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Natural Gas Utilization Studies: Methodology and Application

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NATURAL GAS UTILIZATION STUDIES: METHODOLOGY AND APPLICATION

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Abstract

Particularly for countries at the early stages of natural gas devevelopment, it is important to develop a long-run, sector-wide strategy for the role that gas can play in meeting energy needs. Only with such a perspective can appropriate choices be made about individual gas-using projects and about the design and timing of lumpy investments in gas infrastructure.

Over the past seven years of steadily increasing lending by the World Bank for natural gas development, the Gas Utilization Study (GUS) has become the accepted vehicle for this sector planning and project identification. A GUS is generally a 9-18 month exercise, sometimes involving a substantial consultant budget, and often requiring intensive supervision by Bank staff and country officials. Seven such studies have been completed and were reviewed for the preparation of this paper; viz., Egypt, Indonesia, Malaysia, Nigeria, Qatar, Tanzania and Thailand. They used a variety of approaches (only partly justified by the somewhat different questions being asked in each), and there were major differences in the scope and depth of analysis. Over half contain methodological errors which reduce the credibility of their conclusions. This rather unsatisfactory experience highlights both the difficult nature of the problem and the need to define a consistent and methodologically sound approach.

This paper provides the theoretical framework and a step-by-step methodology for addressing issues of gas utilization. It is intended for those who design, carry out or supervise gas utilization studies in developing countries.

TABLE OF CONTENTS

List of Figures

Summary and Conclusions

Many developing countries are beginning to tap their indigenous gas resources to substitute for expensive oil. They are finding that the development of natural gas - a non-renewable fuel and one which requires large, up-front investments to use - raises complex questions of gas allocation and investment strategy that must be faced at the pre-investment stage. A gas utilization study (GUS) is ususally an essential first step to pre-screen project candidates and to test the major supply options in advance of full feasibility work. The World Bank's experience with such studies has indicated that their design and implementation is complex, and prone to methodological error.

The purposes of this paper are: (i) to outline an economic framework for analyzing questions of gas utilization; (ii) to suggest a practical methodology for applying that framework; (iii) to illustrate its application in gas surplus, gas deficit and surplus window countries; and (iv) to discuss the role of the gas utilization study in gas planning. Following the Introduction, Chapter II develops the theoretical basis for allocating limited gas resources over time. The basic methodological problem of the GUS is that the economic price of gas - which is necessary for project ranking - is itself dependent upon the set of projects selected. An iterative process to solve for the economic price path of gas is illustrated graphically. Once the price is known, project ranking can proceed directly. However, the substitutability of gas use over time and the complementarities in gas investment mean that packages of projects must usually be ranked; a simple framework of comparing alternative projects as though they were mutually exclusive will seldom be appropriate.

Chapter III develops a practical methodology for applying the economic framework. A gas utilization study should generally encompass three areas. First, it should determine the aggregate gas demand/supply balance over time. This sectoral context is necessary to derive one or more scenarios for the economic price path of gas. Second, it should identify, evaluate and rank alternative packages of gas-using projects and related infrastructure investments. This project evaluation analysis is the core of the exercise and should be based on the gas price scenarios from the sectoral work. Third, consistency checking and sensitivity analysis should be undertaken to spot necessary revisions in the other areas and to identify critical project design issues and information gaps. A network of 11 steps to cover these three tasks is developed and discussed. Special attention is given to the demand analysis and the project selection and ranking, where many of the existing studies are particularly weak.

In Chapter IV the application of the general methodology is illustrated for three types of country: gas surplus, gas short and surplus window. For gas surplus and short countries, it is shown that certain simplifications to the full methodology can be made, which would result in a significantly different focus and work program for the two cases. For the surplus window countries, few short-cuts are possible, although it will still be important to use country-specific information early in the study period to focus the work effectively. The final chapter presents some pointers on the appropriate timing, scope and continuing use of a gas utilization study.

NATURAL GAS UTLIZATION STUDIES: METHODOLOGY AND APPLICATION

I. Introduction

1. For a number of developing countries, indigenous natural gas resources hold the key to reducing expensive reliance on oil. Yet in many cases, the current level of gas use is still low relative to the reserve base and to an economically desirable level. Embarking upon the development of natural gas -- a non-renewable fuel and one which requires large, up-front investments to transport and use -- raises complex questions of gas allocation and investment strategy that must be faced at the pre-investment stage of development.

2. Many of these questions are similar across countries, for example:

- Should gas be used in electricity generation to replace imported fuel oil or coal, or should a gas-based fertilizer plant be built to replace imported urea?
- Would the high cost of a city gas distribution network be justified by the very high and growing cost of the kerosene and LPG used by households that gas could replace?
- If gas reserves are large, should the country try to attract commercial partners for an LNG export project or would it be better to keep the gas in the ground to satisfy future growing domestic markets?
- As a producer of fertilizers or petrochemicals for export, could the country compete with supplies from the Middle East or Mexico where production is based on associated gas?

3. There are two things to note about such questions. First they are essentially economic rather than technical questions. The technical feasibility of using gas for power generation, for fertilizer production, for LNG, and so forth, has been well-proven in other countries and need not be established anew. The important issue is the relative economic merit of the different alternatives. This will depend upon such country-specific parameters as the amount of base-load hydro in the power system, the proximity to major export/import markets for urea and the density of housing in urban areas. The second point to note is that although such questions concern specific project alternatives, they are really about long-run sectoral strategy. What should be the role of gas in a country with abundant lignite or hydro resources? Can gas be used as an engine of economic growth through its 'embodied export' as urea or LNG? Through which sectors can the penetration of gas as an oil import substitute be most rapidly achieved? How can such substitution be phased out later if supplies become scarce and can be allocated only to the highest value uses?

4. Because gas is depletable, such trade-offs over time, as well as the trade-offs between gas-using projects at any point in time, must be explicity considered. Further, because gas infrastructure is lumpy, it should generally be designed on the basis of total, long-run gas demand rather than that of an individual project. For these reasons, a long-run, sector-wide framework is generally necessary for the economic evaluation of gas-using projects and for the design of gas investments. The development of such a framework is the first objective of gas utilization study (GUS).

5. Following from that sector-wide framework, the second objective of a GUS is to provide an early comparative screening of potential gas-using and gas-producing projects. Despite the large number of uncertainties typically facing the gas planner in the early days of development, it is important to undertake a rigorous pre-selection analysis then, while the quality of estimates for different projects is comparable. This analysis should aim to exclude the non-starters as much as to identify the clear choices (upon which full feasibility or preliminary design studies can begin). It should also define the critical, but currently uncertain, parameters that affect individual projects and provide direction for the appropriate focus of the next round of feasibility or design studies.

6. A GUS should not be expected to make final project selection decisions for the country's gas development program over, say, the next two decades. That would be impossible, given the large and numerous uncertainties inherent in pre-investment analysis. Rather the GUS should be regarded as a preliminary, but rigorous, planning exercise that produces specific recommendations for the next steps in gas development and that becomes the basic management tool for future strategic analysis as more information and new options arise in the gas sector.

7. The purposes of this paper are: (i) to outline an economic framework for analyzing questions of gas utilization; (ii) to suggest a practical methodology for applying that framework; (iii) to illustrate its application in gas surplus, gas deficit and surplus window situations; and (iv) to discuss the role of the GUS in gas development. The following four chapters deal with these objectives in turn.

II. The Theoretical Framework for Optimizing Gas Use

8. The scope and focus of a gas utilization study will vary depending on the complexity of the country's energy sector and the size of its gas reserves relative to its domestic demand. The methodology set out in this chapter is a general one, however, applicable to all country situations. (Certain shortcuts to this full methodology will be legitimate in some cases, as discussed in Chapter IV). The underlying objective of the GUS is to determine the sequence of investments - i.e., the set of projects - that will yield the largest total benefit to a country from the use of its finite gas resources. Gas-using projects also require capital, labor and other inputs, and in many respects a GUS is similar to the project evaluation exercises that are routinely handled by economists and planners. Indeed, if unlimited quantities of gas were available at a fixed price, then gas could be treated exactly like any other (say, imported) input, and the net present values (NPVs) for projects could be calculated based on the prices of all inputs including gas. Those with the highest NPVs would be selected.

9. The distinctive economic attribute of an exhaustible resource, such as gas, is that its economic price is composed of its production (or extraction) cost and an additional component, sometimes called the depletion premium, to reflect the cost of future consumption foregone by using the resource today. If these two components, and therefore the economic price of gas, were known for each of the relevant time periods of the GUS exercise, then it would be fairly straight-forward to rank project alternatives on the basis of their NPVs, calculated from the economic prices of gas and all other inputs. The basic methodological problem of the GUS is that the economic price of gas is itself a function of the set of projects selected. While it is argued in the next chapter that an iterative process with certain checkpoints can be used to produce robust conclusions about gas use, it is necessary first to understand the essential simultaneity of the solution process. The paragraphs below discuss the determinants of the demand, supply and price of gas. Simplifying assumptions are employed to construct an example whose solution can be illustrated graphically.

10. The demand function for gas is not dissimilar to that for other intermediate goods. At any time, t, the quantity demanded, (Q_t^D) will be related to the price of gas at that time (P_t), the prices of relevant substitutes and complements (e.g., fuel oil and fertilizers) and income variables such as the level of GDP or the world demand for methanol. For simplicity, in the equation below the income variables are lumped together into an aggregate trend variable, Y_t.[1/] The analysis is further

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1/ This would not be an appropriate estimation short-cut. It is used here only to indicate that all such income variables are exogenous and may vary independently over the time period.

simplified by assuming that the only relevant non-gas price is that of fuel oil, which is assumed to be constant over the period and equal to \$4/MMBTU. The demand equations can then be represented as follows:

$$Q_t^D = f(P_t, Y_t) \quad \text{for } P_t \leq 4$$

$$Q_t^D = 0 \quad \text{for } P_t > 4$$

Figure 1(a) shows the demand function for a particular level of Y, and Figure 1(b) shows two of the family of functions associated with various gas prices over time.

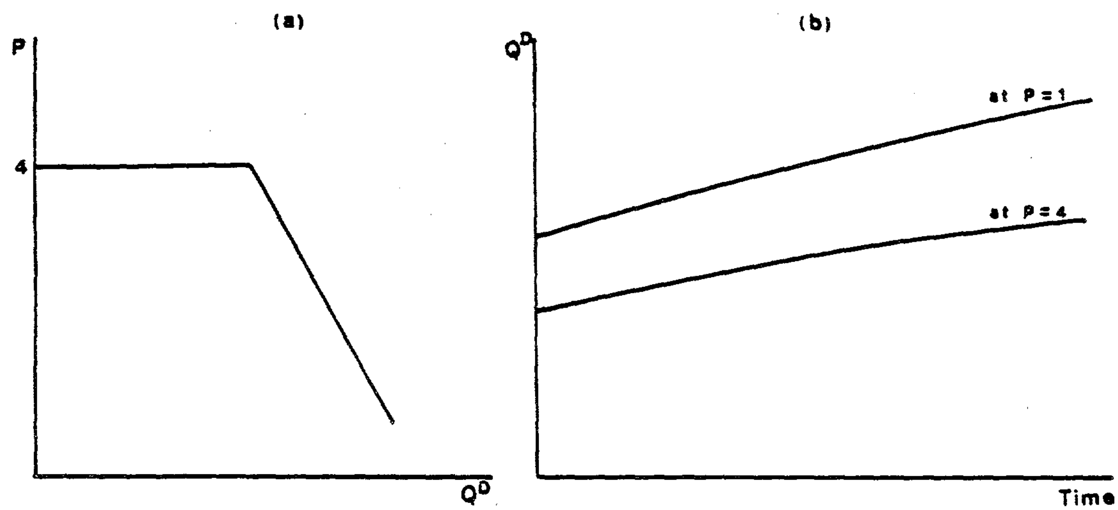

Figure 1. The demand functions for gas.

