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Republic of Yemen

Household Energy Strategy Study, Phase I
A Preliminary Study of Northern Governorates

Report No. 126/91

REPUBLIC OF YEMEN

HOUSEHOLD ENERGY STRATEGY STUDY, PHASE I

A PRELIMINARY STUDY OF NORTHERN GOVERNORATES

March 1991

CONVERSION FACTORS AND ABBREVIATIONS

CURRENCY EQUIVALENT (1987 through)

US$1 = 9.75 Yemeni Rials (YR) (mid-1989)
US$1 = 12.50 Yemeni Rials (YR) (late 1990)

CONVERSION FACTORS

Fuel	TOE/Metric Tonne	Specific Gravity	Liters/tonne
LPG	1.06	0.56	1,785
Gasoline	1.03	0.72	1,351
Kerosene	1.01	0.80	1,240
Diesel	1.00	0.85	1,041
Firewood	0.38		
Charcoal	0.70		
Crop residues	1 kg. = 13.5 MJ		
Dung	1 kg. = 13.5 MJ		

Conversion efficiency for charcoal production: 23%

1 TOE = 10.2×10^6 kcal = 40.5×10^6 BTU = 40.5 Mcf = 42.7 GJ

1.0 GWh = 86 TOE; 1.0 kWh = 860 kcals (net calorific values, note that net calorific values are 5% less than gross for oil and 9-10% less than gross for gas)

CONVERSION FACTORS FOR GAS

Thousand Cubic Feet (mcf) = 1 million British Thermal Units
38,500 cubic feet = 1 tonne of fuel oil
0.12 mmcfd = 1 tonne of fuel oil/year

ABBREVIATIONS

bbl	Barrel
bpd	Barrels per day
cif	Cost, insurance and freight
CLCCD	Confederation of Local Councils for Cooperative Development
ESMAP	Joint UNDP/World Bank Energy Sector Management Assistance Program
FAO	Food and Agriculture Organization
fob	Free-on-board
GDP	Gross Domestic Product
GCOMR	General Corporation for Oil and Mineral Resources
GWh	Gigawatt hour (10^6 kWh)
GTZ	Deutsche Gesellschaft Für Technishe Zusammenarbeit
ha	Hectare

kWh	Kilowatt hour (10^3 Wh)
LDC	Local Development Council
li	Liter
LPG	Liquefied petroleum gas
Mcf	Thousand cubic feet (gas)
MEW	Ministry of Electricity and Water
MJ	megajoules
mmcfd	Million cubic feet per day (gas)
MOMR	Ministry of Oil and Mineral Resources
MPD	Ministry of Planning and Development
PDRY	People's Democratic Republic of Yemen
ROY	Republic of Yemen
SCOMRED	Supreme Council for Oil and Mineral Resources and Economic Development
TCF	Trillion cubic feet (gas)
TOE	Tons of oil equivalent
t or ton	Metric ton
USAID	United States Agency for International Development
YAR	Yemen Arab Republic (now northern Republic of Yemen)
YGEC	Yemen General Electricity Corporation
YHOC	Yemen Hunt Oil Company
YPC	Yemen Petroleum Company

Republic of Yemen: Household Energy Strategy Study
Phase I: Preliminary Study of Northern Governorates

Preface

In late 1986, the joint World Bank/UNDP/Bilateral Aid Energy Sector Management Assistance Program (ESMAP) initiated the Household Fuel Marketing Study for Yemen Arab Republic (YAR) at the request of the Government, with funding from the Government of the Netherlands. After three years of intensive study and field work with several Government agencies, the final report for the study was submitted to the Government for review.

The report was received as a valuable addition to the Government's planning efforts. Nonetheless, the Government rightly noted that the work focused only on the region formerly represented by the YAR and did not take into account the unification between the YAR with the People's Democratic Republic of Yemen and the creation of the Republic of Yemen. Although the *issues* identified in the report were no doubt relevant to the whole of the Republic of Yemen, an energy *strategy* could only be effective if it encompassed the entire country.

These political developments were only one example of the rapid pace of profound change in the country. The discovery and development of large oil and gas reserves continue, new legislation is pending which will influence the roles of the public and private sectors, and agencies which before unification worked in separation are being merged and embarking on new courses. The Government recognizes the importance of sectoral strategy work in this dynamic environment to ensure that it becomes an agent of change rather than a victim of it.

Therefore, this report represents only a preliminary step in the on-going planning process. The Government has requested a second phase of the project which will expand and update the work presented here to reflect the new realities brought about by unification. Naturally, the second phase will consider the whole of the Republic of Yemen, including the southern governorates. In addition, the scope of the study is enlarged to consider all relevant energy issues in the household sector rather than just fuel marketing. Finally, certain follow-up recommendations contained in this study, such as the development and commercialization of certain household energy technologies, will be implemented as soon as possible so as not to delay the potential benefits of these projects and to allow the results of these projects to be considered in the course of the second phase of strategy work.

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خلاصة

مقدمة

١-١ تواجه عملية التنمية في جمهورية اليمن(١) منعطفا حاسما. فالتطور السياسي والاقتصادي السريع الذي عرفته البلاد خلال ربع القرن الأخير مكّن الأسر اليمنية الحضرية والريفية على السواء من تحسين دخلها ومكّن البلاد من اقامة بنية أساسية اقتصادية هامة.

حاليا ورغم اكتشاف احتياطيات من النفط والغاز، تباطأ معدل النمو الاقتصادي لأن الاكتشافات الأخيرة جاءت في وقت انخفض فيه دخل البلاد من تحويلات العاملين في الخارج مع انعدام الثروات الطبيعية الأخرى. لذلك تواجه البلاد مهمة اتخاذ عدد هام من القرارات فيما يتعلق بكيفية المحافظة على نسق النمو الذي عرفته خلال العقدين الأخيرين وذلك باستخدام الامكانيات البشرية والثروات الطبيعية الشحيحة على نحو يتسم بالكفاءة.

ويرتبط اتخاذ هذه القرارات ارتباطا شديدا بتطور قطاع الطاقة الذي يرتبط هو الآخر بدخل البلاد من العملة الصعبة وبرفاهة الأسر وبالبيئة.

١-٢ القطاع المنزلي هو أكبر القطاعات المستهلكة للطاقة في جمهورية اليمن. ويعتبر الحطب أهم وقود في البلاد.

ويمثل القطاع المنزلي أكثر من ٦٠ في المائة من مجموع الطلب النهائي على الطاقة في الجزء الشمالي من جمهورية اليمن ويمثل الحطب وحده أكثر من ٩٠ في المائة من استهلاك هذا القطاع. ولكن ثروة البلاد من حطب الوقود سوف تتلاشى وتنتهي في حدود فترة تتراوح بين ١٠ سنوات و١٥ سنة من الآن وذلك اذا تواصل استهلاك الحطب بنفس النمط.

وبانقراض الحطب وتلاشيه خلال السنوات المتبقية من هذا القرن، يتدهور مستوى معيشة الأسر وذلك باستعمال وقود ومحروقات أخرى بديلة أقل كفاءة مثل بقايا المحاصيل

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(١) وقت اجراء البحث الخاص بهذه الوثيقة (١٩٨٨-١٩٨٩)، تركز العمل على الجمهورية العربية اليمنية سابقا (الجزء الشمالي حاليا من جمهورية اليمن).

ومخلفات الحيوانات (المؤثرة بطريقة سلبية على صحة أفراد الأسر)، أو باستعمال محروقات أخرى بديلة أغلى ثمنا، مما ينتج عنه زيادة أعباء ميزانية الأسر وبالتالي انخفاض دخلها. ويعني ذلك أن الأسرة سوف تخصص نسبة متزايدة من دخلها للحصول على ما يلزمها من محروقات على حساب مواد أخرى أساسية مثل المواد الغذائية والأدوية. وقد يؤدي ذلك أيضا بالأسر الى استهلاك كميات أقل من الوقود لأغراض أساسية كالطهو والتدفئة وذلك على حساب صحة الأفراد ومستوى معيشتهم. وسوف تكون المرأة، نظرا لأهمية دورها في اختيار نوع الوقود واستعماله في المنزل، وكذلك الفئات الفقيرة التي تعتمد اعتمادا شديدا على الحطب، هي الأكثر تضررا في هذه الحالة.

