Total Population		* $ Millions Gross Domestic Product		$ Per Capita Product		Per Capita Product Ratio
	Agriculture/ Total %	Rest/Total %	Agriculture	Rest	Agriculture	Rest	
1965	6.5336	10.075	115.6	682.9	394.05	1509.5	3.8307
1966	5.9691	9.8855	134.6	685.5	487.02	1497.7	3.0752
1967	5.7430	9.9081	151.7	751.1	551.45	1582.5	2.8697
1968	5.7673	10.135	120.7	781.7	421.93	1555.0	3.6854
1969	5.9461	10.135	165.8	928.4	543.53	1751.5	3.2224
1970	5.5572	10.472	148.9	982.5	504.59	1766.7	3.5012
1971	5.6007	10.631	195.1	1139.4	633.35	1948.5	3.0764
1972	5.9557	10.864	226.7	1289.1	668.95	2085.2	3.1171
1973	5.9796	11.061	209.2	1400.5	592.97	2145.8	3.6187
1974	6.3026	11.295	282.4	1680.8	800.45	2439.3	3.0474

* P.12. Economic Survey of Rhodesia 1974.
Published by Ministry of Finance, April, 1975[14]

TABLE IV

SKILLED MANPOWER DATA : RHODESIA 1969-1982

Trade Group	1969	1970	1971	1972	1973	1974	Additional Number Required (Estimated) November, 1974-November, 1978	November, 1978-November, 1982	Total 1974-1982
Aircraft	275	283	286	350	360	331	152	158	310
Building	2360	2644	2812	3011	4314	4478	1866	1967	3833
Electrical Engineering	1216	1266	1314	1561	1630	1663	724	770	1494
Mechanical Engineering	3378	3689	3852	3141	4623	4548	1952	2065	4017
Motor Trades	1313	1455	1547	1633	2074	1679	895	941	1836
Printing	634	657	689	749	779	788	319	336	655
	9176	9994	10500	10445	13780	13487	5908	6237	12145
							13487	19397	13487
							19395	25632	25632

Ref. Private communication "Skilled Manpower" dated 8th July, 1975.
Ref. D/2/16/452. Apprenticeship Training and Skilled Manpower Development Authority. E. V. McCormack.

Conclusions:

The main conclusions to be drawn from this study are:

1. **Employment rate.** Table II shows that there has been a slow increase in the percentage of the population employed in the total industrial sector (including the cash crop agricultural industry) over the decade 1965-1975, estimated at an increase of 0.2% per annum. However it is clear from Figure 1 that in absolute terms the total number of the population outwith this sector has increased over the same period.

   At the present rate of increase it would take about 380 years to reach the 95% employment level, regarded as tolerable by developed countries.

2. **Employment distribution.** Table II shows that there has been a slight movement towards employment in the non-agricultural industrial sector, but it has not been without fluctuations. The ratio of Rest: Agriculture is far below that of an industrialised country of 100 to 500:1. In the non-agricultural sector of industry, manufacturing is the largest employer and also the largest contributor to the Gross National Product, even exceeding that of agriculture.

   Figure 4 and Table IV shows that both the existing and the projected skilled manpower proportions of the labour force have a higher content of mechanical engineering than the rest, even when the motor trade is not included. The reservoir of graduate engineers in Rhodesia is an ageing one on average at present. This together with the skilled manpower statistics in Figure 4 means that there will be an increasing shortfall of graduate mechanical engineers, possibly of the order of 30-40/year over the next eight years.

3. **Efficiency of employment** (Productivity) As might be anticipated, the efficiency of employment (productivity) measured on a dollar per capita (G.N.P.) output, Table III

shows that the non-agricultural industrial sector is 3 to 4 times more efficient than the agricultural sector. Therein lies the motivation to move towards this sector in an industrialising country. There is no trend in the ratio in Table III, both the agricultural and non-agricultural sectors shows approximately equal rates of increase of productivity.

4. **Distribution of outputs.** Although the agricultural sector is the largest employer of labour, the productivity ratios are such that the manufacturing sector is the largest contributor to the G.N.P. in dollar output terms. The results are shown in Figure 3.

SCIENCE AND TECHNOLOGY

Just prior to the industrial revolution of the eighteenth and nineteenth centuries, Europe had seen the rise of the modern scientific spirit, still very much in evidence in our own time, under which the traditional dogma and doctrine relating to the natural world came under critical scrutiny. Technology still depended in the eighteenth century on the application of empirical methods and rules by man, never straying far into the world of theoretical concepts.[5]

In this context, science gained more from technology than vice versa. Examples are: the growth of thermodynamics from the study of heat engines, continuum mechanics from the strength of materials and hydrodynamics from hydraulics. The Royal Society, founded in 1660, greatly stimulated the growth of science by the observation and rationalisation of natural phenomena occuring both in the field and the laboratory. The laboratory is essentially an environment to bring about the idealisation of a small part of reality for comparison with the conceptual models. Questions are formulated in physical terms and answers sought.

The basic sciences however have contributed immeasurably to technology from the beginning of the industrial revolution to the present day, both on the theoretical and experimental aspects.

On many occasions the desired analytical solutions to problems or experimental data are not available. This could easily occur in areas such as heat and mass transfer or fluid dynamics for example. Then research workers in technology must find their own answers and engineering science can merge imperceptibly into the basic sciences. University engineering departments are particularly well suited to this type of research which is often of a longer term nature.

It is clear that there are strong specific links between science and technology. The eighteenth century concept of engineering being mainly the practice of empirical mechanical art has ceased to have any credence, and modern high technology has only tenuous links with art, if they exist at all.

At the most fundamental level, art is either explicitly or implicitly religious in nature. The various art forms are manifestations of religious language which itself is either trivial or the most fundamental type of utterance. This being accepted, the language is several orders of magnitude more general than scientific language, which as we have noted is the basis of technological work, therefore, there is no basis for stating that technology or engineering is an art. This serves only to imply that there is some mystique involved, whereas I have been able to find none.