11. The supply function for a depletable resource has a special constraint to reflect the fixed nature of total production over time. For this simple case we assume that production costs are constant at \$1/MMBTU and that production rates are not a function of the price unless it falls below the cost of production, in which case no gas is supplied by the producers.1/ The technical parameters affecting the pace at which

1/ Strictly, this assumption would prevent the derivation of the Hotelling principle of depletable resource economics since the resource owners must be able to vary their production in response to price changes in order to derive the first order condition that the present value of profits in each period must be equal. The assumption is used here in order to permit a graphical presentation. The Hotelling principle is retained through the demand side so that the time trend of consumption follows the appropriate path, and it is introduced independently in the set of price equations.

gassupplies can be expanded, and the rate at which production declines from reservoirs can be expected are again lumped together into a trend variable (T_t) for simplicity. They are also defined with reference to a maximum production scenario (Q_t^{max}) which represents the fastest, technically appropriate, gas development program based on total reserves of R. Thus the quantity of gas supplied at time, t, (Q_t^S) will be defined as follows:

$$Q_t^S \leq Q_t^{max} \qquad \text{for } P_t \geq 1$$

$$Q_t^S = 0 \qquad \text{for } P_t < 1$$

$$Q_t^{max} = g(T_t, R)$$

$$\sum_{t=o}^{T^e} Q_t \leq R \qquad \text{where } T^e \text{ denotes the point of exhaustion}$$

Figure 2(a) shows the supply function for a particular level of T (i.e., a particular point in time), while 2(b) shows the maximum supply curve over time. The final constraint in the set of equations above ensures that no alternative supply curve can enclose an area larger than that enclosed by Q^{max}.

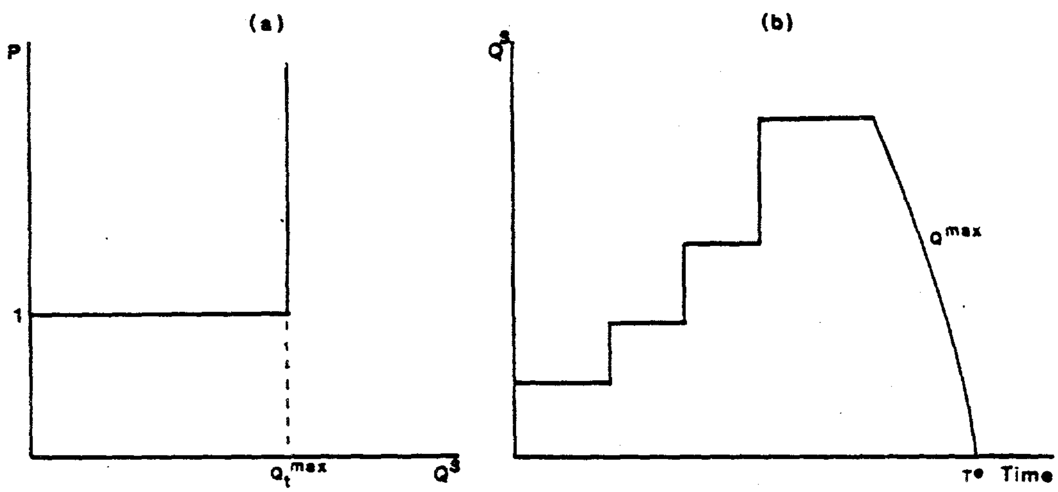

Figure 2. The supply functions for gas.

12. The final equation set needed to complete the system concerns the <u>price of gas</u>. In the general case, the price of a depletable resource will contain two components: the cost of extraction (here assumed to be a constant $1/MMBTU) and the depletion premium (i.e., the shadow price of the reserve constraint), V. The fundamental principle of depletable resource economics (also called the Hotelling principle) is that under equilibrium conditions, the depletion premium must increase over time at a rate equal to the opportunity cost of capital (r). As the price of the

resource grows over time, the demand for it naturally falls (other things equal), until the resource is just exhausted as the price has risen so high that the demand has fallen to zero. In this example, the demand for gas falls to zero when its price reaches the cost of its substitute, thereby placing an effective limit on V. Such a limit also provides the critical end point from which earlier V_t can be derived using the Hotelling principle.

13. The lumpiness and long lead times of investment in gas infrastructure often result in periods of supply constraint where production is limited not by gas reserves but by the investment needed to produce and deliver the gas to consumers. This creates the steps in the early part of the Q^{max} supply function shown in Figure 2(b). If the demand for gas is greater than Q^{max} during these early periods, then the economic price of gas will include an element representing the scarcity rent of capacity (i.e., the shadow price of the supply constraint), C, during those periods when production is limited by available infrastructure.

14. Thus, where Q_t denotes the quantity of gas consumed at time t, the set of price equations will be as follows:

$$P_t = 1 + V_t + C_t$$

$$\text{where } i = T^* - t$$

and T* denotes the date at which $(Q^D - Q^S)$ switches from a negative to a positive value. Figure 3 illustrates a typical price path described by the equations. During the early years when $t < T_1$ and gas consumption is constrained by infrastructure development, the rental element of the gas price $(V_t + C_t)$ is equal to its maximum value of 3. Then between T_1 and T^* the potential gas production has caught up with or exceeded demand so that the depletion premium is less than 3 and C_t equals zero. The depletion premium approaches its full replacement value at the rate r until, at T^*, demand again exceeds supply at a total price of $4/MMBTU.

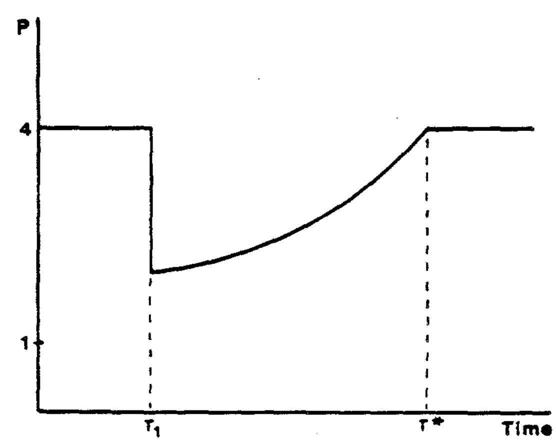

Figure 3. The price path of gas.

15. The solution to this set of equations can be illustrated graphically using an iterative process. Trial 1 consists of superimposing the time-variant demand curves of Figure 1(b) onto the maximum supply curve of Figure 2(b). The two demand curves shown for P equal to 1 and 4 represent the limits of potentially relevant demand. Based on Q^{max} Figure 4 shows that from year 0 until T_1, the consumption of gas will be constrained by supply, with the country continuing to import the amount of fuel oil represented by the shaded area between the demand and supply curves. During that period the opportunity cost of the gas is clearly its fuel oil equivalent, and the total rent is the difference between that value and its cost of production, or \$3/MMBTU. After T_1, however, the consumption of gas will depend on demand which, in turn, will depend partly on the price of gas. Assume for the first iteration that consumption followed G^{max}. Then the price of gas could be calculated by noting that at T_1* the depletion premium will again become \$3/MMBTU. This value could be deflated by the opportunity cost of capital to solve for the gas price for every period back to T_1. The price path for gas would then look like the curve shown in Figure 3.

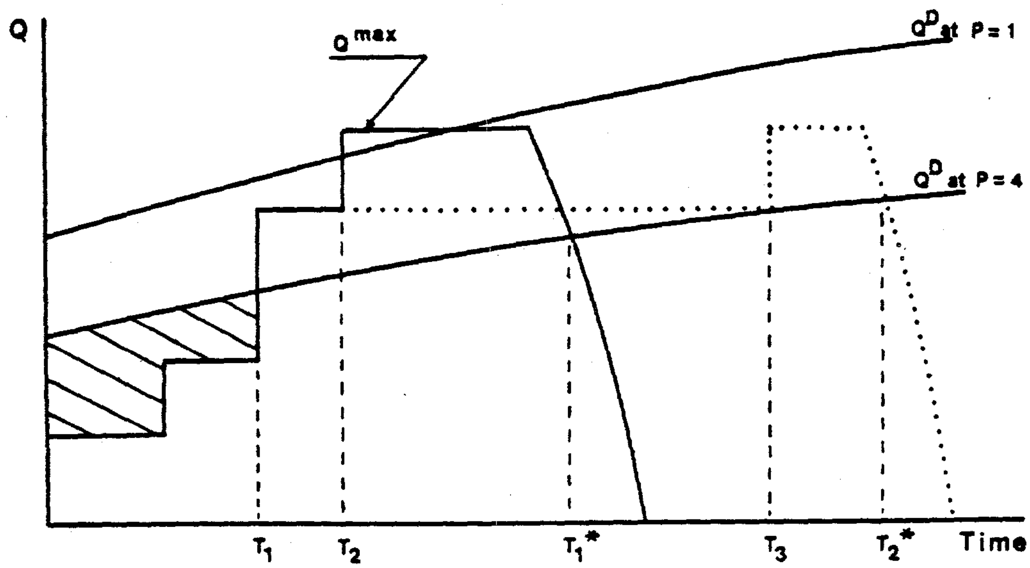

Figure 4. Initial trial solutions.

16. This first round price path does not represent the optimal one, however, since it is based on the maximum supply scenario, which produces excess capacity during much of the period between T_2 and T_1^*. Furthermore, it is inconsistent with the demand functions shown since T_1^* is derived from a consumption path that would follow the supply function, whereas the full supply capacity at a point such as T_2 could only be absorbed at prices below \$1/MMBTU. Thus additional iterations are needed to find T* and V. As a second iteration, assume that consumption follows its lowest feasible path corresponding to P=4. In that case the capacity expansion that could be undertaken as early as T_2 would not be needed until some later point, T_3, when demand has grown enough to absorb

the full production of the existing facilities. Taking into account this change, and the fact that consumption after T_1 will follow the demand curve, yields T_2^*, the new date at which gas consumption becomes constrained by reserves and therefore has a price equal to \$4/MMBTU. T_2^* implies a new price path for gas which, during the period of potential excess supply, is everywhere below the one generated by the first iteration because the depletion premium is discounted from the more distant date T_2^*.

17. These first two iterations bound the range of feasible gas consumption, and thus T*. For the third iteration, select T_3^* midway between T_1^* and T_2^*. Derive a gas price path by calculating the depletion premium between T_1 and T_3^*. Using this price path -- which will be low just after T_1 and gradually rising to reach 4 at T_3^* -- derive the demand function and the schedule of supply investments needed to meet that demand. Further iterations on the price path should be undertaken in this manner until a consistent consumption path is obtained. Figure 5 shows how it might look, where the heavy line represents the consumption path. Consumption falls in later years in this example because the effect of increasing gas prices outweighs the stimulative effect of economic growth.

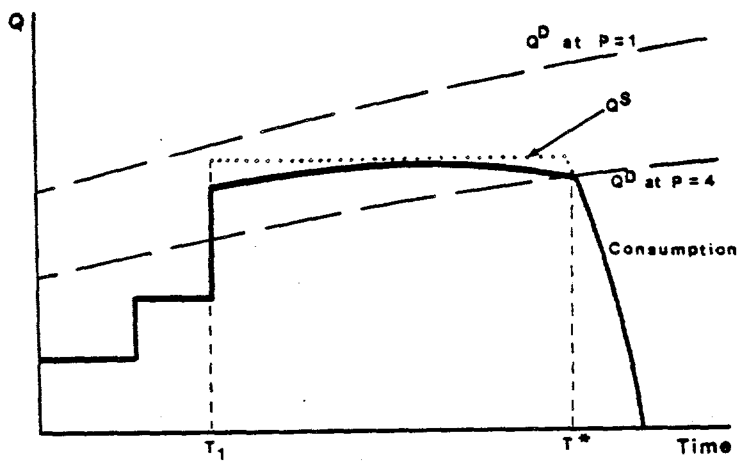

Figure 5. Final iterative solution.

18. This example illustrates the links described in the equations between the depletion premium, the price of gas, the quantity of gas demanded and the point of economic depletion, T*. The loop that they form

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1/ By assumption in this simple example, the change in investment timing has no effect on the cost of gas produced. In fact, it would require a new calculation of the long-run marginal cost, which would be lower than that of the maximum supply scenario, thereby reinforcing the downward revision in the economic price path of gas.

represents the framework within which specific questions of gas utilization can be analyzed. Once the general parameters of this framework have been determined for a particular country, the resulting estimate of the price path for gas can be directly used to calculate the NPV of any particular project candidate. In countries where gas is relatively scarce and the surplus window (i.e., the period between T_1 and T*) is short, the direct incorporation of the gas price path will ensure that the critical issues of project sequence are adequately addressed. In countries with abundant gas resources relative to potential demands, the depletion premium may be insignificant over the time period of the analysis so that the economic value of gas will be roughly equal to its production cost, and project ranking can proceed directly. As discussed in Chapter IV, the application of this framework can therefore also highlight which questions are of particular importance for different country situations.