وبالاضافة الى ذلك، يتوقع أن تكون لعملية زوال الأشجار نتائج سلبية على البيئة كانجراف التربة الصالحة للزراعة وتصحر الأراضي وتغير المناخ، الأمر الذي يؤدي الى انخفاض في الانتاجية الزراعية.

من حسن الحظ، تتمتع جمهورية اليمن بمصدر محلي آخر للطاقة تحبذه الأسر وهو البوتغاز (غاز البترول المسيل) ولكنه لا يزال غير مستغل بدرجة كافية.

ومن المتوقع أن تتوصل حكومة جمهورية اليمن وشركة هنت للبترول الى اتفاق بشأن انتاج وتوزيع البوتغاز محليا. غير أنه لم تبذل حتى الآن جهود متكاملة لوضع استراتيجية تهدف الى تحقيق الانتقال الى استعمال وقود عصري بطريقة قابلة للاستمرار.

المشاكل والأهداف

٣-١ تعرقلت عملية وضع خطة لاستهلاك الطاقة في القطاع المنزلي كما تعرقل تنفيذ هذه الخطة لعدة أسباب:

أ - عدم وجود استراتيجية قومية لقطاع الطاقة.

ب - عدم توفر قدرات مؤسسية كافية.

ج - عدم وجود حدود واضحة بين مسؤوليات المؤسسات المعنية في قطاع الطاقة.

د - عدم اعداد وتقييم بدائل أخرى سليمة.

يرجع السبب الرئيسي في ذلك الى عدم قدرة المؤسسات المسؤولة على ادراك مشاكل استهلاك الطاقة في القطاع المنزلي ومحاولة حلها، مما جعل عددا من المسائل تتشعب دون معالجة، وبالتحديد، تعتبر النقاط التالية مشاكل ذات أهمية وأولوية بالغة:

أ - تقلص العرض واستمرار الطلب على الحطب سوف يؤديان الى زيادة ما ينفق من وقت ومال للحصول عليه، وانخفاض في مستوى معيشة الأسر، واحتمال تعجيل تدهور البيئة. والجهود الحالية لزيادة العرض ليست كافية لوضع نظام قابل للاستمرار يرتكز على استخدام الحطب كوقود.

ب - عدم القدرة على الاسراع بتنمية مادة البوتغاز كوقود أساسي لقطاع المنزلي أدى الى حالة نقص ونشوء سوق سوداء وضعف انتشار هذا الوقود البديل الهام في السوق، وتعتبر ازالة العقبات التي تقف أمام زيادة الاقبال على البوتغاز ذات أهمية بالغة لتخفيف الضغط على موارد الحطب القومية.

ج - تستعمل نسبة كبيرة من الأسر الريفية، الى جانب الحطب، كهرباء غير مولّدة من طرف المؤسسة العامة، وبالتالي ذات تكلفة عالية. وتوفر هذه المصادر التابعة للقطاع الخاص امدادا ضعيفا غير موثوق به، وتتسم بعدم الكفاءة في التوليد، وتفرض تكلفة مالية مرتفعة على الأسر والاقتصاد القومي على السواء.

٤-١ وبالنظر الى هذه المشاكل، يتمثل الهدف الذي تنشده استراتيجية قطاع الطاقة المنزلية على المدى الطويل في جمهورية اليمن في تخفيض تكاليف المحروقات التي يستخدمها القطاع المنزلي وزيادة توفرها، مع التأكد من أن أنماط استهلاك القطاع المنزلي للطاقة قابلة للاستمرار بيئيا.

وتتمثل الأهداف الفورية لانجاز هذا فيما يلي:

أ - حماية البيئة وذلك بتشجيع أنماط قابلة للاستمرار لاستهلاك الحطب ومشتقاته في حالة عدم توفر امكانية فورية لاستعمال البديل.

ب - اعداد استراتيجية سليمة اقتصاديا تهدف الى احلال البوتغاز محل الحطب المعرّض للنفاد.

ج - تقييم الخيارات المتوفرة لتوزيع الكهرباء بأقل تكلفة للأسر الريفية، بما في ذلك استخدام البطاريات لتوليد الكهرباء عن طريق الطاقة الشمسية.

ويسترشد في اعداد هذه الاستراتيجية بمبادئ تستهدف تحقيق تحسينات، على المدى القريب والبعيد، في مستوى معيشة الأسر، وترشيد استخدام موارد الطاقة المحلية بما يراعي عدم نفادها، والاعتماد على القطاع الخاص النشط عن طريق اتباع أسلوب يستند الى أوضاع السوق في تنفيذ السياسات والبرامج.

عناصر الاستراتيجية

٥-١ تتمثل العناصر الرئيسية للاستراتيجية في عدد من التوصيات تتعلق بالآتي:

أ - تحسين ادارة موارد الحطب (أي ترشيد انتاج وتوزيع الحطب) المستخدمة كمصدر للطاقة وذلك للمحافظة على هذا المصدر للطاقة المتجددة الآخذ في النفاد على نحو سريع.

ب - التعجيل بعملية احلال البوتغاز محل الحطب، مما يؤدي أيضا الى المحافظة على مستوى رفاهة الأسر مع حماية البيئة والمصادر المحلية للحطب.

ج - تزويد الريف بكهرباء بأقل تكلفة وذلك بتطوير مصادر جديدة غير مركزية واستخدام التوليد الذاتي للكهرباء على نحو أكثر كفاءة.

ويعتبر تحسين ادارة موارد الحطب والتعجيل بعملية احلال البوتغاز محل الحطب عنصرين مكملين للاستراتيجية وينبغي تنفيذهما معا، ولا يكفي أحدهما لتحقيق الأهداف الكاملة للاستراتيجية.

١-٦ ولتعزيز جهود ادارة موارد الحطب يوصي التقرير بالاضطلاع بالأنشطة اللازمة للحصول على المعلومات الأساسية بشأن قاعدة الموارد وأساليب الادارة، وتقييم وتحسين طرق تفحيم الحطب، وتحسين الكفاية الانتاجية للحطب، ومساندة عادات البلاد فيما يتعلق بادارة الأراضي، واعداد برامج فعالة للحراجة المقترنة بالزراعة على مستوى الأسر والتجمعات السكانية. ويتطلب جمع المعلومات الأساسية ما يلي: (١) اجراء تحليل لعمليات تغيير استخدام الأراضي، (٢) اجراء دراسة مفصلة لأنظمة توفير موارد الحطب ومشتقاته، (٣) اضافة رصيد جديد من موارد الحطب، (٤) اجراء بحوث اضافية عن انتاجية موارد الحطب ومشتقاته. وفيما يتعلق بطرق تفحيم الحطب، يجب اجراء تقييم لصناعة الفحم النباتي في المنطقة الشمالية الوسطى من تهامة، وتطوير أساليب جديدة أكثر كفاءة لتفحيم الحطب ونشر استعمالها، اذا أثبت التقييم وجود مبرر لذلك. ولمساندة عادات البلاد فيما يتعلق بادارة الموارد، يجب جمع معلومات عن أساليب ادارة الأحراج التقليدية في مختلف مناطق جمهورية اليمن، وذلك لتعزيز الأساليب المطبقة بنجاح للزراعة المقترنة بالحراجة. وفيما يتعلق ببرامج الزراعة المقترنة بالحراجة، يجب تحديد الأساليب المطبقة بنجاح في مناطق معينة ونشر استعمالها على نطاق أوسع. ويجب أن تستخدم هذه البرامج الحوافز لتشجيع اشتراك الأسر والتجمعات السكانية المحلية في تنفيذها. وتتضمن الفقرات ٤-٣٦/٤-٣٩ مزيدا من التفاصيل عن هذه الخيارات.