It is in studying the sociological consequences of engineering that the language of science proves inadequate. Such discussion needs to be transformed into a more general and fundamental religious framework. It seems that many pseudo-religions have been created as a result of sociological (and management) theories, many complete with taboos, messiah, jargon and priestly class. The field of education has also been afflicted in this way. The wealth of dissatisfaction and unrest in the so-called developed countries, considered by some to be living in a post-Christian era, is witness not so much to the fact that the sociological theories need more vigorous advertisement, as to the fact that they are fundamenally untenable. Science and technology themselves have not been entirely free from these activities and a scientific style has become commonplace in non-scientific problems.

It seems that there is scope for a complete revision in the approach to problems in the non-scientific field. An interesting and extreme example occurred in the life of that renowned linguistic philosopher, Ludwig Wittgenstein, who in his first work applied a highly formalised analytical approach to philosophic problems and who, in his second and final major work adopted a free style which may be described as rhapsodic.

In the sociological problems therefore there is a need to re-assert certain basic principles, and I think that no one has satisfactorily shown that Christian principles are either invalid or inappropriate. There may well be here an adequate framework and language for all that is required.

Further discussion along these lines would take us too far away from the theme of this talk. Sufficient has been said to indicate my concepts of the inter-relationship between technology and science, as well as their limitations and relationship to other principal areas of intellectual and human activity. Perhaps the most succinct way of saying the engineering-science-society relationship is, that engineering is the point in which science and society meet.

THE NATURE OF MECHANICAL ENGINEERING

In general terms, Mechanical Engineering is by definition concerned with harvesting, transport, conversion and utilisation of materials, mechanical and thermal energy, and information, also as a corollary the application of physical phenomena. In this field sociological and economic aspects are also of importance, perhaps even of overriding importance in recent times. Examples of materials and energy interests will be familiar enough to all, the physical phenomena interests may not be so easy to exemplify;

an extreme and perhaps bizarre example is the laser, a coherent light source, considered by some to be a scientific solution in search of a problem.

Information is another abstract concept, but less so now that we have machines, namely electronic computers, specially designed to deal with the processing of information. Within many large public and private organisations there are now units to collect, convert (or process) and utilise information ranging from simple accounts to the simulation and control of complex industrial plant. The original device designed to deal in line with information in this way was a mechanical one, namely, the engine governor of James Watt (1736-1819) designed to maintain a steam engine at constant speed even though the load varied.

The importance of information cannot over-stressed in an organised society, which cannot function without an adequate flow. It sometimes seems to be made an unnecessarily scare commodity in Rhodesia.

At this point it is possible to draw out a distinction between the technological aspects of engineering and the basic sciences, namely that in engineering one is often concerned with the behaviour of systems, rather than isolated physical phenomena per se. This may range from the assembly of such systems, to the dynamics of inter-linked but distinct systems. For example, a motor car may be considered to comprise an assembly of three sub-systems:

(i) The prime mover or engine;
(ii) The transmission;
(iii) The chassis and superstructure.

The actual road performance of the car is the result of the interaction between these three sub-systems, each with its own charateristics.

The system itself may not be a mechanical or electrical system, but may, for example, be a manufacturing organisation. More recently the concepts of systems engineering have also been applied to community sociological problems, such as the transfer of technology to rural communities. They have also been misused in an inhuman concept termed human engineering, which seems to be the ultimate in the mechanistic treatment of human beings. Whilst accepting that the engineering of people is a heresy, it is feasible, when certain desires of the community are known, to employ technological methods to help with the achievement of these desires with the utmost efficiency.

TECHNOLOGY TRANSFER AND COMMUNITY DEVELOPMENT

Within the developing countries of Africa and other parts of the world there is a two-fold problem in education, since there not only exists a younger generation to be taught the academic and cultural background to our civilization, which may be visualised as a vertical propagation; there is also a horizontal propagation to rural communities which may only possess a set of customs, an elementary theology and an equally elementary technology.

Under these circumstances the concept of education becomes transformed into that of community development containing technology transfer as one of the main ingredients. It has been mentioned previously that the Tribal Trust Land Development Corporation Limited (Tilcor) has as its objective the planning, promotion and establishment of commercial, industrial, agricultural and mining undertakings within rural areas. The horizontal transfer of the necessary technology must of course be present in this work.

The large scale organisation of a rural development programme is shown in Figure 5. which exhibits the three basic co-operating sectors namely:

(i) Government Planning Function;

(ii) Private Sector Operations;

(iii) Public Sector Operations.

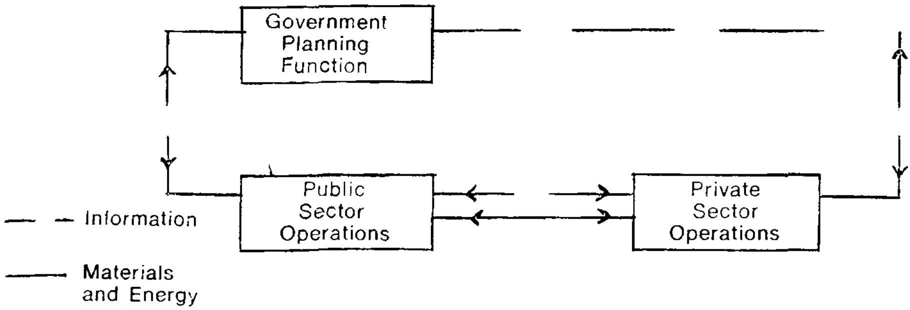

Figure 5. The three basic sectors in a Rural Community Development Scheme.