19. The theoretical framework described in this chapter provides the economic perspective within which gas project selection and optimization can take place. The actual work involved in a GUS, however, may focus on aspects which are glossed over in the theoretical discussion; for example, the demand analysis. Furthermore, there may be practical reasons for emphasizing certain aspects of the analysis (e.g., the role of gas in the power sector) which are entirely subsumed in the framework presented above. The following chapter develops a step-by-step methodology for conducting a gas utilization study based on this theoretical framework.

III. A Practical Methodology for Gas Utilization Studies

A. Overview

20. There are three general areas that a gas utilization study should cover. First, it should develop a profile over time of the aggregate gas demand/supply balance. This sectoral context is necessary in order to derive one or more scenarios for the economic price of gas over the relevant time period. Second, it should identify, evaluate and rank alternative packages of gas-using projects and related infrastructure investments. This project evaluation analysis will be based on the gas price scenarios derived from the aggregate sectoral work. Third, consistency checking and sensitivity analysis should be undertaken to highlight any necessary revisions in the preceeding two areas (and possible additional iterations) and to identify critical project design issues or information gaps that need to be filled before certain decisions on gas strategy should be taken. As is true in most pre-investment analysis, the judicious use of sensitivity testing in GUSs is not only essential to the credibility of the results, but is also a valuable tool for defining the future work program and the scope of later feasibility studies.

21. Figure 6 illustrates these three parts of a GUS, the main components of each and the major relationships and connecting links among the components. The sectoral analysis (Part I) begins with largely independent evaluations of aggregate gas demand (Box 1), as a function of the price of gas and aggregate gas supply (Box 2), perhaps based on several alternative reserve assumptions. In Box 3 these are translated into time-dependent profiles of potential gas demand (at various prices) and supply (under various reserve scenarios). From this information and the costs associated with the investments for the aggregate supply scenario(s), the long-run marginal cost of gas can be calculated (Box 4). Using the framework described in the previous chapter, the economic price path(s) for gas is then derived in Box 5.

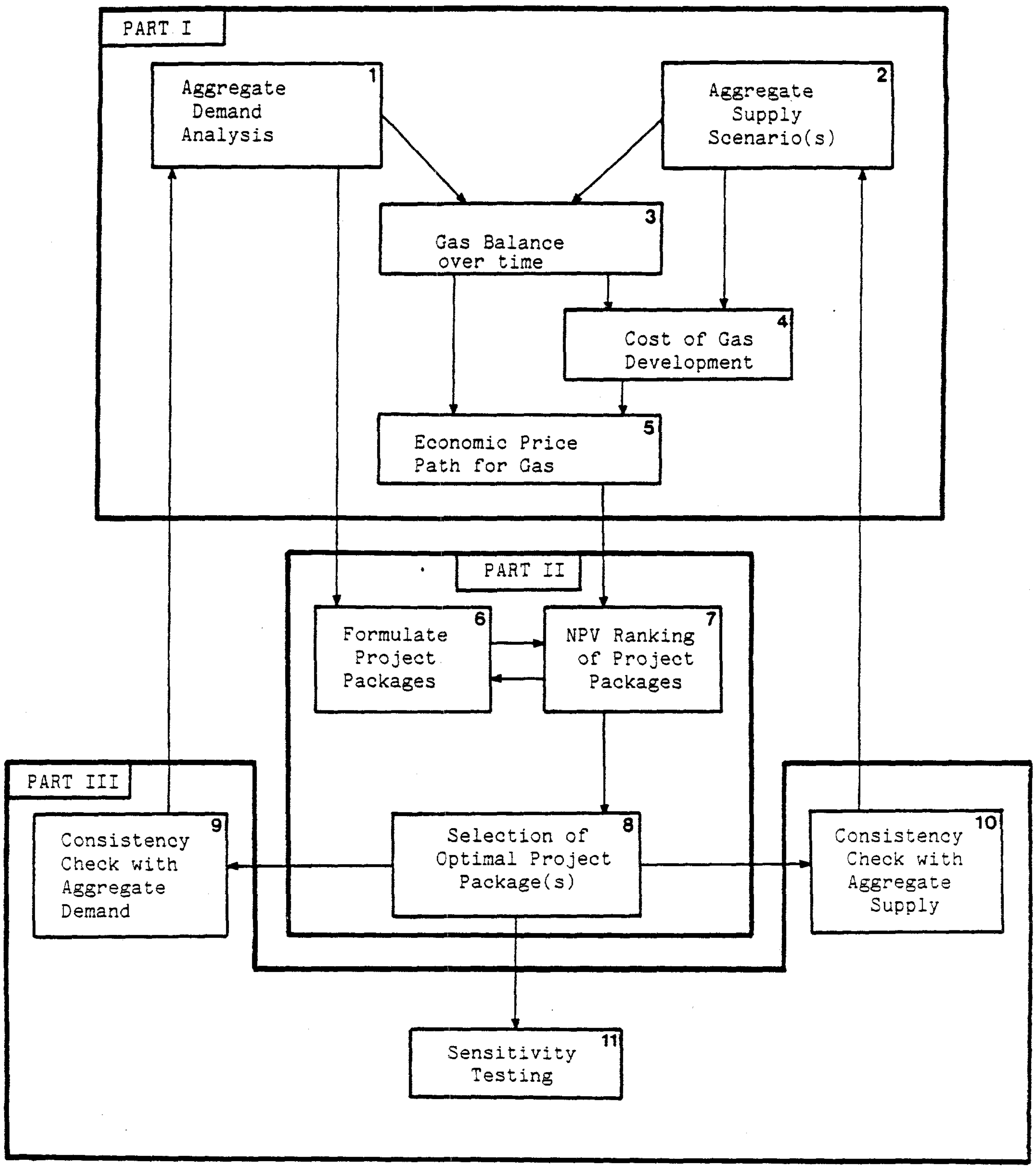

Figure 6. Components of a gas utilization study.

22. Part II constitutes the core of the GUS where the actual project formulation and comparative project evaluation are carried out. First projects are identified and grouped into tentative packages based on their technical characteristics and economic complementarities (Box 6). In the largest gas-using sectors such as electric power and fertilizers, the aggregate demand analysis from Box 1 will have already identified a sequence of projects. To these will be added gas-using projects from other sectors and for the export market, and NPV calculations will be performed on the various trial packages (Box 7). If there is more than one gas price scenario, then there may be correspondingly numerous 'optimal' project packages selected in Box 8.

23. In Part III the gas consumption stream implied by each optimal package is checked against the aggregate demand and supply analyses (Boxes 9 and 10). Any divergence should be traced through the steps in Part I to see if there is a significant impact on the gas price path. If so, another iteration through Part II will be needed. Once a consistent set of optimal project packages has been derived, sensitivity analysis should be carried out (Box 11) in order to test the robustness of results and to identify the critical areas of uncertainty in the analysis.

24. The following sections of this chapter discuss each of the study components, paying particular attention to the demand analysis (Box 1) and the project selection and ranking (Boxes 6 and 7) where most of the studies reviewed were especially weak. As discussed in the next chapter, for certain types of countries, some of the components shown in Figure 6 will be unimportant or can be handled by general estimates. In countries where the gas market is segmented (i.e., where certain reserves are linked to certain consuming centers, without interconnection), a separate GUS exercise for each market will be needed, with the option of interconnection at some future date explicitly considered.

B. The Sectoral Context (Part I)

Aggregate Demand Analysis (Box 1)

25. The estimation of potential future demand for a commodity which is often not yet widely available in the market is a difficult task prone to uncertainty. Furthermore, for a GUS one needs both aggregate demand estimates and detailed information on the individual projects that comprise the demand. Such macro and micro analysis often require different types of expertise (i.e., economics for the former and engineering for the latter), yet the two must be merged into a consistent picture.

26. Before discussing the recommended approach for demand analysis in a GUS, it is useful to describe the two approaches that were used in the studies completed so far. The first, and most common, is micro or bottom-up demand estimation. This consists of identifying specific projects (e.g., a cement plant that could be converted to gas), and estimating and summing their gas requirements. While this approach appears to have the

advantage of being clearly anchored to reality, it suffers from two important limitations. First, it is dependent for its success on a thorough knowledge of all the country's potential gas-using sectors; e.g.,the industrial base, electric power system, and agricultural patterns (as they affect fertilizer needs). Few external consultants have the time or range of skills to obtain such knowledge unless the country is very small and underdeveloped. Secondly, using this approach, the production of estimates for gas demand beyond the next 5 years or so is generally crude. Yet the medium and longer term prospects for gas use are usually the main focus of the study. Without an explicit grounding in the country's macroeconomic conditions, and in the interfuel options for the energy sector (particularly in electricity generation), the projections generated by bottom-up extrapolation may miss the mark badly.

27. The second approach used in some of the studies for gas demand projections is a macro or top-down estimation. In it, estimates for such macroeconomic parameters as the GDP growth rate and the increase in the share of the industrial sector are used to project gas demand. There are also two problems with this approach. First, in countries where gas is still a new fuel, the base figures from which extrapolations are made are often too low. In the early years of gas availability, consumption may double or triple annually since there are once-for-all opportunities for fuel switching and because consumption is generally constrained by supply. Macroeconomic parameters such as the growth rate of the country's industrial sector will be directly related to gas consumption only once the initial supply contraints and once-for-all market penetration investments are over. The second problem with exclusive reliance on the top-down approach is that the estimates produced will be only as good as the model they come from. The level of disaggregation of most macroeconomic models is not such as to capture intra-sectoral changes (such as the fuel pattern in electricity generation) which may critically affect gas demand.

28. The bottom-up approach has clear attractions for near-term demand projections (say, 1-5years). The top-down method can produce reliable projections for the long-term (say, beyond 15 years, or sooner in a country with an already established gas market), provided the projection period starts with a reasonable base level of consumption. Neither approach is likely to produce good figures for the medium-term period (say, 5-15 years) - the time of greatest interest for most countries, given the lead time required for both infrastructure and gas-using project investments. The medium term is when the transition is made from a market with a new fuel whose consumption grows as fast as supply expansion can take place to a mature market where most once-for-all opportunities have been exploited and consumption grows in line with the markets for the end products which gas is used to produce (e.g., fertilizer, electricity). During the medium term, the availability of gas can provide the opportunity for structural changes in those end-use sectors themselves, for example, the choice between a gas or coal-based power development program. This type of change should be a principal focus of the GUS.

29. To estimate gas demand for this critical medium-term period, a sectoral focus - rather than micro or macro - is needed. The GUS should analyze in depth the demand/supply/import/export opportunities for the main gas-using sectors and their supply/investment alternatives to gas. This time-consuming exercise should be limited to those sectors in which potential gas demand is very large, i.e., electric power, fertilizers, and sometimes cement. Since these sectors also provide the major opportunities for gas-using projects, an understanding of their demand determinants will aid both in the estimation of aggregate gas demand (and thus the economic price path of gas), and the identification of individual project opportunities for gas use (Box 6 in Figure 6). The analytical treatment for each of the three main gas-using sectors is outlined below.

30. Electric power sector. In order to estimate the medium and long term role of gas in a country's power system, the GUS must generally employ the same tools that power planners use in projecting power demand and developing their least-cost expansion path for power investments. The introduction of gas will not be a simple matter of substituting a planned hydro or coal-fired plant with one of equal megawatts of gas-based power. Because gas-using equipment has lower capital costs (per megawatt), and therefore less pronounced economies of scale, a least-cost expansion program based on gas might involve more frequent, smaller investment increments than one based on, say, coal. This ability to match more closely demand and supply may, in turn, imply that gas-based power would prove to be less costly than coal even in conditions where the economic price of gas was higher per MMBTU than that of coal. For reasons such as these, a simple plant-by-plant comparison of gas versus alternative fuel units will rarely be an adequate basis for projecting demand for gas by the power sector.