١-٧ وللتعجيل بعملية انتشار استعمال البوتغاز في السوق، يوصى بتنفيذ بعض البرامج لتحسين هياكل التسويق وتوفير أسطوانات التعبئة، وتحسين ادارة هذه العملية من خلال زيادة اشتراك القطاع الخاص، وتبني سياسة أسعار ترتكز على المنافسة، ووضع

قواعد تضمن سلامة استعمال البوتغاز، وتسويق الأجهزة المنزلية التي تعمل بالبوتغاز. ولهذا الجزء من الاستراتيجية هدفان هما: (أ) تشجيع الأسر التي تستخدم حاليا البوتغاز وحطب الوقود معا على استخدام كميات أقل من الحطب وكميات أكبر من البوتغاز، و(ب) تشجيع الأسر التي تستخدم حطب الوقود و/أو الفحم النباتي على التحول الى استخدام البوتغاز. وتشمل الاجراءات التي يجب اتخاذها لمساندة الهدف الأول زيادة توفير أسطوانات تعبئة البوتغاز والوقود نفسه بما يتجاوز الجهود المبذولة حاليا، وتحسين تسويق وتوزيع البوتغاز، وتسويق الأجهزة المنزلية التي تعمل بالبوتغاز وتستخدم لاعداد الخبز بتكلفة منخفضة، ومساندة جهود انشاء مخابز تخدم التجمعات السكانية. ولتحقيق الهدف الثاني، يتعين اتخاذ نفس الاجراءات وتخفيض تكلفة أسطوانات التعبئة والمنظمات والأجهزة المنزلية عن طريق دعم هذه الأصناف من حصيلة بيع البوتغاز. ولتحقيق ذلك، يجب أن يظل سعر بيع البوتغاز بالقطاعي عند مستوى ٤٠ ريالا يمنيا للأسطوانة، على أن تستخدم الأرباح المتحققة من ذلك كدعم متبادل لتخفيض تكلفة أسطوانات البوتغاز والأجهزة المنزلية. وحتى مع بيع البوتغاز بهذا السعر، يعتبر البوتغاز أرخص وقود للاستعمال المنزلي. وتتضمن الفقرات ٥-١٥/٥-٣٩ مزيدا من المعلومات عن هذه التوصيات.

١-٨ ولتحسين تزويد الأسر الريفية بالكهرباء، حددت معالم مشروعات تستهدف اجراء اختبار السوق لبطاريات تستخدم في توليد الكهرباء عن طريق الطاقة الشمسية للأسر الريفية، واعداد استراتيجية فعّالة لتوليد الكهرباء في الريف. ويتطلب اجراء اختبار السوق ما يلي: (أ) اجراء فحص فني لأنظمة بطاريات توليد الكهرباء في المنازل ووضع مواصفات لتعميم نظام ملائم، (ب) اجراء اختبار بشأن تقبل المستهلكين لهذه البطاريات، (ج) وضع أنظمة فعالة لتمويل شراء هذه البطاريات، و(د) مساندة قيام القطاع الخاص بتسويق هذه البطاريات محليا ونشر استعمالها وصيانتها. ولاعداد استراتيجية لتحسين خدمات توليد الكهرباء في الريف وتخفيض تكاليفها، يجب زيادة الالمام بالأنظمة القائمة حتى يمكن مقارنة الخيارات المتاحة على أساس واقعي. ويتطلب ذلك اعداد معلومات مفصلة عن تكاليف ومنافع مولدات الكهرباء التي تعمل بزيت الديزل والبنزين والشائعة الاستعمال حاليا في المناطق الريفية في جمهورية اليمن. وبعد ذلك، يمكن وضع

استراتيجية لتزويد المناطق الريفية بالكهرباء تستند الى مجموعة من الاجراءات التي تنفذ بأقل تكلفة وتتألف من تمديد شبكة الكهرباء، واستخدام مولدات خاصة تعمل بالبترول، واستخدام بطاريات غير مركزية لتوليد الكهرباء عن طريق الطاقة الشمسية. ويرد شرح هذا الجزء من الاستراتيجية في الفقرات ٦-١٣/٦-٢٢.

١-٩ وتحتاج المؤسسات اليمنية الى تعزيز قدراتها لتسهيل تنفيذ الاستراتيجية. وتتضمن بعض الخطوات اللازمة لذلك، والتي تم تحديدها في تقرير البنك الدولي المتعلق بمراجعة استراتيجية قطاع الطاقة في جمهورية اليمن،(٢) ما يلي:

أ - استمرار الاستعانة بالخبرات الأجنبية.

ب - صياغة هياكل تنظيمية ملائمة "لوزارة النفط والموارد المعدنية" و"وزارة الكهرباء والمياه" و"المؤسسة العامة للكهرباء".

ج - اعداد برنامج ملائم لتخطيط القوى العاملة. يضاف الى ذلك أن عملية المتابعة والتقييم يجب أن توفر معلومات هامة لاكتساب المعرفة والتكييف طوال فترة تنفيذ الاستراتيجية.

١-١٠ ويمكن أن تبدأ مجموعة متناسقة من المؤسسات اليمنية، شاملة القطاع الخاص الحيوي، تنفيذ الاستراتيجية على مدى فترة السنوات ١٩٩١-٢٠٠٠.

وقد تم دمج بعض عناصر هذه الاستراتيجية ضمن مشروعات أخرى اقترحها البنك الدولي وبدأ تنفيذها بالفعل، كبرنامج انتاج البوتغاز والمشروع القومي لادارة القطاع الزراعي.

١-١١ خلال العشر سنوات اللازمة للتنفيذ، يتوقع أن تؤدي هذه الاستراتيجية الى تحقيق وفورات قدرها أكثر من ٢ر٣ مليون طن من الحطب وأكثر من ٤٠٠ جيجاوات ساعة من الكهرباء بجانب كميات أخرى من الكيروسين والبنزين وزيت الديزل.

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(٢) الجمهورية العربية اليمنية، مراجعة استراتيجية الطاقة، التقرير رقم YAR-7862 بتاريخ ٣١ يناير/كانون الثاني ١٩٩٠.

وتقدر التكلفة الحدية لتنفيذ هذه الاستراتيجية بكامل عناصرهـــــا، ما عدا العناصر التي تم دمجها في المشروعات القائمة، بحوالي ١٥٥٠٠٠٠ دولار أمريكي لاعـــداد السياسات والبرامج، بالاضافة الى مبلغ مبدئي قدره ٦ ملايين دولار، ثم ٣ر٠ مليـــون دولار سنويا بعد ذلك لشراء اسطوانات بوتغاز اضافية.

وباستكمال سنواتها العشر الأولى، يتوقع أن تؤدي هذه الاستراتيجية الـــى وفورات مالية للأسر تقدر بحوالي ٢٣٦ مليون دولار أمريكي بالقيمة الحالية. وبتحقيق هذه الوفورات المالية، تكون استراتيجية استهلاك الوقود في القطاع المنزلي قد ساعدت علـى احداث تحسّن في مستوى معيشة الأسر اليمنية في نطاق قابل للاستمرار بيئيا.

I. EXECUTIVE SUMMARY

Background

1.1 The Republic of Yemen (ROY) 1/ is at a crucial nexus in its development. Rapid political and economic development over the past twenty-five years has produced large increases in rural and urban household incomes, and the creation of important economic infrastructure. Now, despite the discovery of oil and gas reserves, the pace of growth is slowing as this new-found wealth is tempered by a decline in workers' remittances, and increasingly constrained by an absence of non-petroleum natural resources. Thus, Yemen faces an important set of decisions about how to best sustain the development of the past two decades through the efficient use of scarce human and natural capital. This decision-making will be strongly influenced by developments in the energy sector, with its significant links to foreign exchange earnings, household welfare and the environment.

1.2 **Households** are the largest group of energy consumers in ROY, and **wood** is the dominant national fuel. In northern ROY residential energy consumption accounts for over 60% of total final energy demand and fuelwood comprises over 90% of the energy used by Yemeni residences. Unfortunately, if past trends continue, available fuelwood resources will be depleted in the next ten to fifteen years. As woody biomass supplies erode over the remainder of the century, there will be a decline in the welfare of individual households caused by an increased use of inferior fuels, higher woodfuel prices, an increasing percentage of the family budget being spent on fuel rather than other basic needs, a lower per capita consumption of cooked food, and/or less space heating during the cold season. **Women**, who collect and use most of YAR's household fuels, and **the poor**, who are most heavily dependent on energy from woody biomass, will suffer the greatest **welfare loss**. In addition, there will be increasingly **negative consequences for the environment** (e.g., accelerated wind erosion, sand encroachment and microclimate degradation from wood harvesting, all of which reduce agricultural productivity). Fortunately, ROY is endowed with a popular but under-exploited domestic source of household energy - liquefied petroleum gas (LPG). It is expected that the Government of Yemen and Yemen Hunt Oil Co. will eventually finalize an agreement on the production and sale of domestic LPG. To date, however, there has been no concerted effort to develop a strategy for ROY to make the transition to a modern and sustainable fuel regime.