There is nothing particularly difficult in the elementary system described in Figure 5. viewed as a simple steady state set of operations. It is when one considers the transient nature of the system that the analogies with an industrial process start to formulate. If in addition one grafts on to the basic system a control system,[6] capable of monitoring the progress towards a set goal and the temporal and spacial deviations therefrom, then a whole corpus of theory becomes available. For the academic study of self optimising systems is already well developed. Note however that one is concerned with applying the technology of systems to flows of information, materials and energy, not to people. The sensing and control elements would very frequently themselves be people.

The structure of rural development plan might be as shown in Figure 6. The model is hierarchical in form and lends itself to a corresponding adaptive control system.

Together with a defined plan structure it is postulated that there is required an effective control system, which has within limits, the power to adapt the targets or objectives and therefore to be self adjusting to a limited extent. A possible control system, capable of his dynamic control is shown in Figure 7.

The design of a rural community development scheme has been indicated in brief outline only. The time of operation

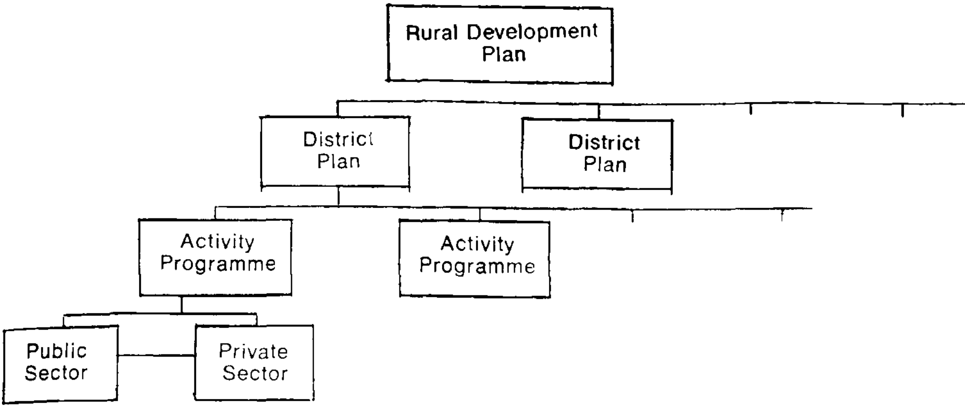

Figure 6. A possible Structure of a Rural Development Plan with a hierarchical structure.

of the process control system parts would need to be specified in a more complete discussion. This would lead in turn to analysis of the dynamics of the system, in this the application of existing technology could well prove fruitful.

MATERIALS, ENERGY AND CONSERVATION

The last decade has been the demise of the robust, but false, philosophy of engineering entertained in the 1940's and 1950's and earlier, whereby it was considered to be the means of mankind achieving ever increasing levels of consumption by the exploitation of natural resources.

It was hitherto possible to provide for the material requirements of mankind as though providing for a limited population by drawing from a limitless reservoir. However, this arcadian concept has now been completely inverted to that of a very limited reservoir supplying a limitless population.

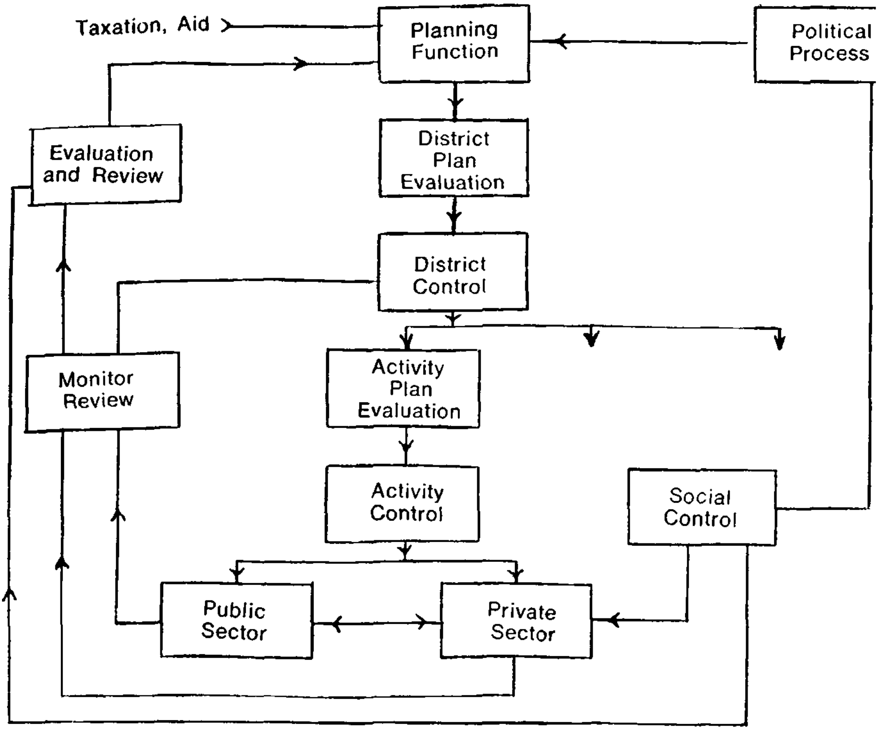

Figure 7. An Adaptive Control System for a Rural Community Development Operation

No longer is the process of collect, consume and commit to waste a tenable modus vivendi. It does not hold a future for man held in the cleft stick of increasing participation in consumer society of the previously uninvolved rural communities, and increasing population. The sharpness of the economic death rested upon Rhodesia by the world at large can be escaped by none in the context of relying on unlimited supplies of natural resources from other countries. The wisdom and knowledge derived from living with the restraints imposed, if responded to in a creative manner by the careful husbandry of resources, both material and human, could ultimately be of long lasting value, regardless of any political changes.

Recently a survey has been conducted by the authorities here with the object of finding out the amount of spent lubricating oil disposed of with a view to reclaiming and reusing it. Whilst this is a useful step it does not go far enough. I would like to propose to the authorities that a careful survey of *all* industrial waste be undertaken with a view to establishing recycling or reuse of materials in addition to the few, namely paper, lubricating oil[7] and plastics[8] which at present receive a modest effort at reclamation.