31. To examine more closely the determinants of the demand for gas in power, the World Bank commissioned an empirical study of that issue based on three power systems: a large system with significant hydro, a small system with no hydro opportunities and a 'green field' case which assumed no inherited capacity.[1/] There were two main conclusions. First, the shape of the demand curve for natural gas by power is system-specific. Despite using common assumptions on the capital costs of alternative units, the efficiency rates of each unit type, the discount rate, etc.; there were significant differences in the gas demand curves for the three cases studied. Even the switching values for gas versus coal, for example, were different, primarily because of differences in the inherited plant mix, the demand growth for electric power and the structure (i.e., peak versus off-peak) of demand. The second conclusion was that the demand curve for natural gas by power will generally consist of a series of steps, such as that shown in Figure 7. The size of the steps is dictated by certain critical prices of gas which are system specific.These are the prices which switch investment decisions; for example between gas-

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1/ Albouy & Mashayekhi, "Value of Natural Gas in Power Generation," November 1984, Energy Department Paper No. 19, World Bank.

fired steam units and coal-fired steam units ($2.9/MMBTU for the large power system with hydro), or the decision on conversion of inherited oil-fired plants to gas firing ($6.1/MMBTU in the same case). In addition to these steps, there may be areas of the curve whose shape is determined by the prices which change the merit order ranking of plant; e.g., between Q_1 and Q_2 on Figure 7.[1/]

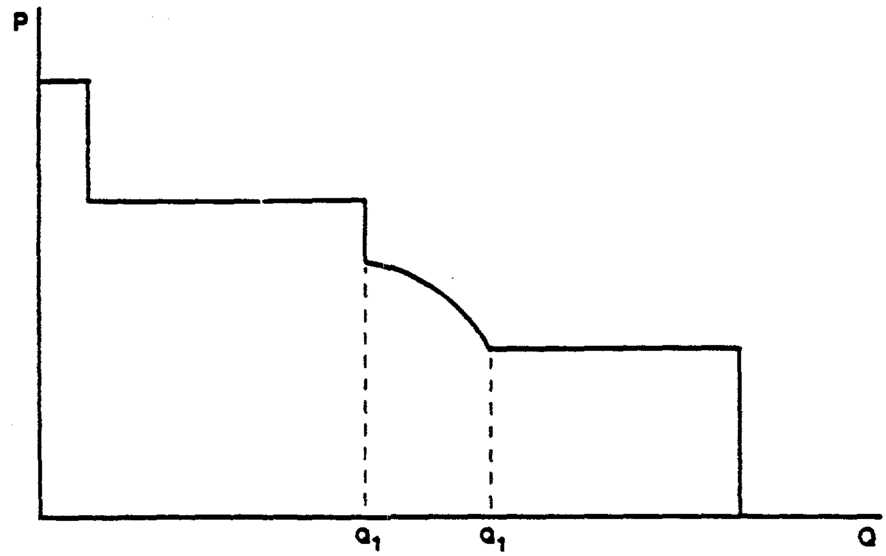

Figure 7. The demand for gas by power at time t.

32. The implications of this study for a GUS are that: (i) there is generally no substitute for a country-specific analysis of the power system expansion program and the role that gas could play at various prices; and, (ii) because of the stepped nature of the demand curve for gas in power, this analysis can be simplified by a judicious selection of both trial prices for gas and critical years to be examined (e.g., when a hydro plant would otherwise be commissioned). Thus specified expertise on power system planning is likely to be required as part of the GUS team.

33. Fertilizer sector. Because of the dominant role of agriculture in the economies of many developing countries, and because of the continuing shift within the agricultural sector from traditional to modern farming methods, the domestic production of fertilizer often offers a large and growing market for natural gas. On the other hand, the NPV of gas-based fertilizer production may not be particularly high. For all but the largest developing countries, it is no longer economic to build diesel or fuel oil based plants to produce amonia/urea compared with importing

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1/ The merit order is the ranking by whic it is determined which plants will be used to meet the peak demand for power. It is the short run variable (once the investment decisions have been taken) which allows for minimizing operating costs.

the latter: thus the value of gas in fertilizer production will often be lower than in other uses where it directly replaces fuel oil. Further, when the gas is used to produce fertilizer for export, rather than to replace imports, its value falls significantly. For these reasons, in order for a GUS to properly assess the amount of gas that would be used in the fertilizer market at various gas prices, it is necessary to develop an understanding of the country's present and future demand for fertilizer.

34. This analysis will be considerably simpler than that needed in the power sector because economically-sized urea plants are quite large relative to the market in most developing countries and there are few design issues that would significantly affect the amount of gas consumed. The principal relevant questions are those of project timing and the degree of export-orientation of each plant over its lifetime. In the early years, the potential for switching existing plant from some other feedstock to gas should also be examined and compared with the option of replacement.

35. Once a schedule of fertilizer plant investment to meet domestic needs has been drawn up, capacity utilization rates (for each plant, for each year) should be calculated from the fertilizer demand projections. This is important because economies of scale often dictate building large facilities even where they may not reach full production levels for several years. Yet the capital investment is so large, relative to other uses of similar amounts of natural gas, that capacity underutilization can significantly lower the project NPV.

36. Cement Sector. For the purposes of a GUS, the projection of demand for gas by the cement industry is even more straightforward than is the case for fertilizer. Because it is seldom economic to export cement, investment in the industry will follow the growth of domestic demand, perhaps with an initial period of rapid expansion to substitute for imports. Plant sizes are often large, relative to the market, with many low-income developing countries needing only one or two new plants per decade. Choice of technology for a new plant will clearly favor the energy-efficient dry process, and it will often be economic to convert or replace old wet process plants even if the economic price of gas is relatively low. The main economic issues in projecting gas demand for cement are the growth rate of the domestic market (and thus the scheduling of new plant) and the appropriate benefit basis. The latter will depend on the alternative, at the margin, to building a gas-based plant. If the country would otherwise find it economic to build a plant based on fuel oil or coal, then the benefit derived from gas will be based on the capital and operating costs of a plant using that alternative fuel. On the other hand, if the country's best alternative to gas-based plant is to import cement, then the benefit will be derived from the projected import prices it would face.

37. Demand curve construction. The demand analysis for the three sectors described above may need to be augmented in some cases by similar studies of other sectors where significant gas use is expected (e.g., steel) or is likely to occur in lumps rather than in a smooth build-up

over time. Once this sectoral analysis has been accomplished for the largest users, the information must be combined to give a picture of the aggregate gas demand function. This can be done in five steps. The first step is to calculate the netback value of gas consumed in each of the large gas-using projects outside the power sector. The netback value of gas, N, is the total discounted NPV of the project with a zero cost of gas (in constant price monetary units) divided by the total discounted quantity of gas consumed (in volumetric units):

$$N = \frac{\sum_{t=1}^{T} (B_t - I_t - O_t)/(1 + r)^t}{\sum_{t=1}^{T} Q_t / (1 + r)^t}$$

where B_t = project benefits in year t

I_t = investment costs incurred in year t

O_t = operating and maintenance costs of the project in year t excluding the cost of gas

Q_t = consumption of gas by the project in year t

r = opportunity cost of capital

T = the time horizon for the project.

The netback value thus represents the highest average price for gas that the project could pay and still break even over its lifetime, relative to the best 'without gas' alternative. As noted above, the alternative could be either a similar plant based on a different fuel or feedstock or the import of the end-product, whichever would be more economic in the absence of gas. Annex 1 shows a sample netback calculation for an LNG project.

38. The second step consists of determining the power-related gas demand by postulating several trial price paths. For this preliminary round a constant price can be assumed. Once the potential for plant conversion has been taken into account, the process can be simplified by seeking the optimal share of gas for a few widely spaced test years on the basis of annuitized investment costs and full requirements which assume that for a major part of its life a plant is utilized at a fairly constant capacity factor. The result would resemble Figure 8.

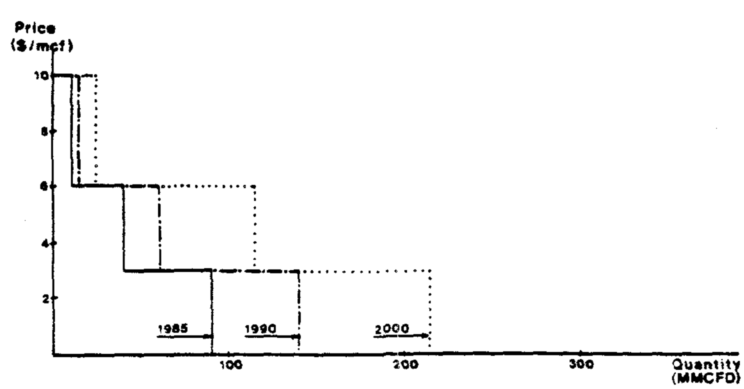

Figure 8. The demand for gas by power over time.

39. In the third step, the netback information is used to graft the relevant demand for gas from other large projects onto the set of demand curves for power. Suppose, for example, that two additional projects are considered; one with a netback of $4/MMBTU that uses 40 MMCFD from 1985 onwards; and a second with a netback of $2/MMBTU to be commissioned in 1990 and consume 80 MMCFD from start-up. Figure 9 shows how this information could be added to that on the power sector shown above.

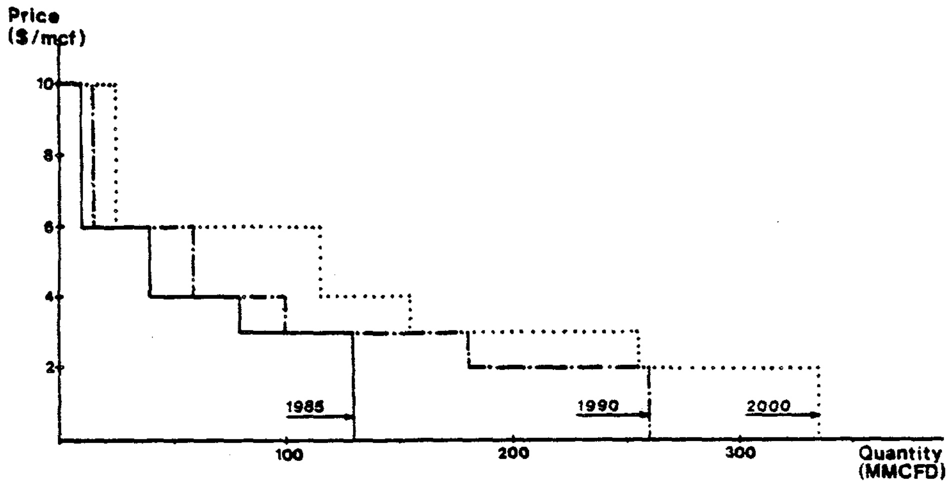

Figure 9. The demand for gas by power and other major sectors over time.

40. The fourth step is to translate the price-versus-quantity graphs into quantity-versus-time graphs. This is done by connecting the points from the various demand curves over time at each important price level. The fifth and final step is to add to this gas demand from the major sectors the demand from other users to arrive time-dependent aggregate demand cuves. This is where micro estimates of demand for the early years of the period are used and macro projections of total gas demand for the intermediate and later years of mature markets are incorporated. The result is shown in Figure 10.

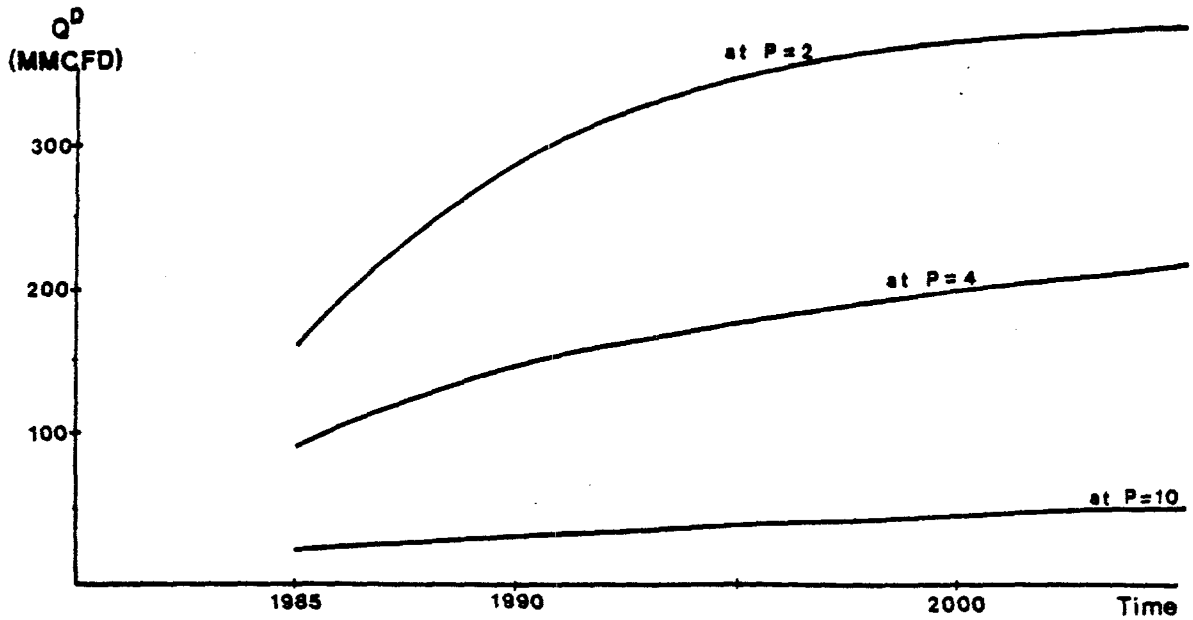

Figure 10. The aggregate demand for gas over time.