Issues and Objectives

1.3 Household energy planning and implementation have been stymied in Yemen because of: (i) the absence of a national energy strategy, (ii) inadequate institutional capabilities, (iii) ambiguous lines of authority between sectoral agencies, and (iv) the failure to develop and evaluate valid alternatives. Because authorities have not been able to recognize and respond to residential energy problems, a number of important issues have thus far gone unaddressed. Specifically, the following are priority problems:

1/ *At the time that this document was being researched (1988-89), the focus of the work was on the former Yemen Arab Republic (now northern ROY).*

(a) the decreasing supply of and persistent demand for woodfuels will lead to increased expenditure of time and money on wood acquisition, a decline in household welfare and possible acceleration of environmental degradation. Current efforts to augment supply are inadequate to develop a sustainable wood-based energy regime;

(b) the inability to rapidly develop LPG as a principal source of household energy has led to shortages, black market conditions and impaired market penetration of this essential domestic fuel. Removing impediments to LPG substitution will be essential for reducing pressure on national wood resources; and

(c) a very high proportion of rural households use non-grid, high-cost electricity, in addition to woodfuels. These unreliable and inefficient rural supply systems have imposed heavy financial costs on individual residences and economic costs on the country.

1.4 Given these issues, the **long-term development objective** of the household energy strategy for ROY is to improve household welfare by reducing the costs and improving the availability of household fuels, while ensuring that household energy consumption patterns are environmentally sustainable. The **immediate objectives** for achieving this are to: (i) protect the environment by promoting sustainable biomass management practices where substitution is not immediately feasible; (ii) prepare an economically viable strategy for the substitution of LPG for threatened biomass resources; and (iii) assess options for least-cost rural power supply to residences, including the use of photovoltaics. Formulation of this strategy is guided by the **principles** of achieving short and long-run improvements in residential welfare, efficiently using domestic energy supplies to promote resource sustainability, and relying on the buoyant Yemeni private sector through a market approach to policy and program implementation.

Elements of the Strategy

1.5 The central elements of the strategy are a series of recommendations concerning (a) **improvement of woodfuel management** to safeguard this increasingly scarce renewable energy resource, (b) **accelerated interfuel substitution** to displace wood with LPG and thus maintain residential welfare while protecting domestic woody biomass supplies, and (c) **supply of rural electricity** at least-cost through development of new decentralized power sources and more efficient use of autogeneration. Improved woodfuel management and accelerated interfuel substitution are complementary elements of the strategy which must be implemented together; neither of these elements alone can fully achieve the objectives of the household energy strategy.

1.6 To enhance efforts to manage woodfuel resources, activities are recommended to acquire basic information on the resource base and management practices, to assess and improve carbonization methods, to support indigenous land management practices, and to develop effective community and household agroforestry programs. Basic information acquisition involves (i) land-use conversion analysis, (ii) detailed investigation of woody biomass supply systems, (iii) additional wood inventories, and (iv) further research on biomass productivity. With respect to carbonization methods, the charcoal industry in north-central Tihama needs to be evaluated and, if warranted, more efficient carbonization techniques should be developed and disseminated. To support indigenous resource management, information should be developed on traditional woodland management practices in different areas of Yemen in order to reinforce successful agroforestry techniques. Regarding agroforestry programs, successful practices from certain areas need to be identified and more broadly disseminated. These programs should take advantage of market incentives to stimulate community and household participation. More details about these options are presented in paragraphs 4.39-4.46.

1.7 To accelerate LPG market penetration, programs are recommended to improve the infrastructure for fuel and bottle supply to consumers, introduce greater private sector involvement and safer operations, adopt a competitive pricing policy, and commercialize LPG-using appliances. This component of the strategy has two objectives: (a) to encourage households which are currently using both LPG and firewood to use less wood and more LPG, and (b) to encourage households which use only firewood and/or charcoal to switch to LPG. The actions which need to be taken to support the former include increasing the supply of LPG bottles and fuel beyond the current efforts underway, improving the marketing and distribution of the fuel, commercializing low-cost LPG baking equipment, and supporting the development of community bakeries. To achieve the second objective, the same actions are required and the costs of bottles, regulators and appliances need to be reduced by cross-subsidizing these items from fuel sales. To accomplish this, LPG should remain at a retail price of YR 40/bottle. The resulting windfall would be used as a cross subsidy for bottles and appliances. Even at this price, LPG would be the cheapest household fuel. More information on these recommendations is presented in paragraphs 5.15-5.40.

1.8 To improve rural electricity supply, projects are outlined to market-test photovoltaics (PV) for rural households, and to develop an effective rural power strategy that will improve the use of autogeneration. The market evaluation will involve: (a) technical testing of household PV systems and the specification of appropriate system design; (b) consumer acceptance testing; (c) the development of effective financing mechanisms; and (d) support for local private sector marketing, dissemination and maintenance of systems. To formulate a strategy to improve rural power services and reduce their costs, knowledge about existing systems needs to be expanded so that options can be realistically compared. This will entail developing detailed information about the costs and benefits of the most common diesel and gasoline generators currently used in rural Yemen. Then, a rural electrification strategy can be developed based on the least-cost mix of grid extension, private petroleum-fueled generators and decentralized PV. This component is described in paragraphs 6.13-6.22.

1.9 Yemeni institutions need to be strengthened to facilitate strategy implementation. Such steps, which are discussed in the Bank's Energy Strategy Review 2/, include:

(a) the continued use of foreign expertise;

(b) the formulation of appropriate organizational structures at the Ministry of Oil and Mineral Resources (MOMR) and Yemen General Electricity Cooperation (YGEC); the Ministry of Electricity and Water (MEW) and;

2/ *YAR: Energy Strategy Review, Report No. YAR-7862, January 31, 1990.*

(c) development of appropriate human resource planning. In addition, monitoring and evaluation can and should provide feedback for learning and adjustment throughout the implementation period.

1.10 The strategy can be initiated by a coordinated set of Yemeni institutions, including the vital private sector, over a period from 1991 to 2000. Many elements of the strategy have already been incorporated as part of other Bank projects which have already been initiated, such as the LPG Crash Program and the National Agriculture Sector Management Project.

1.11 During its ten-year life, the strategy should result in fuelwood savings of over 3.2 million tons and electricity conservation of over 400 GWh, as well as savings of kerosene, gasoline, and diesel. The marginal cost of strategy implementation (for components other than those already included in existing projects) is estimated to be US$1,550,000 for policy and program elements, plus approximately $6 million initially and $3.5 million annually thereafter for the purchase of additional LPG bottles. Over its first ten years, it is estimated that strategy implementation will result in present value financial savings to households of US$ 236 million. Through the realization of these financial savings, the household fuel strategy will help bring about an environmentally sustainable improvement in Yemeni household welfare.

II. INTRODUCTION 3/

Country Background

2.1 In 1990 the People's Democratic Republic of Yemen (PDRY) and the Yemen Arab Republic (YAR) merged to create the Republic of Yemen. This unification has entailed sweeping economic and political reform, and is only the latest in a series of political, economic, and social changes in the region over the past twenty-five years. PDRY had been a socialist state, but the new government will encourage free market economy. YAR, on the other hand, had been an isolated theocracy until a revolution in the 1960's opened the country to greater contact with the rest of the world. In both of these countries, change had been fueled by the remittances of Yemeni workers abroad during the 1970's and early 1980's, foreign aid and, more recently, by the discovery and development of domestic petroleum resources. Until now, remittances were perhaps the largest source of foreign exchange and financed much of the country's rural development.

2.2 These events have had a profound impact not only on the government, but also on individual Yemeni households, primarily by increasing household incomes in both rural and urban areas. For example, in YAR from 1973 to 1981, private transfers (mainly workers' remittances) averaged about $900 million per year in current terms and amounted to half of GDP. Since about 75% of the ROY population is rural, most of these remittances were ultimately sent to rural areas, resulting in a smaller disparity between rural and urban incomes and the private provision of basic infrastructure.