Complaints have been made in the U.K. that industry often did not know what was being disposed of.[9] It is remarkable that although the flow of material into industry is known, the flow of material out, except as finished items is not.

Coupled with a survey of wastes there is required an establishment of expertise on the reclamation and recycling of waste, together with determined efforts at a maximum of achievement.

As an aid to materials conservation an immediate revision of ideas on the part of engineering designers can be suggested. About two decades ago there was concern that manufactured articles were being "over designed", in the sense that they could be too safe or too long lasting. A new outlook is now called for that the design of manufactured articles should aim at:

(i) Keeping them off the scrap heap as long as possible — Durability not disposability.

(ii) Easily repairable design.

(iii) Easily reclaimable materials.

This represents a change of direction from the "throw-away" concepts now practiced and from the idea of designing obsolescence into the so-called consumer durables. Except for item iii) this represents a reversion to earlier cannons of design.

Ultimately all volume production and large scale project designing may be subject to two major constraints:

(i) Minimal use of scarce materials.

(ii) Minimal *total* energy deficit. The energy deficit being budgeted not only for the direct energy requirements but also in addition *all* indirect inputs of energy from whatever source, including that for recycling the materials.

MATERIALS CONSERVATION: THE SYSTEMS APPROACH

In considering the problems involved in the proper husbandry of material and energy resources it is clear that a fundamental difference exists between the two in that materials can be recycled (with the aid of an energy input) in a closed loop and hence are never lost in the ideal case, except in the case of nuclear energy. However energy suffers what is virtually a degradation in use (scientifically expressed as an increase in system entropy) and is lost ultimately by infra-red radiation from this planet out into space.

Apart from reducing the energy budget involved in the production of material items, there is a large volume of interest now in the recovery of materials after use and in the creation of improved material loops, even to the extent of proposing urban farming schemes. Also as an aid to the more efficient use of resources the conversion of waste material into valuable substances is now being investigated.

An interesting example of the conversion of waste is in the possibility of producing plastics from trees.[10] Normally the economics of the process and the availability of crude oil as a feedstock prohibit this consideration. Current world interest is now moving to possible alternatives amongst them two of which are available in Rhodesia, namely, coal and wood. Coal as an alternative feedstock to oil is known. However the use of wood is worth a brief description since it is not proposed to use whole timber but rather *waste* wood, for example, sawmill waste which would be equally useful since the fibre length is unimportant in this application.

The potential routes for this are:

(i) Converting wood polymers to liquid feedstock;

(ii) Production of petrochemical starters such as ethylene, butadiene and phenol from wood stock;

(iii) Use of the natural wood polymers.

An example of class (ii) would be the conversion of cellulose to polythene.

Cellulose — (hydrolysis) — glucose — (fermentation)
— ethanol — ethylene — (polymerisation)
— polythene.

The end product should then be considered for recycling, after passing through its active life stage.

The growth of urban populations has posed pollution problems which have often and vividly been described in the world's news media. Proposals are available[11] for the use of microbes, plants and animals to convert some wastes, of which domestic garbage is a principal source of the organic variety, into useful materials rather than disposal by burning or burying as at present.

For some time in various countries waste food and sewage has been used in ponds where fish are cultivated. Wastes have also been used as a feedstock for mushrooms and ethanol. An example of a biological engineering system based on recycling of material through a foodstuffs chain is shown in Figure 8.

The example given above is typical rather than exceptional of a number of biologically engineered systems suggested. It is to be hoped that these will receive due consideration especially by those countries well endowed with solar energy which could provide the required energy input to a large extent.

It is suggested that a post should be created, specifically with the object of considering materials conservation. What is required is not so much basic research in the first instance, as innovation and application of known technology in a rationalised system. industry is often unable to take a full perspective view of the strategies and tactics of a national materials system, therefore, internationally there is an increasing tendency for governments to take up responsibilities in this field.

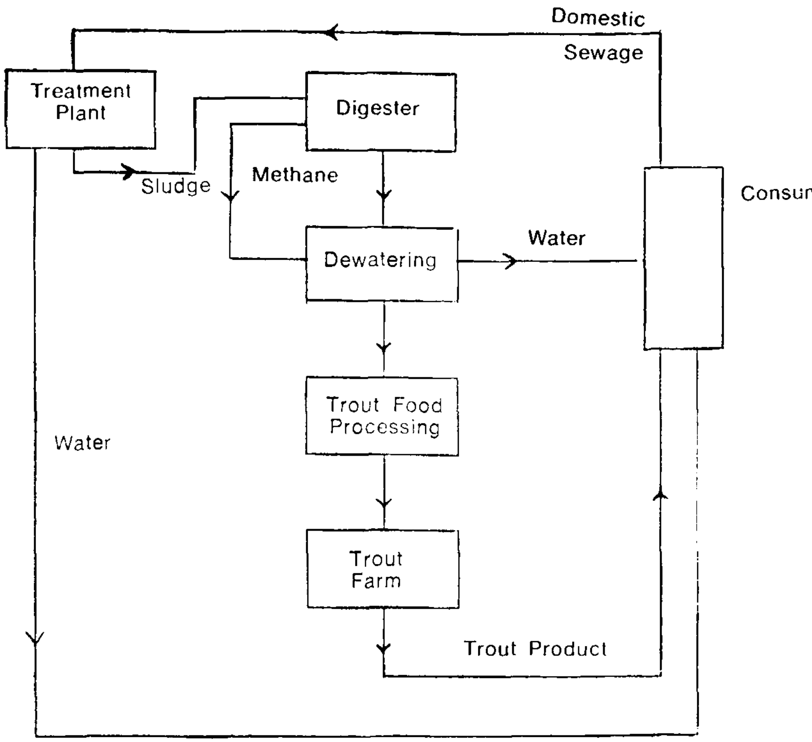

Figure 8 Biological Engineering System for Fish Foodstuff Production

In Rhodesia at present there is some control of material transfers across the national boundary. There is also legislation on effluent control, and some control of forestry reserves. What could be done however, is to establish complete materials accounting, together with an identification of possible material cycles and the energy requirement thereof. This latter requirement will be discussed in more detail later. This would probably require a materials intelligence and innovation unit.