Aggregate Supply Scenario(s) (Box 2).

41. The derivation of gas supply scenarios is generally a matter more of judgment than of firm information. Because the information on gas reserves is bound to change as exploration proceeds, and because a GUS is usually undertaken early in gas development, it is seldom worthwhile to invest great time or effort in refining estimates of reserves based on current information. Rather, the views of geologists and other experts working in the country on future success ratios and potential discoveries that could be brought onstream in the study period should be canvassed and assessed. It will often be appropriate to develop a set of two or three reserve figures which bracket or describe the probable range. For each reserve scenario, an estimate should be made of total gas supply for each year of the study period, based on existing infrastructure and the stage of discovery or development of the various fields. This will involve estimates of potential production from each major field or set of fields, taking into account field use and production decline rates as the fields reach maturity.

42. In addition to providing gas supply projections that can be compared with the aggregate demand figures to identify periods of potential surplus and deficit, there are two other purposes of the aggregate supply analysis. The first is to develop a tentative gas project sequence by identifying the major supply options or major alternatives in project design or scope. These can form the basis of some of the project packages whose NPVs are calculated and compared in Part II of the GUS. The other purpose of the supply analysis is to provide the investment framework for calculating the marginal cost of gas supply as an input into the economic price path for gas. The latter will be

particularly important in gas-surplus situations where the depletion premium component of the price may be insignificant (see Chapter IV).

Gas Balance over Time (Box 3)

43. The aggregate demand curves can now be matched with the maximum supply scenario(s) derived in Boxes 1 and 2, respectively. This will provide a date for T_1, the point at which supply catches up with demand; and it will yield the first round estimate(s) of T*, the point of economic depletion at which potential demand exceeds supply at the relevant price. (There will be a T* for each reserve scenario.) It is at this point that the informed judgment and close interaction of the economic and engineering experts on the GUS team becomes important. It is generally possible for those who prepared the demand and supply estimates to jointly develop two or three iterations of the type described in the preceeding chapter which will result in an optimal gas consumption path and thus an optimal T* associated with each reserve scenario. Chapter IV provides illustrations of several cases where this step will be self-evident, as well as a description of the circumstances under which it will be different.

Cost of Gas Development (Box 4)

44. In Box 3, an optimal gas supply schedule over time was determined for each reserve scenario. Each will imply an investment program for exploration, field development and possibly transmission and distribution. The costs of these should now be estimated, using economic prices for all inputs. The present value of the stream of investment and associated incremental operating costs can be divided by the discounted volume of gas consumed (as developed in Box 3) to yield the average incremental cost (AIC) of gas development for each reserve scenario.[1/]

45. There are several decisions involved in making the AIC calculation. The first is which costs should be included in the general calculation and which should be allocated to particular users in Part II of the GUS. In countries with diverse sources of gas and little existing use, it will generally be appropriate to calculate a 'wellhead' cost, which includes only the costs of future exploration, field development and delivery to land for off-shore supplies. Major gas-using facilities will often be set up close to the fields or point of landfall, with little additional infrastructure cost. In other cases, where incremental

1/ For a complete explanation of the procedure, see Afsaneh Mashayekhi, 'Marginal Cost of Natural gas in Developing Countries: Concepts and Applications', Energy Department Paper No. 10, World Bank Energy Department, August 1983.

supplies will be used mostly in distant urban/industrial areas or where they will feed a pipeline grid, it will be appropriate to calculate a 'city gate' cost, which will include the wellhead cost and the necessary transmission costs to reach the city or grid. In general, the AIC should include all incremental system costs that cannot be clearly allocated to particular consumers or consumer groups. Allocable costs should be included in the gas-using project packages assembled in Box 6.

46. A second issue in the cost calculations is the degree of precision that is needed. Developing detailed cost estimates for a 20 year investment program is time-consuming, and would be based on many, often arbitrary, assumptions. Empirical studies carried out by the World Bank on ten developing countries with gas resources showed that the range of city gate AIC was surprisingly small, considering the widely differing country circumstances.1/ This implies that detailed cost estimates will not be necessary to yield an AIC with an acceptable level of confidence. However, where there are major issues of gas project design (e.g., onshore versus offshore pipelines which imply different consumers to be served en route), careful costing of each option will be important for the NPV comparison of such alternative project packages in Box 7.

Economic Price Path for Gas (Box 5)

47. The derivation of the gas price path is a straight forward application of the equations discussed in para. 12. The depletion premium for each reserve scenario can be calculated directly from the point of economic depletion, T*, developed in Box 3. This is then added to the AIC, as determined in Box 4, to yield a gas price path over time for each reserve scenario.

C. Project Evaluation Analysis (Part II)

48. In Part I, the focus of the GUS is on the entire gas sector for the time period under study. The objective of Part II is to provide an early screening of major project candidates. Thus it should include an analysis only of major projects and project alternatives. This means that the project packages that are formulated and the NPVs that are calculated will usually represent only a part of expected investments in the sector. However, the analysis must be carefully designed to highlight all important investment choices.

1/ As noted in Mashayekhi, ibid., the city gate AIC ranged from $0.5 to $1.8/MMBTU in 1982 constant prices.

Formulation of Project Packages (Box 6)

49. One of the most difficult and potentially time-consuming parts of a GUS is the formulation of trial packages of gas-using projects. Because of the complementarity both of investments (e.g., a transmission pipeline to an industrial complex) and of products (e.g., methane for ammonia and ethane for ethelyne), it is generally misleading to compare individual gas-using project alternatives. Furthermore, since gas is depletable and its price changes over time, questions of project sequence must be explicitely addressed. With a computer, and the price path arrived at in Part I (para. 47) it is possible to generate and compare a large number of permutations of project packages. This is especially important for power, where existing least cost planning models can be used with minor adaptations. For other sectors, it is usually preferable to pre-select the most likely set of projects and spend the computer budget testing basic inclusion/exclusion questions and comparing different sequences of projects within each trial package.

50. Project pre-selection should begin with the sectoral studies carried out in Box 1 for the major domestic users of natural gas. These will provide an initial set of projects with their appropriate implementation dates to serve the local market. For example, in the early years the package might include conversion projects for power stations and cement plants currently using diesel or fuel oil, followed by new gas-fired steam generating plants and ammonia/urea facilities during the intermediate period, with perhaps additional power and cement plants over the longer term as demand grows. During the period prior to T_1, the total gas consumption of the trial package must not exceed Q^{max}. This may place some constraints on the sequence of projects within the package. Once this base case project package to serve the domestic market has been assembled, it is often useful to calculate the total project package net present value (PPNPV) and to explore the potential for increasing the PPNPV through changes in project timing, sequence or basic design. The objective is to identify the best (i.e., highest PPNPV) base case package against which alternative packages can be compared.

51. To this base case can be added various export-oriented projects, one at a time, to see the effect of each on the total PPNPV. In addition, if there are basic questions of gas system design to be explored (e.g., providing partial service to two areas versus serving one fully but with spare capacity in the early years) then appropriate investment packages should be constructed and tested.

52. Figure 11 shows a simplified example of project packaging. Case I is the simplest where the gas is brought onshore and through an onshore pipeline to be used as fuel in an existing power station. Case II involves the addition of an LPG extraction plant with its products entering the market as LPG and natural gasoline. In Case III ammonia and methanol plants are added, and in the last case, an ethylene complex is also included.

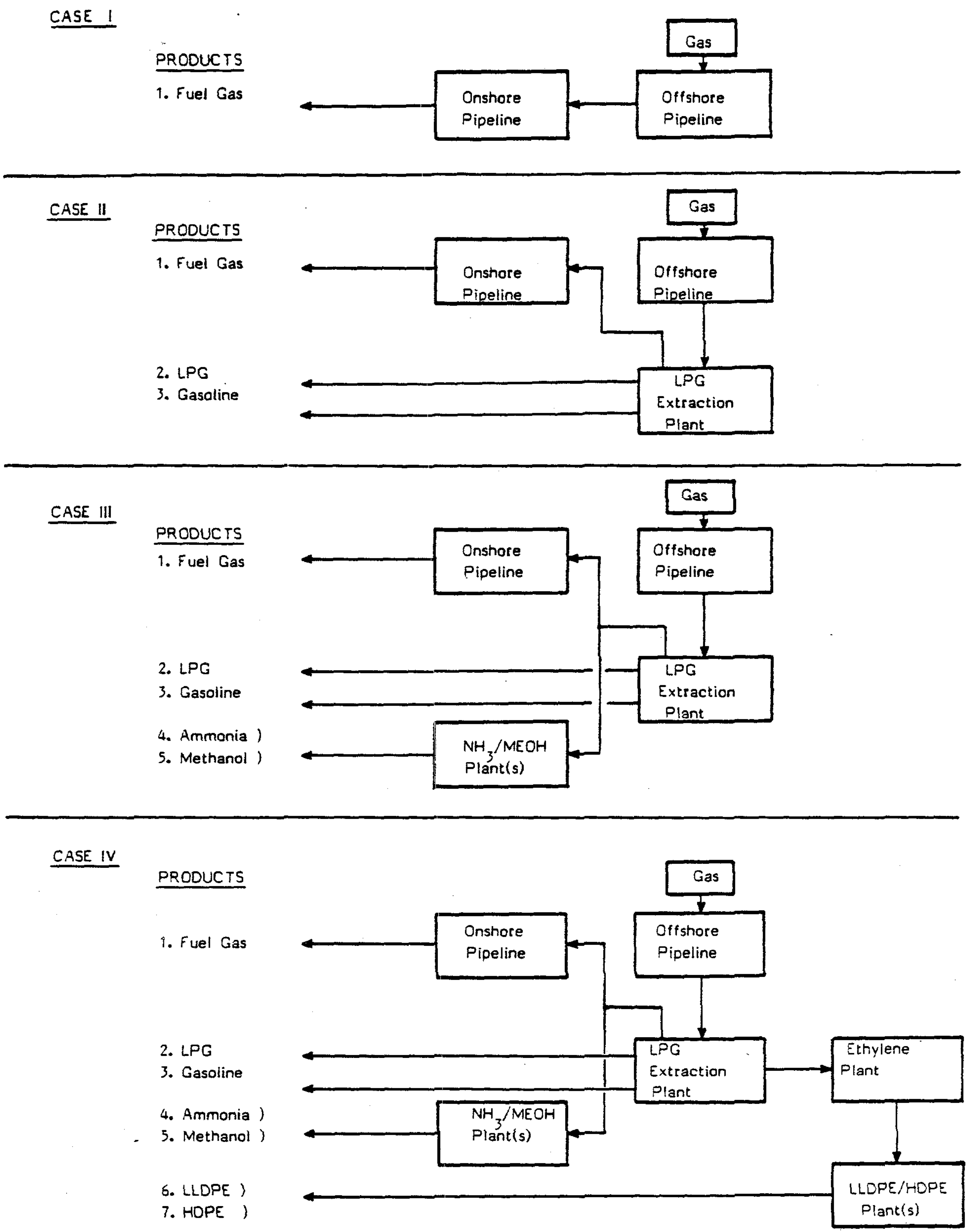

Figure 11. Sample construction of project packages.

NPV Ranking of Project Packages (Box 7)

53. While not conceptually difficult, the development of data to use in the PPNPV ranking is often a time-consuming exercise. Many consulting firms have in their files project cost information on, for example, urea plants of a certain size built in various locations. Such costs can vary by a factor of two when comparing the same plant built in a developed area with good infrastructure and one built in a remote area with no existing infrastructure; it is important to tie them specifically to the site in question. Even then, cost estimates are unlikely to be better than ± 25-50%, which should be considered in later sensitivity testing. In addition to site-specific cost estimates, operating parameters such as start-up time and capacity utilization vary widely and should be derived from similar facilities operating in the same country. For projects with a tradable output, such as urea or methanol, scenarios of the future trend in world prices will have to be developed or adopted from a reputable outside source. If those products are produced for the export market, rather than import replacement, then a borad analysis of the regional market for such products will be needed for sensitivity tests.