2.3 The prospects for continuation of this rapid development are tempered by several factors. Although remittances may have remained at relatively high levels despite the decline in international oil prices since the early 1980's, the recent decision by Saudi Arabia to repatriate Yemeni workers will have serious economic repercussions for Yemen. As many as 750,000 Yemenis returned to Yemen in the latter half of 1990, resulting in a sharp reduction in remittance flows. Unemployment had been increasing even before this repatriation, and has now surged from the traditionally low 4 to 6% of the labor force in the late 1970's and early 1980's to perhaps as much as 20%. Urban housing, in short supply even before these events, has now become critically deficient. Revenues from domestic oil production and exportation may not offset the loss of remittance income.

3/ *This report was written by Michael Crosetti (Energy Planner, ESMAP) and Josef Leitmann (Energy Planner, World Bank) with contributions from Messrs. Azedine Ouerghi, (Household Fuel Marketing Study Field Manager and Survey Analyst), Eric Ferguson (Household Energy Specialist, ESMAP Consultant), David Spottiswoode (LPG Marketing Specialist, ESMAP Consultant), Andrew Millington (Biomass Resource Analyst, ESMAP Consultant), Jeff Dowd (Survey Analyst, ESMAP) and Piet Visser (Cookstove Technologist, ESMAP Consultant), and by Mmes. Theresa Steverlynck (Sociologist, ESMAP Consultant) and Nagwa Zabarah (Sociologist, ESMAP Consultant). Survey field work was managed by Azedine Ouerghi in cooperation with Nasser Al-Aulaqi (formerly Dean, School of Agriculture, University of Sana'a) and Yahya Kayzal (Director, Republic of Yemen Central Statistical Organization). Secretarial assistance and report production services were provided by Janine Littleford.*

2.4 In addition to the effects of the repatriation of workers, savings and investment are low, and consumption of imported goods is relatively high. Budget and current account deficits persist, and the total debt service ratio has increased. Although there has been gradual improvement in social indicators, life expectancy remains under 51 years, and the infant mortality rate is over 125 per thousand births. The most recent social indicator data sheets which detail these and other statistics are presented in Annex 1.

2.5 The current population of about 12 million continues to grow by over 3 percent annually. Nearly 75 percent of the population is rural, but this is decreasing, in part, because of the decline in rural revenue from remittances. Much of the remittance income found its way to rural families, resulting in high rural liquidity, high rural household expenditure, and some infrastructure improvements, e.g., feeder roads and village electrification, all of which helped retard urban migration. However, though oil revenues may help offset decreased remittances, petroleum earnings are received by the Government and do not flow directly to rural dwellers. With decreased economic opportunities in the countryside, movement to the cities has increased and the effective urban population growth rate is around 8 percent per annum compared to less than 2 percent annually in rural areas.

2.6 Geographically, the country consists of three major zones. A coastal plain extends inland 30 to 60 km. The rugged foothills of the central mountain range rise from the plain, eventually forming the mountains and plateaus of the central highlands. Mountains in the central highlands often exceed 3000 m. in elevation. Most of the rural population inhabits this region. The central highlands give way to the rolling countryside of the arid eastern plateau which drops to an elevation of approximately 1000 m.

2.7 Other than petroleum reserves, Yemen is not well-endowed with natural resources. Soil and climatic conditions, as well as the mountainous topography found in much of the country, are not conducive to agriculture. Although effective terrace and irrigation systems have been developed over the past millennium, some of this infrastructure has deteriorated due to a lack of maintenance. This resulted from rural labor shortages which occurred during the 1970's, when more than one-third of the total male workforce was abroad. Furthermore, a significant portion of arable land and agricultural labor is used to grow *qat*, which is chewed by most Yemenis for enjoyment and constitutes an important social activity. Although this cash crop brings money to the countryside, it consumes resources that would otherwise be available for food production or export crops such as coffee.

2.8 In light of the conditions prevailing in Yemen, sustaining the development of the past two decades requires careful planning in all sectors through the efficient use of scarce human and natural capital. The Government is aware of the errors made by other countries which have experienced windfall oil income, and is determined to avoid such mistakes through the prudent use of domestic resources. Yemeni leaders are particularly concerned with the development of the energy sector, which will continue to be the primary source of national income, and an important determinant of the country's future socio-economic development.

Project Background and Objectives

Background

2.9 Before unification, the Household Energy Strategy Study focused on YAR. Oil and gas were discovered near Mareb in 1984 with subsequent discoveries in 1986. To help YAR develop and manage its new petroleum resources, the Bank proposed a credit for technical assistance in April 1986 (Report no. P-4256-YAR). One of the first pieces of work to commence under this credit was a gas utilization study to assist the country with using gas as a fuel for power generation, industry, commercial and residential consumers. This study was completed in 1988. To supplement the gas study, the joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP) prepared a report, issued in February 1987, on the impact of the oil and gas discoveries on the macro-economy and energy investment options (Report no. 6376-YAR). This work recommended that a market survey be conducted to determine the size of an LPG extraction plant. LPG was (and remains) a preferred fuel, particularly among household and commercial consumers. Because of limited storage, processing and distribution facilities, there are chronic shortages of LP gas and cylinders, both of which are entirely imported. The petroleum discoveries have improved prospects for eventually meeting this demand with indigenous resources.

2.10 For the majority of households that cannot obtain or afford LPG, fuelwood has remained the primary fuel. The importance of fuelwood was highlighted in the YAR energy assessment 4/ in late 1984. Because of the lack of data regarding what was clearly an important fuel, the assessment recommended further study of biomass supply and demand. Given the soil, climatic, and topographical conditions found in YAR, the forestry resources of the country appeared to be threatened by the growing demand for fuelwood. Thus, the potential for an increased supply of LPG could substitute for increasingly scarce fuelwood and possibly reduce the environmental threat of deforestation as well as help to improve household welfare.

2.11 To facilitate penetration of LPG into the household market, meet residential energy demand and understand the magnitude of the environmental threat, several central issues had to be addressed. Specifically, the following items required clarification and resolution:

(a) the uncertain size of potential household demand for LPG and implications for the sizing of LPG extraction facilities;

(b) the uncertain environmental effects of household fuelwood consumption;

(c) the lack of information about residential fuel marketing systems;

(d) the need to develop a nationwide LPG marketing and distribution strategy;

(e) the impact of fuelwood, kerosene and LPG prices on consumption and conservation;

4/ *Joint UNDP/World Bank Energy Sector Assessment Program* *YAR: Issues and Options in the Energy Sector, Report No. 4892-YAR, World Bank; Washington, D.C., December 1984*

(f) the tradeoffs between self-generated electricity for village use and the grid-based electrification program; and

(g) the lack of interim and long-term measures beyond substitution, such as pricing policies, efficiency improvements and improved natural resource management to limit deforestation.

2.12 In late 1986, the Government of the Netherlands authorized co-financing, totalling $375,000, to ESMAP to undertake a two-phase Household Energy Strategy Study to address these concerns. The first phase was designed to establish a household energy database through surveys carried out by the Central Planning Organization (CPO) (now reorganized as the Ministry of Planning and Development) and the University of Sana'a. This database could then be used to identify important residential fuel consumption patterns, preferences and causes. Details on the questions, sample size and methodology used with each survey are presented in Annex 2. The second phase focused on data analysis, clarification of major issues and formulation of a household energy strategy to address those issues.

2.13 The major outputs of this activity include:

(a) a one-round household energy survey carried out by the CPO and a two-round survey conducted by the University of Sana'a;

(b) comparison, evaluation and analysis of survey results;

(c) testing of wood- and LPG-fired tannurs and the design of an improved tannur (tannurs are traditional bread ovens, built as upright clay cylinders);

(d) an assessment of rural household electricity supply options;

(e) a nationwide woody biomass resource assessment;

(f) an assessment of LPG supply, distribution and marketing issues and options; and

(g) a study of Yemeni cooking habits, equipment and marketing alternatives for improving household energy-using behavior.

2.14 The results of these outputs are summarized in this document as part of the effort to formulate an energy strategy for Yemeni households. This strategy complements the broader work of the World Bank Energy Strategy Review which focusses on overall energy supply development. Certain activities initiated or recommended under the Energy Strategy Review, such as the LPG Crash Program, have been designed in close association with the Household Energy Strategy Study. This association has helped ensure that data collection and analysis carried out under the Household Energy Strategy Study are available for overall energy sector planning, and that recommendations made under the Household Energy Strategy Study are consistent with broader sectoral objectives and programs.