ENERGY ANALYSIS: RESOURCES AND REQUIREMENTS

In scientific terms, energy simply denotes the ability (of a system) to do work. The system may be one or a combination of various forms such as, for example, mechanical, electrical or chemical.

Previous ages have left for us a volume of fossil material mainly, coal, crude oil and also some gas, all of which have been consumed at an increasing rate over the past 200 years. This bank of energy is having no noticeable deposits placed in it at present, and the crude oil and gas reserves are not, by current estimates, expected to last much into the 21st century. Also, in financial terms, its unit cost is increasing yearly as befits a vanishing asset.

A great deal of thought has gone into the problem of what we will bequeath our children in this valuable commodity. Certainly without careful thought it could be a bankrupt heritage, for there appears to be a reasonable world correlation between the energy consumption per annum per capita and the gross national product per capita:

$$\frac{\text{Energy consumption/annum/capita}}{\text{U.S.\$ G.N.P./capita}} = \begin{array}{l} 60{,}000 \text{ Btu. U.S.\$} \\ (6\tfrac{1}{3} \times 10^{7} \text{ Joules U.S.\$}) \\ = 18 \text{ Kwh/U.S.\$} \end{array}$$

No information is currently available for the energy consumption of the population of Rhodesia which could be compared with this figure.

The figure of 18 Kwh/U.S.$ G.N.P. is a very important exchange rate, since it links a fundamental physical resource with a financial (but arbitrary) resource. It may be used as a ruler with which to measure the gross economic performance of a country.

In Rhodesia with a G.N.P. of R$ 1.681×10^{9} in 1974[14] one can make an estimate of the total energy consumption. Assuming R$1.0 = U.S.$1.74 then the constant is 31.4 Kwh/R$ G.N.P. On this basis the total Rhodesian energy consumption in 1974 is estimated as 5.29×10^{10} Kwh. (Total June 1974 population: 6.1×10^{6}). (Kariba production 4717×10^{6}Kwh).

Based on the manufacturing dollar product the energy consumption would be 1.3176×10^{10} Kwh giving 2.22×10^{3} Kwh per capita/annum. It would be interesting to compare these estimates with the actual figures were these available.

The point of departure for forecasting global energy requirements is a model of population statistics, consumption (based upon life style) and process efficiency. Such is the current interest that a World Energy Conference[12] was staged in Detroit, U.S.A. in September, 1974, attended by about 4000 delegates and addressed by the President of the U.S.A. Much of the interest involves technological forecasting and rehearsing of various scenarios on which we may, with suitable investment and development expect to have options.

The principal sources on which any of the scenarios would depend are:[13]

1. Fossil Fuel (Limited resource)
2. Water Power (Tidal and reservoir)
3. Geothermal Power (Mainly steam)
4. Solar Radiation.
5. Wind Power (Unimportant)
4. Solar Radiation.
6. Nuclear Fission
7. Nuclear Fussion

The above headings are energy sources. To be successfully employed, the energy must be transported in a safe convenient and economic form to the point of application. Various vehicles that have been considered for the future are: electricity and liquid hydrogen.

The total world energy consumption with the major components, is shown in Figure 9. The third column (for 1980) is purely a forecast at present. Consumption of energy increased at an average rate of 5% per annum from 1960-1970, equalling a doubling of consumption in 14 years. The average rate of increase for the present decade, 1970-1980, is 5½% per annum.

The 1972 global population figure was 3 782 million[15] increasing at a rate of 2% per year. Africa as a whole stood at 364 million increasing at a rate of 3.3% per year.

Fossil Fuel

The dominant part played by the fossil fuel, especially the oil resources, in the latter part of the 1960-1980 period is clearly visible.

Looking at the cumulative consumption in Figure 10 it is seen that just after 2000 A.D. the oil supply may well be virtually at an end, even assuming a reducing rate of growth of consumption over the last quarter of the century.

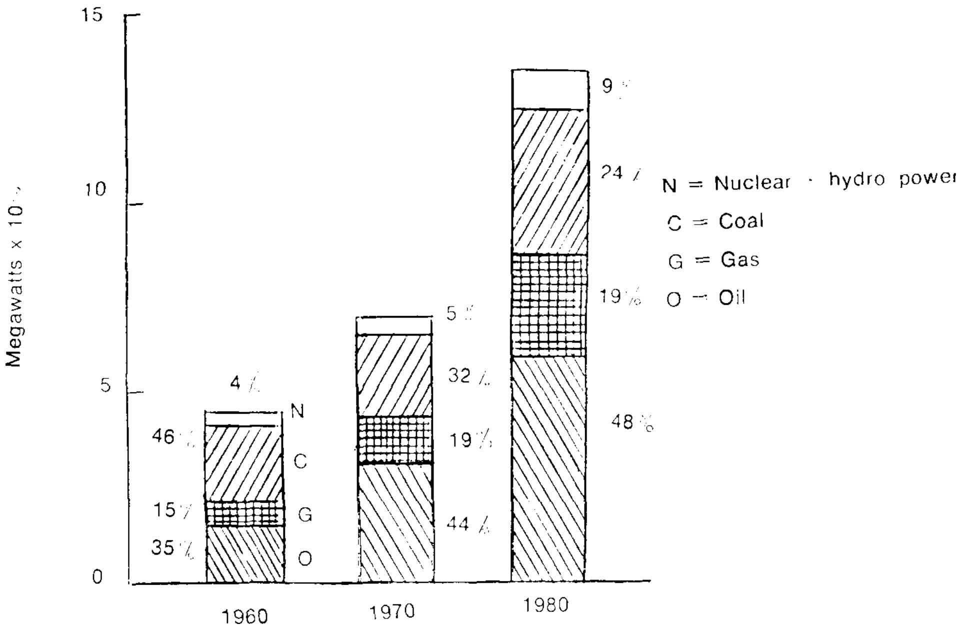

Figure 9. Gross World energy consumption components.
Estimated Reserves in MW years.