54. Once assumptions have been explicity made and the data have been developed, the various PPNPVs can be calculated, using readily available computer software. A surprisingly common mistake that is made during this state of a GUS, however, is to confuse economic and financial parameters. It is critical that the PPNPV comparison be made on strictly economic grounds; i.e., on the total net benefits that will accrue to the country rather than on the sum of net benefits accruing to each firm or project entity. This means, for example, that profits should be calculated before taxes rather than after, that input costs should be on an economic basis exclusive of any subsidies of price controls that may distort their market prices, that all investment costs should be included as spent rather than when loans to finance them would be repaid, that all costs should be on a constant price basis excluding inflation, etc. There are many good texts on such details of economic project evaluation that can be consulted for guidance.[1/]

55. As the calculations proceed, it will often become clear that certain sets of projects always dominate others, or that certain sequences of projects always yield higher PPNPVs than others. For example, the production of ethylene derivatives may always increase the PPNPV, whereas the addition of propylene derivatives may decrease the total project package NPV. In this case, the more elaborate project packages which would include, say, methanal as well as petrochemical production, should be reformulated, if necessary, to encompass ethylene but not propylene derivatives. The objective in the ranking exercise is to compare each larger project package with the best version of the previous package.

1/ See, for example, L. Squire and H. van der Tak, Economic Analysis of Projects, John Hopkins University Press, 1976.

This will generally require formulating some new project packages as the ranking results are generated.

Selection of Optimal Project Package(s) (Box 8)

56. For each gas price scenario (i.e., each gas reserve scenario from Box 2), the project package having the highest total PPNPV should be selected. If the same package is chosen under all price scenarios, then reserve uncertainty is not a constraint to gas utilization. If the first few projects (in time sequence) are the same in optimal packages for the various price scenarios, then developments for at least those projects can proceed without delay. In the unlikely event that the project packages for different reserve scenarios are completely different, with the same package ranking very high and very low on different reserve assumptions, then it may be best to step up gas exploration efforts and delay decisions on gas use until the reserve uncertainties can be reduced. In general, however, this exercise will identify some projects that clearly have a high investment priority (under all reserve scenarios), some that are sub-marginal (under all reserve scenarios) and some that only become interesting under the high reserve scenarios or whose feasibility is sensitive to parameters other than gas reserves. The sensitivity tests in Part III should be used to segregate projects more clearly into these three categories.

D. Consistency Checking and Sensitivity Analysis (Part III)

57. Pre-investment studies, such as a GUS, by their nature have substantial uncertainties. The farther into the future they look, the greater is the potential for significant error. As noted in para. 7, two of the three primary objectives of a GUS involve defining the critical areas of uncertainty that affect project choice and recommending the types of analysis and information collection that should be undertaken in the later feasibility studies for individual projects. These tasks require a rigorous and carefully designed sensitivity analysis, upon which the final credibility of all of the GUS conclusions will rest.

Consistency Check with Aggregate Demand and Supply (Boxes 9 and 10)

58. Because of the circularity of causation from the gas demand and supply profiles, to the conomic price for gas, to the projects selelcted and then back to the total gas demand; it is necessary to check that the project packages selected in Box 8 remain consistent with the demand and supply profiles developed in Boxes 1 and 2. If, for example, a selected project package would require a faster build-up in gas supply than is described in Q^{max} of the relevant reserve assumption, then some reduction or rescheduling of projects within that package will have to be formulated and tested. If the selected package implies a lower rate of demand growth than had been projected in Box 1, this may postpone T^* for a few years which, in turn, will lower the economic price of gas for the period between T_1 and the new T^*, thereby requiring the calculation of a new set

of PPNPVs. In most cases, however, given the range of uncertainty around the estimates in Boxes 1 and 2, minor inconsistencies will not result in large enough changes in the price path for gas to justify another round of PPNPV calculations.

Sensitivity Analysis (Box 11)

59. A well-designed sensitivity analysis should enable the GUS to provide firm recommendations on:

(i) a set and sequence of projects that are clearly attractive under most reasonable circumstances, and for which feasibility work should begin;

(ii) a set of projects that are clearly unattractive under most reasonable circumstances, and for which no further studies should be undertaken at t his time; and

(iii) a set of marginal projects whose feasibility will depend on certain, identified paramters on which either more information is needed or more detailed analysis should be undertaken before or during feasibility studies.

The first step in designing the sensitivity analysis is to identify the set of physical and economic parameters whose magnitude and probability of occurrence are such that they could have a significant impact on project ranking. These will often include world price projections for some project outputs (e.g., urea, LPG), assumptions on domestic demand growth for some (e.g., power, cement), variations around the selected discount rate (where the packages include some capital-intensive projects), variations in capacity utilization rates (expecially for export-oriented projects), etc. They should also include relevant future policy decisions where the linkages with the gas sector are strong, such as whether or not to upgrade a local refinery to reduce supplies of surplus fuel oil that would otherwise substitute for gas. Some of these uncertainties may have such a large effect on project ranking that they should be built directly into the analysis of Parts I or II of the GUS. For example, major variations of reserve estimates should be incorporated into Box 2 and carried through the entire analysis. A major strategy question such as whether to supply gas to two areas of the country initially or to phase development should be tested in the project package formulation and ranking of Boxes 6 and 7.

60. There is a danger that too many different sensitivity tests can obscure, rather than clarify, the ranking of project packages. There are various methods of minimizing this risk. It is often possible to group certain types of uncertainty into a single sensitivity test. For example, delays in project implementation, capacity underutilization or a slower than expected build-up in local demand would all have the same effect of slowing the rate of gas consumption, thereby postponing T^* and lowering the price path of gas after T_1. A single sensitivity test designed around a lower gas price path could be used to test the effect of all three areas of uncertainty.

61. Some uncertainties offset one another and have little net effect on project selection. For example, in estimating the cost of gas development in Box 4, the time path of gas consumption that goes into the denominator of the AIC may be underestimated. However, this would imply that the schedule of investment used in the numerator of the AIC is also underestimated; the net effect is probably small. It is often useful to designate one or a small number of base case project packages from those selected in Box 8, and to apply the general sensitivity tests, such as using alternative discount rates, only to those cases. Through using such base cases, through eliminating sensitivity tests of off-setting effects and through grouping uncertainties that result in similar effects; the number of sensitivity tests can be held to a level that the policy maker can absorb.

62. Figure 12 presents an example of sensitivity test results. The first column represents the base case test, T-1. The next four columns, T-1-1 through T-1-4, are different project packages using the same assumptions as the base case to calculate their PPNPVs. The next three columns, T-1-5-a through T-1-5-c, are sensitivity tests on the base case project package assuming: (i) coal replacement in power rather than fuel oil (T-1-5-a); (ii) all incremental LPG is exported rather than half used domestically (T-1-5-b); and (iii) a combination 'worst case" of these assumptions (T-1-5-c). Next come four policy alternatives, denoted T-2 through T-5, which use the same project package as the base case. These are: that a planned local refinery is not built, (T-2); that the pipeline routing is mainly off-shore rather than on-shore (T-3); that the pipeline is built in one stage rather than two (T-4); and that the LPG projects are located in a different area (T-5). Finally, T-6 represents the 'do nothing' option, assuming that only the existing gas development plans are carried out.

Case No.	T-1	T-1-1	T-1-2	T-1-3	T-1-4	T-1-5-a	T-1-5-b	T-1-5-c	T-2	T-3	T-4	T-5	T-6
Products	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas	Fuel Gas
	LPG	-	-	LPG	LPG	LPG	LPG	LPG	LPG	LPG	LPG	LPG	LPG
	Natural Gasoline	-	-	Natural Gasoline	Natural Gasoline	Natural Gasoline	Natural Gasoline	Natural Gasoline	Natural Gasoline	Natural Gasoline	Natural Gasoline	Natural Gasoline	Natural Gasoline
	Ammonia	-	Ammonia	Ammonia	Ammonia	Ammonia	Ammonia	Ammonia	Ammonia	Ammonia	Ammonia	Ammonia	Ammonia
	Methanol	-	Methanol	Methanol	Methanol	Methanol	Methanol	Methanol	Methanol	Methanol	Methanol	Methanol	-
	Ethylene derivatives	-	-	-	Ethylene derivatives	Ethylene derivates	Ethylene derivatives	Ethlyene derivatives	Ethylene Derivatives	Ethylene Derivatives	Ethylene Derivatives	Ethylene Derivatives	-
	-	-	-	-	Propylene derivatives	-	-	-	-	-	-	-	-
Fuel Gas Value	Fuel Oil	Fuel Oil	Fuel Oil	Fuel Oil	Fuel Oil	Coal	Fuel Oil	Coal	Fuel Oil	Fuel Oil	Fuel Oil	Fuel Oil	Fuel Oil
LPG Market	Local/ export	Local/ export	Local/ export	Local/ export	Local/ export	Local/ export	100% export	100% export	Local/ export	Local/ export	Local/ export	Local/ export	Local/ export
Implementation of local refinery	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Pipeline routing	Onshore	Onshore	Onshore	Onshore	Onshore	Onshore	Onshore	Onshore	Onshore	Offshore	Onshore	Onshore	None
Pipeline phasing	Two	Two	Two	Two	Two	Two	Two	Two	Two	Two	One	Two	None
Implementation period	1984-2000	1984-2000	1984-2000	1984-2000	1984-2000	1984-2000	1984-2000	1984-2000	1984-2000	1984-2000	1984-2000	1984-2000	1984-1988
LPG location	Area A	Area A	Area A	Area A	Area A	Area A	Area A	Area A	Area A	Area A	Area A	Area B	Area A
Project Package Net Present Value	23.4	15.7	16.4	22.6	23.2	19.9	21.2	18.3	27.7	23.0	22.1	23.0	7.1

Figure 12. Sample presentation of sensitivity test results.

Source: Adapted from Chem Systems, 'Master Plan Study for Natural Gas Utilizationin Malaysia'.

IV. APPLICATION OF THE METHODOLOGY

63. While the theoretical framework and the practical methodology discussed in the preceeding chapters have been designed to cover all cases of gas utilization studies, it is clear that the critical issues of gas use in a gas-short country, such as Pakistan, will be much different from those of a gas-surplus country, such as Bangladesh. Different aspects of the analysis will assume primary importance, and other aspects will be incidental in each case. Although the discussion below focuses on country-wide markets, it is also possible to have both gas-short and gas-surplus situations in the same country when the market is segmented. This chapter discusses the application of the general methodology in three general types of situation: gas surplus, gas short and surplus window.

A. Gas Surplus Countries

62. A gas surplus country can be defined as one in which the demand/supply balance is such that the point of economic depletion, T*, is very far into the future. Once T* is 40 or 50 years away, the present value of the depletion premium becomes insignificant, compared with the range of uncertainty surrounding other estimates such as the AIC. Thus, for all practical purposes, the economic price path for gas over the time frame of the GUS becomes the long-run marginal cost of gas development. This implies that Part I of a GUS for a gas surplus country should spend relatively little time developing estimates of gas supply or aggregate gas demand (beyond what is necessary to establish that the situation is indeed one of gas surplus), and relatively more time defining the short and medium term investment program in gas production and infrastructure to provide a firm basis for the AIC estimates. Alternative gas reserve and supply scenarios are probably unnecessary, even where there is considerable reserve uncertainty, because it will make little difference to the GUS analysis, whether T* is 50 or 150 years away. Similarly, aggregate demand projections can be fairly general and focus on the long-run. However, in most cases it will be important to undertake a full analysis of the electric power system expansion program to see if aggressive conversion to gas and a future shift to gas-based power is warranted. Particularly in countries where gas development is at an early stage, the existing plans for the use of gas in power are likely to underestimate the economically desirable level of gas-based electricity generation. It is important to spot this discrepancy early because of the long lead times built into planning for new hydro developments.