2.15 Because this study was originally conducted for YAR, much of it refers only to the northern governorates of the Republic of Yemen. In this report, the "northern governorates" are defined as those which previously constituted YAR. It is thought that many of the issues identified here also pertain to the southern governorates. In order to stimulate the formulation of a comprehensive household energy strategy study for all of Yemen, this report has been released as a preliminary step in the continuing planning process. Further work is expected to expand and update this report in order to formulate a comprehensive strategy for the whole of Yemen.

Objectives

2.16 Given the importance of residential energy consumption in Yemen, a household energy strategy is a critical element in overall energy sector planning. For Yemen, the **long-term development objective** of such a strategy is to improve household welfare by reducing energy costs, improving fuel availability, and ensuring that energy consumption patterns are environmentally sustainable. The **immediate objectives** for achieving this are threefold:

(a) to prepare an economically viable strategy for the substitution of LPG for threatened biomass resources;

(b) to protect the environment by promoting sustainable biomass management practices where substitution is not immediately feasible; and

(c) to assess options for least-cost rural power supply to residences, including the use of photovoltaics.

Energy Resources

2.17 Reserves and production of the principle domestic petroleum and biomass energy resources of the northern governorates are discussed below. With respect to petroleum resources, reserves reflect the current state of knowledge regarding fixed geological conditions, while production is a function of engineering and economic considerations, and political choices. The most recent estimates of reserves and production are given but, since oil and gas has been discovered only recently, these figures are expected to change. Biomass "production" is measured by firewood and charcoal consumption and "reserves" are presented as the stock of woody biomass as calculated in the Household Energy Strategy Study's resource assessment.

2.18 **Oil** was discovered in the Alif and Azal fields of eastern YAR in 1984 and 1986 respectively. Production began in 1986 to supply a 10,000 barrel per day (bpd) hydroskimming refinery in Mareb. The refinery previously met 38 percent of domestic needs for gasoline, diesel and fuel oil in the former YAR. At the end of 1987, the pipeline from Mareb to the coast was opened and crude oil production was eventually increased to the current level of around 180-190,000 bpd, most of which is exported to the Red Sea through a pipeline with a capacity of 240,000 bpd. The Government has indicated that production may be increased to 200,000 bpd. Total reserves are estimated to be 1.8 billion bbl. Estimated recoverable oil reserves are about 900 million bbl at present.

2.19 This oil, from what is termed the Mareb Production Sharing Area, is being developed by the Yemen Hunt Oil Company (YHOC). It is of high quality, with a low sulphur content and 39.5 gravity. In mid-1988, Yemeni oil was being sold at a premium of $0.65/bbl over the spot market average of Brent and Dubai, i.e., about $16.20/bbl, although it is anticipated that this premium will fall to $0.35-0.40/bbl. The Government's share of oil revenues is expected to peak at about $1 billion (constant 1983 dollars) in 1997.

2.20 **Natural gas** finds have been made at Raydan, Lam, Meem and Ma'een, in addition to the important associated gas at Assad al Kamil, Alif, and Azal and the smaller fields at Nacum, and Yazan. The Government has mandated strict conservation requirements covering gas reinjection and flaring to improve long-term oil recovery and conserve the resource for future consumption once an optimal gas exploitation plan has been established. Because the value of natural gas produced now would be less than the value of future oil production foregone by the reduction in reservoir pressure, there is currently no direct production of natural gas. At present, there is 600 mmcfd of reinjection capacity for the Alif and Azal fields, of which some 450 mmcfd has been used during the 1989 production period. Estimates of original gas in place (reserves), provided by MOMR, are 6.8 TCF, of which 3.2 TCF is at Alif and 2.5 TCF at Assad al Kamil while the rest is found at the other from gas fields mentioned above.

2.21 These gas resources are also managed by YHOC; they are significant but insufficient to justify gas export. The Gas Utilization Study has recommended the domestic use of gas for power generation for the grid and to supply cement factories, but has advised against manufacture of methanol or fertilizers. The main constraint limiting the use of gas, though, remains the need for gas reinjection to maintain optimum oil production.

2.22 LPG is currently imported but the availability of rich gases in the Production Sharing Area has made the domestic production of LPG feasible. LPG can be recovered from three potential sources:

(a) solution gas from the Alif, Azal, and Assad al Kamil fields;

(b) the Alif, Azal, and Assad al Kamil gas caps; and

(c) non-associated gas fields such as Raydan, etc.

From the current estimates of gas reserves in Table 2.1, and conservatively assuming that only 75 percent of LPG will be economically recoverable, there are approximately 10 million tons of LPG available from Alif and Azal alone. If it is assumed that the gas composition of Assad al Kamil is the same as the Alif cap gas, total recoverable LPG would be approximately 16 million tons, or over 300,000 t per annum for the next 50 years without any new discoveries.

Table 2.1: LPG RECOVERY POTENTIAL
(tons per year per 100 mmcfd of gas produced)

Component	Alif		Azal		Ma'een
	Cap Gas	Soln. Gas	Cap Gas	Soln. Gas	
Propane (C3)	46,000	74,000	54,000	87,000	50,000
Butane (C4)	44,000	52,500	51,000	59,000	45,000

Note: Assumes 85 percent propane recovery and 100 percent butane recovery, e.g., cryogenic extraction.
Source: MOMR

2.23 Only about 10,000 t per year of LPG are currently produced, although approximately 80,000 t per year of LPG are separated from associated gas at the C5+ gas plant at Safer, the location of the Alif/Azal oil fields. This LPG conforms to standard commercial specifications, but in the absence of sufficient storage, transportation and loading facilities, most of the LPG is reinjected back into the reservoir. The World Bank's recent Energy Strategy Review 5/ estimated that because of the high cost of imported LPG, full domestic production of LPG would replace about US$20 million of imports annually. Consequently, the Government has initiated the LPG Crash Program which incorporates many recommended elements of the household fuel strategy presented here. Specifically, the program aims to:

(a) establish national LPG standards and safety codes;

(b) install market-oriented bottling plants throughout the country;

(c) formulate specific pricing policies and privatization schemes to mobilize private sector resources for LPG marketing and distribution;

(d) establish a bulk distribution system for poultry farms and other large consumers such as hotels; and

(e) install the loading and storage facilities at Safer necessary for the use of indigenous LPG, and purchase and operate trucks for LPG transport to bottling plants and bulk consumers.

It is anticipated that these activities will be completed by the end of 1991.

2.24 Production of LPG from Alif and Azal solution gas could be easily increased to 120,000 t/yr by processing additional gas. Further investment in cryogenic processing could increase total availability by an additional 180,000 t/yr. The stripped gas would then be reinjected to help maintain reservoir pressure. Though unlikely, if LPG production were to reduce long-run oil output, the value of LPG now is greater than crude oil in the future. This is not the case for natural gas, hence the reason why it will continue to be reinjected until economic uses are developed.

5/ *YAR: Energy Strategy Review, Report No. YAR-7862, January 31, 1990.*

2.25 In addition to the LPG Crash Program noted above, expansion of the Hodeida storage and bottling facility from a capacity of 82,000 t/yr to 136,000 t/yr, has been completed as part of the follow-up to the Gas Utilization Study. LPG extraction from other fields, such as Assad al Kamil, and construction of a large bottling plant in Sana'a with a capacity of 135,000 t/yr, are also planned, and would significantly increase available LPG.

2.26 **Fuelwood** production can be measured by annual consumption since there are no fuelwood imports and changes in storage are insignificant. Households are the primary consumers of wood in the form of firewood and/or charcoal. In 1987, residential firewood use accounted for nearly 4.8 million tons of air dry wood per year, or about 1.8 million tons of oil equivalent (TOE). In addition, households consumed about 40,000 t of charcoal. Commercial consumption of charcoal in restaurants, hotels, and among artisans is estimated to be 60,000 t. Total charcoal consumption is approximately 100,000 t per year, which is equivalent to 70,000 TOE. This does not include exports to Saudi Arabia, which may be significant. Because of carbonization losses, roughly 450,000 t of wood are consumed annually for charcoal production. Most charcoal production takes place in the Tihama, by artisans using semi-pit kilns.