Coal	$8\,000 \times 10^6$
Gas	300×10^6
Oil	500×10^6

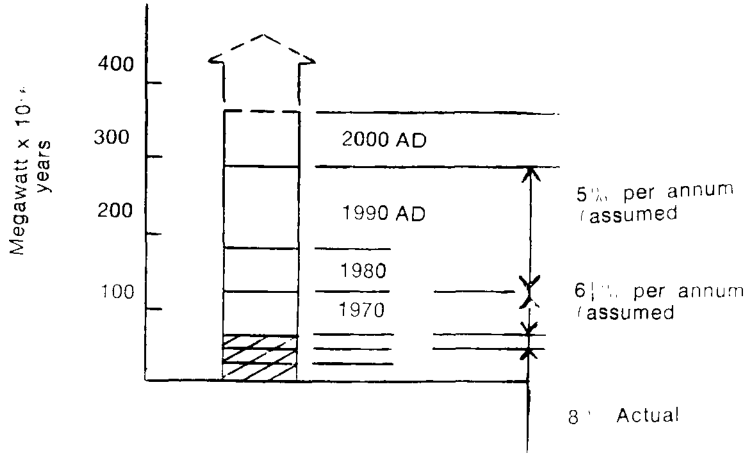

Figure 10. World Cumulative Oil Consumption

It may well be considered that as the coal reserves are very much larger than those of crude oil, that the solution is (especially for those countries with more coal than oil) to convert a part of the coal to oil. Reference to this was made in the recent opening of Parliament speech from the Chair[16] by the President of Rhodesia. However this is to be regarded as a temporary palliative rather than a solution, as coal may well be required in the future as a feedstock for a chemical processing industry in lieu of crude oil. Therefore its use as a fuel should be limited as far as possible.

Water Power

Of the two types of water power namely, tidal and reservoir, only the latter is of interest in Rhodesia. Although it should be mentioned that besides tidal barrage schemes there is now interest in a mechanical device which is rotated by water wave action and can be used as a method to generate electricity.

It has been estimated that there is a potential world capacity of about 2.9 x 10^6 MW hydro-electric power, which is generated by running water from a reservoir deposited by rainfall on high ground. This is the largest known renewable concentration of solar energy. The world capacity is shown in Figure 11. The current usage is only about 7% of world capacity. In principle there is scope for an increasing supply from this source, which has a total capacity of about 3.0 x 10^6 MW.

The supply of energy from tidal sources depends upon the earth — moon — sun system. Tidal dissipation lengthens the day on earth about 0.001 second per century. The total energy in this source is about 3 x 10^6 MW i.e. the same order as hydro-electric reservoir power, but only a fraction is usable, see Figure 11.

Due to silt deposition, reservoir hydro-electric power is a fading source with a limited lifetime.

Geothermal Power

The source of geothermal power arises mainly from hot springs in the form of steam. The volcanic regions of the earth are potentially well located to derived benefit from this. In Kenya work is in progress to harvest some of this energy. The problems is that it is a rather low grade (wet steam) supply which means that the conversion efficiency is low. In arid regions the steam is simply condensed and used for domestic and livestock purposes. The energy supply from this source is therefore rather low, see Figure 11.

Solar Radiation

Apart from nuclear, tidal and geothermal sources, the original source of the earth's supply of energy is the sun. Part of this has been stored and part is the current supply. Some 30% of the radiation approaching the earth is reflected back by the atmosphere, about 20% is absorbed by it and 50% reaches the surface to be emitted back as long wave length radiation, some after absorption by plants and other storage systems.

Considerable interest is being shown in this form of energy in Rhodesia at the present time. The main interest is in how far it can be expected to replace fossil fuels as a source of industrial energy and also in rural environments.

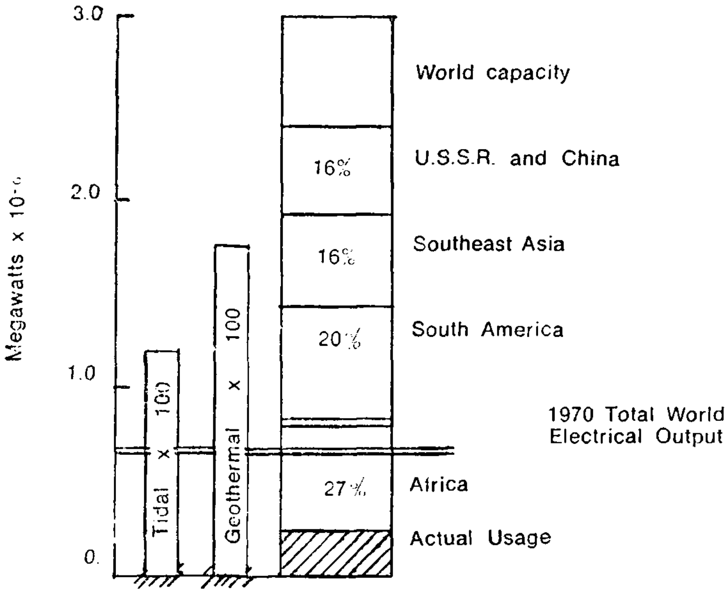

Figure 11. Global Resources of Hydroelectric (Reservoir) Power.
Also for comparison the Global Resources of Tidal and Geothermal Power x 100

As far as industrial use is concerned, one is considering large scale conversion of energy to some more suitable form. A conversion plant of about 1000 MW, say about 1/5th the current output of the Kariba hydro-electric installation, working at about 10% overall efficiency would require a surface collector of about 42 Km^2. This is probably a conservative estimate, it may well require double this ground area for the total installation because the efficiency may well be less, say 5-8%. Experiments along these lines have been discontinued in France, Greece and Israel.