65. Part II of the GUS for a gas surplus country should try to assemble a base case package of domestic gas-using projects that takes full advantage of the opportunities for gas penetration in the country's energy sector. Questions of project sequence will not be paramount, since gas availability is not a constraint, so that increases in PPNPVs will come mostly from bringing projects onstream more rapidly. The constraints to this will often be economy-wide ones: availability of capital, managerial skills, industrial infrastructure, etc. Therefore careful attention should be paid to exploiting potential complementarities and economies of scale in gas investment. Project packages should be designed and costed to include expatriate supervision or construction where that

can be effectively used to overcome implementation constraints. When considering large export-oriented projects, it will often be helpful to treat each candidate initially as mutually exclusive. This will provide a comparative screening of the export options to see which are the most attractive ones, before packages involving the export projects are formulated.

66. In Part III, only a rough consistency check with demand (Box 9) will be needed; the supply check (Box 10) should be more carefully done since inconsistencies with the initial supply projection may imply a different price path for gas through their effects on the AIC. The sensitivity analysis (Box 11) should include the often major technical, financial and market risks associated with any large and/or export oriented projects that are included in the selected pages. This may require a regional analysis of the market for, say, urea in the surrounding countries. Because the returns on such capital-intensive projects are often highly sensitive to the rate of capacity utilization, it is important to establish the boundaries of such parameters that would be required for the project to be economically desirable. This type of broad-brush analysis should be undertaken in the GUS rather than left to further feasibility work on each export project alternative. It is both possible and desirable to use the sensitivity analysis portion of the GUS to screen out those export-oriented projects that have less change of success than others, and thereby to focus future feasibility studies on those candidates with the greatest potential.

B. Gas Short Countries

67. A gas short country is one in which the potential gas availability is projected never (or only briefly) to exceed the potential demand for it. In a number of countries, current fuel oil consumption is several times as large as natural gas production. Even if the latter increases significantly, with projections of continued economic growth, it is likely that incremental gas supplies will continue to replace fuel oil at the margin. In such a case, the economic price path for gas will follow that of fuel oil, so long as the cost of gas development remains below that level. Since consumption will be supply-contrained in a gas short country, Part I of its GUS should spend more time on the demand side. It will often be important to develop alternative supply scenarios and to plot out Q^{max} for each. (In a gas-short situtation, T_1 will never be reached, so that $Q = Q^{max}$.) The costing of gas development (Box 4) can be done roughly, simply to ensure that costs remain below the cost of the replacement fuel. Demand analysis should focus on identifying specific project candidates in the main domestic markets (e.g., electricity, fertilizer, cement), rather than estimating long-run trends in aggregate demand.

68. Project packaging, ranking and selection will be the most critical part of the GUS for a gas-short country. With gas availability a constraint over the entire period, questions of project size and sequence are of major importance. With a high gas value the selection of project candidates is probably limited to those geared towards the domestic market, many of which will have been identified in Box 1. It will often be useful to pre-screen project candidates for inclusion by calculating

their gas netback values and comparing them with the value of gas. Then trial packages can be formulated from those projects passing the netback test, the PPNPVs can be calculated on time dependent permutations of each trial package.

69. In Part III, the consistency check with aggregate supply (Box 10) may show discrepancies which will require repackaging of projects and new PPNPV calculations. The sensitivity analysis will probably focus mostly on the effect of different supply scenarios and their implications for project selection and timing. These could be critical if one of the supply scenarios is optimistic enough to take the country into the surplus window category as described below.

C. Surplus Window Countries

70. A surplus window country is one for which the period of GUS includes times of both gas surplus and gas shortage. T_1 is either past or imminent, T* is either projected within the GUS period or clearly forseeable beyond it, and the economic price path for gas will have a shape similar to that shown in Figure 3. In such a case, there are few short-cuts to the full methodology that can be taken. In Part I of the GUS, both demand and supply must be estimated carefully in order to derive T_1 and T*, and thereby the gas price path. A general estimate of the cost of gas development will be needed to ensure that the price path does not fall below it. In Part II, it may be useful to pre-screen project candidates by calculating their netbacks and slotting each project into the time period at the point where its netback is first higher than the economic price of gas. Some projects will become viable only after T_1 when the price of gas falls, and these should be compared initially on a mutually exclusive basis to find the best candidates for that possibly brief period of gas surplus. If more than one or two such projects are included in the package for that period, the consistency check may show that the resulting level of aggregate gas demand in the years immediately following T_1 will raise the gas price path enough to crowd out the marginal projects.

71. In Part III, both consistency checks and sensitivity analysis will be important to ensure robust results. For a surplus window country, the addition of a single large gas using prject to the base case project package can result in a large enough shift forward in the date of T* to significantly raise the gas price path between T_1 and the original T*. This would require a new calculation of the PPNPV for the larger project using the revised price path. A comparison of the new PPNPV with that of the base case (using the original price path) will explicitly incorporate the trade-offs involved in putting the gas to earlier productive use, versus saving it for higher valued uses in the future. Sensitivity tests should be designed to highlight the physical and economic uncertainties to which the results are most sensitive.

D. Work Program for a Gas Utilization Study

72. It is a mistake to design the work program for a GUS before preliminary estimates of the key country-specific parameters have been made. The cost-effective application of this methodology for gas utilization studies requires judgments early in the study concerning those aspects to emphasize and those to treat only in general terms. As a first cut, it is useful to try to place the country into one of the three categories discussed above. That will require a first, quick pass through Boxes 1, 2 and 3 of the methodology. If that shows the country to be either gas surplus or gas short, then the work program and the study team can be organized around the appropriate issues. If at least one of the supply scenarios under consideration puts the country into the surplus window category, it will probably be necessary to 'crash through' the entire methodology at an early stage in the study, making guesses and assumptions based on prior knowledge where necessary. This exercise, involving both economists and engineers on the study team, often provides early insights so that data may be gathered in areas critical to the study results, while deemphasizing data whose accuracy or validity is less important.

73. Because of the many linkages between technical and economic analysis and data in this methodology, implementation of a GUS does not readily lend itself to a clear division of responsibility (e.g., for certain boxes) among individual team members. Rather, it needs continual interaction between engineering and economic staff so that each develops data and estimates of individual parameters as the other needs it, and so that the time of each can be appropriately directed toward the elements critical for the overall study. A small, multi-disciplinary core team supported by technical specialists as needed, is probably a better organizational framework for a GUS than either an engineering or an economics-based lead team with support from the other.

V. THE TIMING, SCOPE AND USE OF A GUS

A. The Timing of a Gus

74. To be of maximum value, the GUS should be undertaken before major decisions affecting gas use have been made. This generally means that the study should be started as soon as sufficient gas reserves have been identified to indicate that natural gas can play a significant role in the country's energy sector. The questions of reserve uncertainty will always trouble the planner, but it is generally neither necessary nor wise to postpone a GUS until additional reserve information is available. Reserve uncertainty is best handled through the use of multiple supply scenarios. This approach will highlight which decisions in gas development should await the proving of additional reserves and which are valid under all relevant reserve assumptions.

75. A GUS may also be required for countries with a mature gas market when, for example, the supply or demand situation changes suddenly or when a major project decision is to be taken (e.g., commitment to a long-term LNG contract). If an earlier GUS has been undertaken, it will often be a fairly simple exercise to update and use its basic framework for this new analysis.

B. The Scope of a GUS

76. The scope of a GUS should be limited to the essential issues discussed in the preceeding chapters. There is a tendency to use the GUS as a vehicle to address other related, but essentially separate, issues involved in gas development. For example, some of the studies reviewed included gas tariffs, financing options for gas projects, gas reservoir assessment, organizational/institutional studies, detailed tests of alternative pipeline routes and, planning for LPG development. While such aspects are clearly important elements of gas development in some countries, the GUS should not try to address <u>all</u> relevant issues in the gas sector. Particularly when other issues require mainly non-economic expertise, it is often counterproduction to package them with a GUS.

77. It will sometimes be desirable to sub-divide implementation of the GUS by undertaking Part I separately in, for example, the planning or energy ministry or through an energy assessment by the World Bank. The gas price path(s) that result from this sectoral analysis could be incorporated directly into the terms of reference for the project evaluation and sensitivity analysis of Parts II and III of the GUS, which might be better undertaken or supervised by gas utility. Another alternative is to commission the full study but schedule a review by all concerned ministries at the completion of Part I. Interim reviews will lengthen the overall time required for the study, but often have a high payoff in making the study's results more useful, accepted and understood by all parties.

78. If the country has a segmented gas market, careful consideration should be given to the geographic scope of the study. A GUS covering all gas reserves and potential country-wide demand may be a waste of time and

resources if the major gas markets are concentrated in one part of the country while some of the reserves are far offshore or on other islands. At the same time, one should not restrict the geographic scope of the study to exclude possible indirect gas transportation through, for example, the power grid. For a country with multiple gas fields and multiple potential markets, the most important gas planning issues may be the scope for, and timing of, interconnection of the separate gas markets; which can only be tacked through parallel GUS exercises for each market segment, integrated in the project packaging box.

C. The Continuing Use of a GUS

79. Once the basic GUS framework has been set up, it can become a simple and revealing tool for strategic planning in the gas sector. Comparable to the power system planning models used routinely to aid decision-makers in the electricity sector, a continuously updated GUS can provide gas managers with a consistent framework to quickly test the effects of alternative investment decisions. As gas development proceeds, the GUS can also be expanded and made more sophisticated by incorporating better information on reserves or better methods of demand forecasting.

80. The successful institutionalization of the GUS as a management information tool will require the close involvement of local staff and managers in its initial development. If the original study is undertaken by consultants, it is important to build into the terms of reference and the budget the need to create or transfer the model onto the in-house computer (or simpler analytical) system and to train both the local staff in its use and the managers in interpreting the output.

ANNEX: Example of a Gas Netback Calculation

1. Consider a 500 MMCFD liquefied natural gas (LNG) project to be built in a developing country with a market 5000 nautical miles away. Project construction will occur over a five year period, and the project is assumed to operate for 15 years. Investment outlays will include the liquefaction plant, LNG carriers and the re-gasification facility in the receiving country. They are shown as incurred, in constant dollars, in Column 1 of Figure A1. The second column shows the total operating costs of the project, exclusive of the cost of gas. The third column lists the annual project revenues, assuming a gas price in the receiving country equal to 80% of crude oil parity. The final column shows the quantity of gas consumed by the project in billion cubic feet.

2. To calculate the netback value of gas, each column is present valued at 10% and summed. The totals for the columns are shown at the bottom in Figure A1. Then the formula given in para. 38 is applied to yield the average netback value, N, of $2.97/MCF for the total project life. In other words, if the project were to pay a real price of $2.97/mcf for the gas going into the liquefaction plant, it would earn a real rate of return of 10% on the capital invested.

FIGURE A1. Calculation of Gas Netback Value

Year	Investment Costs ($ mil)	Operating Costs ($ mil)	Project Revenues ($ mil)	Gas Consumed (bcf)
1	59 -	-	-	
2	388	-	-	-
3	818	-	-	-
4	521	-	-	-
5	276	55	292	58
6	- 85	515	100	
7	-127	840	158	
8	-134	911	166	
9	-135	931	166	
10	-178	951	166	
11	-137	973	166	
12	-138	994	166	
13	-140	1017	166	
14	-141	1039	166	
15	-184	1061	166	
16	-143	1085	166	
17	-144	1108	166	
18	-146	1133	166	
19	-147	1159	166	

Total present value of investment costs = $ 1669 x 10^6
Total present value of operating costs = $ 725 x 10^6
Total present value of project revenues = $ 4862 x 10^6
Total present value of gas consumed = 830 bcf

$$N = \frac{4862-1669-725}{830} = \$\ 2.97/\text{mcf}$$

Notes: Discount rate = 10%
All figures in constant 1982 US dollars.
Operating costs exclude gas
Figures adapted from Jensen Associates,'The Economic Value of Natural gas in LNG Export', on file in the World Bank Energy Department.

ENERGY DEPARTMENT PAPER SERIES

EGY PAPER No. 1

Energy Pricing in Developing Countries: A Review of the Literature by DeAnne Julius (World Bank) and Meta Systems (Consultants). September 1981. 121 pages, includes classified bibliography.

Reviews literature on the theory of exhaustible resources and on sectoral, national and international models for energy demand. Emphasis on project selection criteria and on pricing policy as a tool of energy demand management.

EGY PAPER No. 2

Proceedings of the South-East Asian Workshop on Energy Policy and Management edited by Michael Radnor and Atul Wad (Northwestern University). September 1981. 252 pages.

Contains the edited version of the lectures and discussions presented at the South-East Asian Workshop on Energy Policy and Management held in Daedeok, South Korea, October 27-November 1, 1980.