2.27 An assessment of woody biomass standing stocks carried out as part of the Household Energy Strategy Study suggests that total woody biomass growing stocks in the northern governorates are equivalent to approximately 36 million tons of air dry wood (54 million tons wet weight), and that annual sustainable yield is about 4.7 million air dry tons. This productivity is equivalent to an area-weighted national average of 0.38 t/ha/year (air dry) 6/. This is a sustainable yield equivalent to 13% of total standing stock whereas productivity for similar mature, unmanaged land classes is typically on the order of 3 to 5%, which would yield a total of only 1.8 million air dry tons annually. This suggests that wood resources are intensively managed in Yemen (and likely being depleted), a conclusion supported by field observations of intensive pollarding and coppicing in all land classes throughout the country.

2.28 Once again, these resource estimates refer only to the northern governorates. The southern governorates also contain large oil and gas reserves. Production at Shabwa has been constrained to only 10,000 b/d by a lack of facilities, but further development of this area is underway. The Government has not yet released official oil and gas reserve estimates for the country as a whole, but some industry sources mention oil reserves of up to 5 billion bbls and gas reserves of between 15 to 20 TCF. The fuelwood resource situation in the southern governorates is unknown.

Energy Balance

2.29 Energy consumption by sector and fuel type for the northern governorates is depicted in Figures 2.1 and 2.2. Details are provided in Annex 3. A brief analysis of this data highlights the relative importance of both the household sector and fuelwood in the national energy regime.

6/ *These estimates are for the area formerly covered by YAR west of 45 deg 30' W, an area of nearly 120,000 km2. This does not include much of the arid eastern plateau. Approximately 70,000 km2 of this area is not included; the area has an average productivity of only 0.07 t/ha/yr. Average productivity for the entire country including this area is 0.24 t/ha/yr.*

Household energy consumption accounts for 63% of total final energy demand; the next most important sector is transport with 28% of total final energy (consisting entirely of gasoline, jet-fuel and diesel). The key fuels in Yemen are clearly woodfuels which make up 58% of the total final energy supply in the northern governorates. Other petroleum products besides LPG (gasoline, kerosene, jet-fuel, diesel and fuel oil) are the next most important energy source, amounting to 37% of 1988 consumption. Within the household sector, fuelwood comprises over 90% of the energy used by Yemeni residences. Thus, households are the most important consumers of energy in Yemen and fuelwood is overwhelmingly the dominant source of energy.

2.30 Estimates of final energy consumption have also been prepared for the year 2000 based on analysis carried out under this project and the World Bank Energy Strategy Review. Total final energy consumption in the northern governorates is expected to increase from about 3.3 million TOE in 1988 to 5.3 million TOE in 2000. The breakdown of this future consumption by sector and fuel type is also shown in Figures 2.1 and 2.2. Details are provided in Annex 3. Clearly, woodfuels and the household sector will both continue to dominate the domestic energy scene in Yemen assuming a continuation of current trends and the implementation of recommended policy.

Existing Policies and Institutions

2.31 Modern Fuels. For "modern" sources of energy such as petroleum products and electricity, the basic responsibility for formulating and implementing policies in Yemen is split between the Ministry of Electricity and Water (MEW) and the Ministry of Oil and Mineral Resources (MOMR). The integration of their policy proposals is undertaken at three levels: by the Cabinet, the Ministry of Planning and Development (MPD), and the Supreme Council for Oil and Mineral Resources and Economic Development (SCOMRED). The Cabinet, by definition, has the ultimate responsibility for energy policy in Yemen and decides anything of national importance, e.g. electricity tariffs or oil product prices. The MPD, in principle, should spell out sectoral objectives and establish comprehensive energy programs as part of Yemen's 5-year planning process. SCOMRED, chaired by the Prime Minister and composed of the ministers of State, MEW, MOMR, Industry, Finance, and MPD, is charged with drawing up general policy for the development and use of the country's hydrocarbon resources.

2.32 In the **power subsector**, MEW is responsible for the formulation of policies and plans for electricity development, including the control and licensing of private and industrial autogeneration. The Yemen General Electric Corporation (YGEC), a semi-autonomous part of MEW, is responsible for electricity generation and distribution through several grids. Its planning functions are mostly limited to its projects department which identifies investments in concert with MEW for preparation of the national Five Year Plan. Several factors impose constraints on YGEC: (a) its semi-autonomous status is a source of friction with MEW; (b) it receives no guidance because the Government lacks a national energy strategy; (c) the organization is overstaffed in general but understaffed in highly qualified personnel; (d) regional political considerations interfere with national grid planning; and (e) delays in customs clearance hamper availability of needed spares, leading to equipment cannibalization.

Figure 2.1: SECTORAL COMPOSITION OF FINAL ENERGY CONSUMPTION, 1988 AND 2000
TOE Equivalent Basis

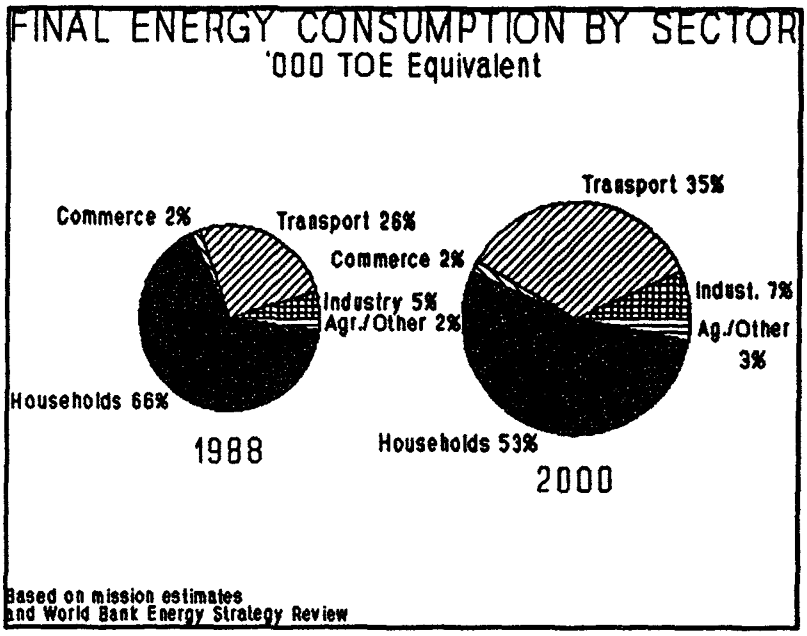
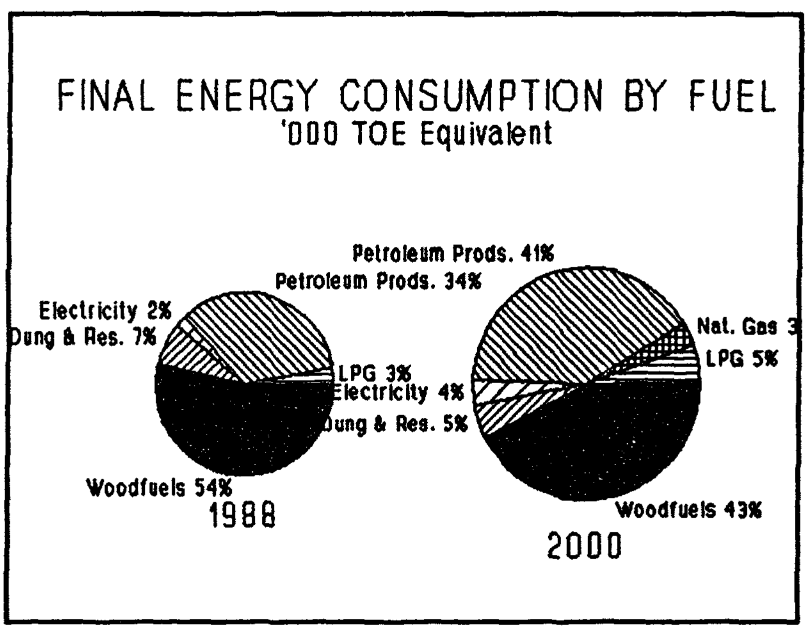


Figure 2.2: FINAL ENERGY CONSUMPTION BY FUEL, 1988 AND 2000
TOE Equivalent Basis



Based on Mission Estimates and World Bank Energy Strategy Review

2.33 In the **petroleum subsector**, the General Corporation for Oil and Mineral Resources (GCOMR) is responsible for oil supply and marketing. Petroleum exploration and production is carried out by joint ventures with international firms. Yemen-Hunt Oil Co. is the most active, having developed the oil and gas fields in the Mareb region. The Yemen Petroleum Corporation (YPC), a subsidiary of GCOMR, is responsible for operating the LPG bottling plant and for all domestic distribution of petroleum products (including LPG). YPC has a small statistical unit but no planning department; it has only recently begun to plan and implement investment projects, primarily involving LPG.