As a scenario, to provide the principal source of the global energy requirements over the next century, there would be required solar collector farms to harvest the radiation, covering thousands of square kilometers, which together with the associated pipework and wiring would constitute the largest engineering undertaking of all time. The arid regions of the present oil producing countries would provide suitable sites for the requisite collector farms. Perhaps these countries may feel encouraged to conduct further feasibility studies.

An alternative U.S.A. project involves using absorption panels made up of silicon solar panels of about 72Km^2 producing about 10 000MW. The collector panels would be carried by a satellite in synchronous orbit well above the earth's atmosphere and therefore receiving a radiation density about twice that on the earth's surface. The energy must then be transmitted to earth by microwave generators. Such a project is highly speculative and not a possibility for most countries, if any.

Nuclear Fission

Many of the future scenarios, especially those of a long term nature, envisage nuclear energy as the basis of the physical needs of mankind with a projected quadrupling of the world population. The world model on this basis would have about 3000 reactor parks each[17] containing about 8 fast breeder reactors and each reactor producing 5 GW of electricity. (The largest current reactors produce about 1 GW (E)).

In order to provide the requisite 24,000 reactors in 100 years we should now be building at least 4 reactors per week. Or allowing for a limited reactor life of 30 years the requirement increases to about two per day. It would seem that the obvious procedure would be to start a world reactor building programme with the object of reaching the target of 24,000 reactors as closely as possible.

Even on a much shorter time scale than 100 years there are considerable problems to the nuclear driven world model. These revolve around production of raw material and waste disposal.

Current technology depends upon uranium 235 which is a naturally occurring isotope with an adequate neutron production to sustain the chain reaction required for nuclear fission. 0.365 Kg can yield approximately 1.0 MW years. Now natural uranium contains about 0.7% U^{235}, therefore a 1 GW(E) plant of 33% thermal efficiency will consume natural uranium at about a rate of 160,000 Kg/year.

The global nuclear generating capacity of 1980 is planned to be only 0.45 x 10^6 MW(E) and yet this will consume 72 x 10^6 Kg/year of natural uranium. At present extraction rates from the ore the reserves are 0.8 x 10^9 Kg U_3O_8. Using a higher and more expensive extraction rate the reserves could yield 2.7 x 10^9 Kg natural uranium. At the consumption rate of 72 x 10^6 Kg/year, even at the higher figure, the stock could only last 37 years. This does not allow for an increasing consumption rate. However there is probably 2 x 10^9 Kg of poorer ore available and possibly 4 x 10^{12} Kg available in the sea, both of which are of dubious value at the moment.

A suggested solution to the problem is to convert U^{238} and Th^{232} into long-life, usable fissile isotopes. The reactions are:

$U^{238} + n$ — U^{239} — Np^{239} — Pu^{239}

$Th^{232} + n$ — Th^{232} — Pa^{233} — U^{233}

The reactions are performed in breeder reactors which produce more fuel than they consume. All the natural uranium can be fissioned in the above manner and the uranium reserves could be stretched to 37 x 100/0.7 i.e. 5000 years.

This panacea unfortunately tends to disappear when it is remembered that breeder (fast) reactors are inherently less safe than the more common thermal reactors. There are the following problems:

1. Siting of breeder reactors
2. Transport of highly dangerous nuclear fuel from the breeder to the thermal reactors
3. Disposal of highly radioactive waste. (This problem may now have been solved with the announcement by the U.K.A.E.A. of a method of converting the waste into a glass).

No satisfactory solution to these is known at the present time. Therefore the development programme proceeds along tentative lines.

Nuclear Fusion

There are two possible reactions for the fusion process, namely; deuterium-tritium (DT) and deuterium-deuterium (DDO). The former is the most likely to be used due to lower plasma temperatures and the tritium can be produced from lithium of which there are large (possibly 9×10^{6} tonne) reserves with a content of about 7.4% of about 7.4% of the Li-isotope.

The development of the fusion process is at a much earlier stage than for the fission process due to the more difficult technology. It may be feasible to have a fully operational reactor by 1990.

The fusion reactor is intrinsically safe and the materials used much less obnoxious than for the fission reactor. It is therefore unfortunate that unless there is an expected change of fortune in this technology, it is unlikely to contribute much in the short or intermediate range.

ENERGY ANALYSIS: FUNDAMENTAL ASPECTS

In making estimates of global energy resources it is really not satisfactory to simply estimate the calorific or heating value of the source since the fuel must be used in a system with a certain process efficiency and furthermore it is the Gibbs Free Energy which is available at the input to the process. As a domestic example: the calorific value of the fuel in the tank of a car is only partly available as energy at the road wheels. Even in an engine with no friction losses the efficiency is not 100% but is limited by the Carnot efficiency, (η)

$$\eta = \frac{T_1 - T_2}{T_1}$$

where T_1 is the upper temperature and T_2 is the lower temperature of the process fluid.

An attempt to standardise methodology and conventions was made at a meeting in Sweden in August, 1974, when the International Federation of Institutes of Advanced Study held a meeting.[18]

The meeting recommended that for fuels the Gibbs free energy could be replaced by the fuel enthalpy, with not more than 10% error, or, the heating value when it combusts with air (roughly).

In producing a unit of output, the meeting defined the *Gross Energy Requirement* (GER) as the amount of energy resources sequestered by the process. The amount of energy being the gross heat of combustion with air at 1 bar pressure and °C.

The amount of energy resources sequestered involves not only the amount of energy, for example for the heating process, but also the other energy resources required to make the process possible. For example, it is also required to know the energy required to win coal from the ground, bring it to the grading plant, grade and deliver it to the customer. In the case of agriculture it would include not only fuel requirements of tractors but also, that required to make the tractor, pesticides, fertilisers processing equipment and transport. The error involved in not taking these demands into consideration can be considerable.