Topics that are addressed include: the overall problem of energy policy and its relationship to economic development; the management of energy demand and related data; the role and value of models in energy planning, and the use of energy balances. Transport and rural sectors are also discussed in terms of their relationship to energy planning.

EGY PAPER No. 3

Energy Pricing in Developing Countries: Lessons from the Egypt Study by DeAnne Julius (World Bank). December 1981. 14 pages.

Study on the effects of energy price change in a developing country. Provides insight into the mechanisms through which energy prices affect other prices in the economy and, therefore, the incomes of rich and poor consumers, profitability of key industries, the balance of payments, and the government budget.

EGY PAPER No. 4

Alternative Fuels for Use in Internal Combustion Engines by G.D.C., Inc. (Consultant). November 1981. 179 pages, includes appendices.

Presents several alternative fuels used as replacement for conventional (gasoline and diesel) fuels in internal combustion engines. These alternatives, including LPG, natural gas, alcohol and producer gas, are derivable from natural resources that exist in so many developing countries. Also provides up-to-date information on the newest alternative fuel option currently available and those that are being developed and tested.

EGY PAPER No. 5 — Bangladesh: Rural and Renewable Energy Issues and Prospects by Fernando R. Manibog (World Bank). April 1982. 64 pages, includes bibliography.

Analyzes subsector issues and recommends courses of action for energy project possibilities; identifies renewable energy projects which could create a positive impact in the short to medium term.

EGY PAPER No. 6 — Energy Efficiency: Optimization of Electric Power Distribution System Losses by Mohan Munasinghe (World Bank) and Walter Scott (Consultant). July 1982. 145 pages, includes appendices.

Discusses the reasons for high existing levels of power distribution losses in developing countries. Identifies areas within a power system where loss optimization would be most effective. Shows that reducing losses is often more cost effective than building more generation capacity.

EGY PAPER No. 7 — Guidelines for the Presentation of Energy Data in Bank Report by Masood Ahmed (World Bank). October 1982. 13 pages, includes 4 annexes.

The growing importance of energy issues in national economic management has led to increased coverage of the energy sector in many types of reports. However, there is still no clear, consistent and standardized format for presenting energy sector information. This paper reviews the problem and proposes guidelines for policymakers and operational staff who deal with energy issues. The paper is divided into three parts: part one sets out the basic framework for presenting aggregated energy data -- "the national energy balance"; part two deals with the use of appropriate units and conversion factors to construct such a balance from raw demand and supply data for the various fuels; and part three briefly discusses special problems posed by: (i) differences in end use efficiency of various fuels; (ii) the inclusion of wood and other noncommerical energy sources; and (iii) the conversion of primary electricity into its fossil fuel equivalent.

EGY PAPER No. 8 — External Financing for Energy in the Developing Countries by Althea Duersten (World Bank). June 1983. 66 pages, includes appendices.

Provides an overview of energy financing in the developing countries. Identifies energy investment requirements and past financing patterns. Discusses the historical roles of multilateral and bilateral assistance programs in helping to mobilize financing, particularly for low income oil importers and in providing economic and sector advice. Examines the role of official export credit, and discusses lending by private financial institutions which has been the predominant source of financing for energy projects in the middle and higher income developing countries.

EGY PAPER No. 9 — Guideline for Diesel Generating Plant Specification and Bid Evaluation by C.I. Power Services, Inc. (Consultant, Canada). December 1982. 210 pages, includes appendices.

Explains the characteristics and comparative advantages and disadvantages of large low speed two-stroke diesel engines intended for electric generating plant service, and develops a bid evaluation procedure to permit comparing of bids for both types.

EGY PAPER No. 10 — Marginal Cost of Natural Gas in Developing Countries: Concepts and Application by Afsaneh Mashayekhi (World Bank). July 1982. 21 pages, includes appendices.

Defines the concept of marginal cost and average incremental cost. Uses the detailed supply, demand and investment data to apply this concept to estimate the average incremental cost of natural gas supply to major markets in ten developing countries. Demonstrates that the cost of natural gas delivery to the city-gate in many developing countries is far below the cost of competing fuels.

EGY PAPER No. 11 — Power System Load Management Techniques by Resource Dynamics Corp. (Consultant, U.S.A.). November 1983. 132 pages.

In recent years, techniques referred to as load management have begun to play an important role in shaping the patterns of electricity consumption in industrialized countries. Along with pricing, a variety of hardware is used to control loads directly and save on energy and peak capacity. This study reviews the state-of-the-art of these so-called "hard" techniques in light of recent technological advances, provides data on cost and manufacturers of this equipment, and identifies controllable loads in developing countries.

EGY PAPER No. 12 — LNG Export Opportunities for Developing Countries and the Economic Value of Natural Gas in LNG Exports by Afsaneh Mashayekhi (World Bank). November 1983. 36 pages, includes appendices.

This paper reviews the LNG export opportunities for developing countries and clarifies some of the issues related to economic costs and benefits of LNG projects from the point of view of an exporting country. It identifies the major technical parameters that affect costs and analyzes factors affecting the economic size of projects and the effect of scaling them down. Its principal objective is to estimate, given explicit assumptions, the netback values for gas at various stages in the LNG delivery system. It examines three basic scenarios of small and medium scale projects as well as a multi-destination project with several small markets. It also tests the sensitivity of netbacks to the level of infrastructure, discount rates and the price of gas delivered at the importing country.

EGY PAPER No. 13 — Identifying the Basic Conditions for Economic Generation of Public Electricity from Surplus Bagasse in Sugar Mills by Syner-Tech Inc. (Consultant, U.S.A.). October 1983. 167 pages, includes appendices.

The study identifies several ways, all using presently available technology, to greatly increase the overall energy efficiency of existing mills, produce surplus bagasse and generate electricity for sale to the grid. These include installing pre-evaporators to conserve steam, drying wet bagasse with flue gasses to improve combustion efficiency, installing high-pressure boilers to increase steam generation efficiency and pelletizing or compressing bagasse to enable it to be stored and used beyond the harvest season.

EGY PAPER No. 14 — A Methodology for Regional Assessment of Small Scale Hydropower by Tudor Engineering Company (Consultant, U.S.A.). December 1983. 105 pages.

This paper presents a methodology for regional assessment of small hydropower development potential involving sampling procedures, study execution, energy planning, regional hydrology development, technical site evaluation, cost and economic analysis, environmental and social considerations. Its use should result in reasonably accurate estimates in a short period of time of the viable small-scale hydroelectric projects in a particular region or country. A development program based on such an assessment would be of sufficient reliability to support requests for financing assistance.

EGY PAPER No. 15 — Central America Power Interconnection: A Case Study in Integrated Planning English Summary by Fernando Lecaros (Consultant). April 1984. 55 pages.

This paper is a summary of the study, titled "Regional Electrical Interconnection Study of the Central American Isthmus", performed by the Regional Office in Mexico of the United Nations' Economic Commission for Latin America (ECLA) between 1975 and 1979. Its goal was to provide a firm economic and technical foundation to decisions about the interconnection investments in the region. The purpose of this English Summary is to disseminate the methodology retained by ECLA and to show an example of integrated system planning using models such as WASP developed by the International Atomic Energy Agency. The figures reproduced in this report are limited to the extent necessary for these illustrative purposes.

EGY PAPER No. 16 — An Economic Justification for Rural Afforestation: The Case of Ethiopia by Ken Newcombe, (World Bank). June 1984. 23 pages, includes appendices.

It has proven difficult to quantify the economic benefits of large-scale rural afforestation and to establish the priority for public investment in traditional rural energy supply vis-a-vis investment in the supply for modern fuels (electricity, petroleum) to the urban industrial market. This paper outlines, in simple terms, the biological links between deforestation and agricultural production at the subsistence level, and quantifies the economic benefits of increased food production obtained by replacing animal dung as a fuel with firewood from rural forestry programs.

EGY PAPER No. 17 — The Future Role of Hydroelectric Power in Developing Countries by Edwin Moore (World Bank), George Smith (Consultant, Canada). June 1984. 59 pages, includes annexes.

The study examines the role of hydroelectricity in the power programs of 100 developing countries in the period 1982-1995. The report indicates that hydro will continue to play a significant role, accounting for 43% of electricity production in 1995. Preparation and engineering expenditures of about $10 billion will be needed in 1982-1990 for the projects required to support this growth. The study concludes that an intensified hydro program would add only 3% to the capacity otherwise planned because the main constraints to hydro development are economic and lack of poor markets rather than lack of knowledge about resources and prospective projects. Nonetheless, the study identifies specific actions that can be taken in many countries to accelerate hydro development.

EGY PAPER No. 18 — Guidelines for Marginal Cost Analysis of Power Systems by Yves Albouy (World Bank). June 1984, 31 pages, includes annexes.

These guidelines provide hands-on but state-of-art instructions for conducting a sound and quick analysis that yields the marginal cost structure needed for applications in the power sector and for the review of related studies. These include not only pricing but also the less known marginal analysis of system planning decisions. The paper does not give the detailed theoretical background but draws on the reference literature. It illustrates the basic principles and calculation methods with the help of many examples going from the simplest to the more complicated system conditions.

EGY PAPER No. 19 — The Value of Natural Gas in Power Generation by Yves Albouy and Afsaneh Mashayekhi (World Bank). November 1984. 28 pages.

This paper is one of a series to examine the "netback value" of natural gas in major domestic and export uses. The netback can be compared to the cost of gas to permit a rough estimate of the net economic benefit to gas use in various sectors.

With the help of case studies and simple calculations, the netback value to power generation is found to be fairly high on average even though it diminishes as the use of gas spreads from peak to base load. The paper also highlights the important role of power in the natural gas market and the specific analytical framework in which an assessment of this role can be undertaken for preliminary gas utilization studies.

EGY PAPER No. 20 — Assessment of Electric Power System Planning Models by Yves Albouy (World Bank) and Systems Europe, (Consultant, Belgium). January 1985. 107 pages, includes annexes.

This paper addresses both the models and methods for power generation and transmission planning. It provides first an overview of the methodology preferred by the Bank and of the promiment planning issues in developing countries. On this basis the study attempts to assess the applicability of forty five models now available from leading utilities and consultants. The paper also contains recommendations on the development and use of models. An extensive bibliography is given in the Annex.

EGY PAPER No. 21 — Diesel Plant Performance Study by C.I. Power Services Inc. (Consultant, Canada). February 1985. 83 pages.

The study was prepared under an EGY-sponsored research project as a guideline for use by Bank staff and consultants. This report summarizes the results of an investigation of the performance and cost of operation of four stroke medium speed engines and two stroke low speed engines used as prime movers for electricity generation in both developing and developed countries. Operating data for units of 4,000 kW and larger was collected from 28 countries and is analyzed here. Data from some 3000 - 4000 kW units was also incorporated.

EGY PAPER No. 22 Eonomic Value of Gas in Residential and Commerical Markets by Afsaneh Mashayekhi (World Bank), Sofregaz (Consultant). March 1985. 21 pages.

This paper sums up our current knowledge on the subject of the economics of gas use in residential and commerical markets. It clarifies some of the issues related to the demand by the residential and commerical sector for gas, design of gas distribution networks and the economic costs and benefits of gas distribution to these sectors. The netback and NPV figures are estimated for 16 model networks with different demand and density patterns and types of city. The conclusion is that many developing countries with low cost gas reserves could benefit from developing and expanding their gas distribution networks to residential and commercial markets and displacing high costs fuels such as LPG and kerosene.

EGY PAPER No. 23 Domestic Coal Pricing: Suggested Principles and Present Policies in Selected Countries by J. Roberto Bentjerodt, John Strongman, Jorge Barrientos (World Bank) and DeAnne Julius (Consultant). May 1985. 65 pages, includes annexes.

The paper addresses some theoretical issues concerning the pricing of coal and notes a number of practical matters that must be taken into consideration in applying the theoretical framework to actual pricing policy. It first analyses the general pricing framework and conditions under which setting prices, rather than letting market forces operate unobstructedly, makes sense from an economic viewpoint. It deals with the basic pricing model, the role of prices, and questions such as tradeability and depletability of coal. Various general pricing policies are reviewed and their economic effects analyzed under different conditions of demand and supply for coal. The paper also reviews coal markets in sixteen countries, of which eleven are LDCs. In all but two of them (the US and Colombia) there is price intervention. It was found that intervention is generating severe economic distortions in several of these countries, where partial or total freeing of market forces is warranted.