Figure 12 shows a hypothetical production process and the total energy inputs. With more conventional and less fundamental analyses only the energy content of the coal at the process produtcion point would be accounted for.

In cases where the product is itself a combustible material then instead of the Gross Energy Requirement, the *Net Energy Requirement* (NER) is defined, which allows for the energy content of the product.

If the output of the process is in fact energy, for example as in a hydroelectric scheme, then the *Energy Requirement of Energy* (ERE) is defined.

$$\text{ERE} = \frac{\text{Energy of Source sequestered} - \text{Energy Delivered to the Point of Use}}{\text{Energy Delivered to the Point of Use}}$$

No data is available for Rhodesian production. As a matter of interest, those for the U.K. are shown in Table V. It is interesting to note that:

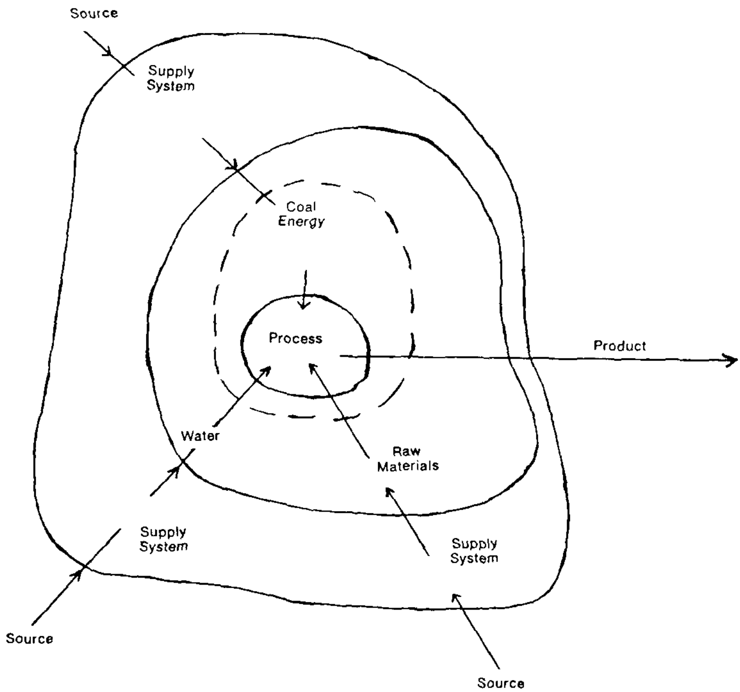

Figure 12. The Total Energy Inputs to a Hypothetical Production Process

TABLE V. ERE FOR U.K. FUEL INDUSTRIES

Coal	0.047	0.042	0.047
Gas	0.48	0.390	0.23
Oil	0.23	0.134	0.11
Electricity	3.54	3.192	2.98

1. Coal has by far the lowest ERE
2. The ERE of gas, oil and electricity has declined steadily for almost a decade
3. The ERE of coal reached a minimum in 1968
4. The ERE of electricity is higher than coal by a factor of about 80.

There are some very important uses for energy analysis carried out on the above basis. For example, it is a much more reliable method for technological forecasting. Figure 13 shows the GER ammonia production, from it we deduce that the GER for this output will be approximately 45 MJ Kg^{-1} in 1990.

The use of the above criteria has also been extended to pollution and waste studies. It has also been shown on this basis that it is unlikely that a nuclear reactor building programme can be expected to fill the approaching energy gap because of the huge energy investment required to make it a reality. An energy *deficit* would be created in the first decade.

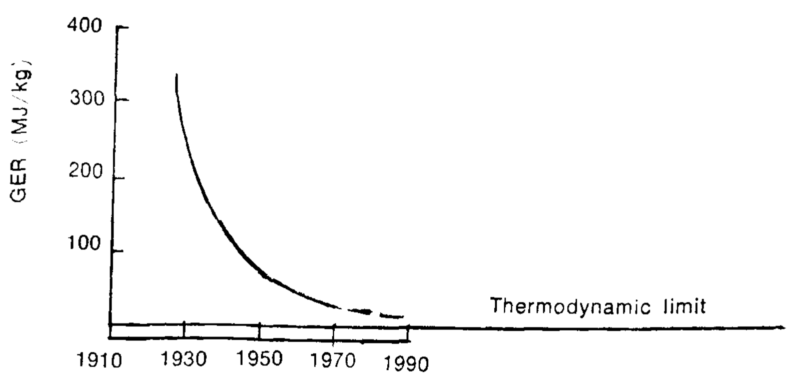

Figure 13. The GER for ammonia manufacture.

IMPLICATIONS

The implication of the above fundamental discussion is that so colossal are the energy requirements of establishing the energy production processes to provide a global life style equalling the current European level, not only for the existing world population, but also for the increases over the next century, the demand, based on any currently available options, is beyond our resources of energy, since an energy *deficit* would be created.

For the largest projects, consideration is now being given to budgeting in energetic as well as financial terms. It is expected that on a national and international scale this will become more commonplace in future, and could become of overriding importance in about a quarter of a century.

Recently there has been established within the Faculty of Engineering a post in Solar Energy. In view of the preceding discussion it is suggested that this be converted to a post to study Energy in all its ramifications; sources, transport and budgeting, since solar energy applications may never proceed beyond small scale application. No government could hope to fulfil its obligations and the aspirations of the populace without having a regard for the full impplications of the problems we are only partially considering at the present time.

Wherein lies our salvation? Technology has no revelation or a haven to offer from the uncomfortable prospect of an energy hungry globe, nor an a priori theorem from the basic sciences which will reduce the problem at a stroke to text book proportions. Only the advice, that we must carefully consider *all* our uses of energy resources, with a view to improving, always within the realms of thermodynamic feasibility, the efficiency of their use.

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