2.34 Traditional Fuels. The demand and supply of biomass for energy is not explicitly incorporated in any ministerial portfolio. Rather, several public agencies are concerned with woody biomass for a variety of purposes. A Supreme Council for Afforestation (SCA) was established in YAR in the late 1970's to coordinate various organizations involved in afforestation and organize an arbor day. A small Directorate of Forestry was set up in 1975 as part of the Ministry of Agriculture to eventually develop and manage national forest policy. There are 26 Government tree nurseries which come under the Ministry of Agriculture, many as part of regional agricultural authorities or projects. Successful field operations in forestry are largely dependent on the Agricultural Extension Service. Most tree planting programs along roadsides, in townships and around amenity areas in the northern governorates have been undertaken by Local Development Councils (LDCs). Their activities are coordinated, supervised and sometimes funded by the Confederation of Local Councils for Cooperative Development (CLCCD). Additional re- and afforestation activities have been undertaken by some of the Regional Development Authorities which manage a number of agricultural projects throughout the northern governorates. The Agricultural Research Authority (ARA) has a small program which has initiated work on land rehabilitation, sand dune stabilization, species trials, agroforestry and seed collection. MPD's statistics department has been involved in collecting data on traditional fuel expenditures in the family budget.

2.35 Policies. Household energy policy planning and implementation have been stymied in Yemen because of the lack of: (i) a national energy strategy, (ii) an institutional framework capable of carrying out the planning task, (iii) a well-defined division of responsibility between sectoral institutions, and (iv) information, evaluation and planning mechanisms. In the power subsector, the organizational and operational difficulties of YGEC policy-making have been mentioned in para. 2.32. In the petroleum subsector, several constraints limit household energy policy-making: (a) the division of authority between YPC, GCOMR and MOMR for planning and implementing policy has not been finalized; (b) performance indicators, especially profitability, appear to be non-existent in the subsector so efficiency is not a great concern; (c) formal private sector involvement in LPG marketing and distribution has been discouraged by a heavy-handed bureaucracy; and (d) no one agency is charged with developing and enforcing safety and health measures for the use of petroleum products. Concerning fuelwood, a forest policy was approved by the YAR Minister of Agriculture in 1980 but not accepted by Government. The preamble to the Government of YAR's third Five Year Plan (1987-91) confirmed the intention to adopt an official forest policy, approve a forest development strategy and enact forest legislation within the plan period. In fact, all of these forestry activities should be implemented as part of the Bank's National Agricultural Sector Management Development Project and the proposed Land and Water Conservation Projects. To date, though, there is no organized forest management or fuelwood policy in Yemen. Specific activities in each of these subsectors related to the principle household energy issues are discussed further in Chapters 4-6.

III. THE STRUCTURE OF HOUSEHOLD FUEL USE

3.1 The following chapter will examine the overall structure of residential fuel consumption in the northern governorates of Yemen. It is expected that many of these patterns also exist in the southern governorates. The principal household end-uses are discussed in terms of the fuels and equipment used to meet residential needs. Regional and rural/urban differences in consumption patterns are highlighted, and energy-related expenditure is examined. In addition, the sociological dimensions of household energy consumption are explored with particular emphasis on gender roles, and the environmental consequences of the status quo are outlined.

Patterns of Residential Fuel Use

Fuels and End-Uses

3.2 Households use a variety of fuels at present but, as suggested earlier, firewood is the predominant source of energy. Table 3.1 summarizes the household energy balance derived from the surveys carried out by the YAR Central Planning Organization (CPO) and the University of Sana'a in 1987 and 1988.

Table 3.1: 1988 HOUSEHOLD ENERGY BALANCE FOR NORTHERN GOVERNORATES ('000 TOE)

	Firewood	Charcoal	Electricity	LPG	Kerosene a/	Dung	Residues	Total
Cooking & Baking	1800	2		80	21	96	152	2151
Lighting			18		40			59
Space Heat	23	2	3					28
Water Heat	29		5	6	2		5	48
Water Pipes		25						25
Other	7	1	5	2	2	7		24
Total	1860	29	31	88	65	103	157	2333

a/ Total Kerosene consumption is based on official figures. However, both the University an CPO surveys suggest total consumption of twice this level. The discrepancy may be due to smuggling and/or survey measurement errors. End-use shares for kerosene are allocated based on CPO and University of Sana'a survey results.
Source: CPO Family Budget Survey and University of Sana'a surveys.

3.3 Cooking accounts for the bulk of household energy consumption by far (92% of final energy). This reflects the prevalence and energy intensity of cooking as well as the widespread use of inefficient firewood stoves and ovens as discussed in paragraph 3.13 below. Firewood is the predominant household fuel in general and cooking fuel in particular. Dung and crop residues are the next largest cooking fuels. Charcoal, on the other hand, has limited use as a cooking fuel because of its high price, and is instead used primarily in water pipes (*madaa*) in households as well as commercial establishments.

3.4 The analysis above obscures the important regional and rural/urban distinctions regarding household fuel use in the northern governorates. To illustrate these differences, Table 3.2 provides estimates of fuel use by region and rural/urban location. The northern governorates have been clustered into the following regions on the basis of geographical and socio-economic considerations:

Region	Governorates
SANA'A	Sana'a
COASTAL	Hodeida
NORTHWEST	Hajja, Mahweet
SOUTHERN	Taiz, Ibb
CENTRAL	Dhamar, Beidha
NORTHEAST	Saada, Mareb, Jawf

3.5 The Coastal region consists of the Tihama plain, which is a poor region of the country. The Northwest region, on the other hand, is one of the wealthier regions of the country, due in part to the cultivation of *qat*. The increased rainfall found along this section of the escarpment also results in greater wood availability and productivity. The Southern region consists of densely populated highlands. The Central region covers a relatively dry plateau which is nonetheless cultivated. It is correctly thought of as a region where wood stocks have been severely depleted. Finally, the Northeast region includes sparsely populated inland desert areas of YAR. This is where petroleum is produced and where despite the poor rainfall, significant wood stocks are found in the numerous seasonal river beds (*wadis*) which flow towards the east.

3.6 Table 3.2 shows large regional and rural/urban differences in household energy use. Urban final energy consumption per household is approximately one-half the rural level. This is due to: (i) the use of less efficient fuels and end-use devices in rural areas, particularly for cooking and lighting; and (ii) the observation that many energy-intensive tasks performed in the rural households are not performed, or are performed less often, in urban households. For instance, urban households often purchase bread from bakeries, and may eat more meals outside the home 7/. Given the rapid urbanization taking place in the northern governorates (urban population growth rates on the order of 9 percent, as opposed to about 3 percent nationally), understanding rural/urban differences in energy consumption is essential for national energy planning.

3.7 Regional variations in energy consumption are also significant. These variations reflect differences in fuel accessibility and price, as well as in household incomes and cooking practices. Investigating these differences can help to determine the effects of income and price changes and improved fuel accessibility.

7/ *According to University of Sana'a Survey #1, nearly 98 percent of rural households bake all of their bread, whereas less than 25 percent of urban households do so. In fact, about one-quarter of urban households fall into each of the following categories: buy all their bread, buy more than they bake, bake more than they buy, and bake all.*

Table 3.2: 1988 HOUSEHOLD FINAL ENERGY CONSUMPTION BY REGION AND FUEL
(KGOE/Household/yr; averaged over all households)

	Firewood	Charcoal	Electricity	LPG	Kerosene	Dung	Residues	Total
URBAN								
Sanaa	245	36	154	200	7	(6)	3	651
Coastal	(58)	88	142	110	75	0	0	473
Northwest	(1325)	(65)	(60)	142	31	0	(47)	1670
Southern	400	55	71	134	21	(2)	(58)	740
Central	938	(13)	45	142	49	(61)	3	1251
Northeast	(966)	(71)	NA	90	58	0	0	NA
	Urban Average	884						
RURAL								
Sanaa	2224	(16)	20	69	64	120	(73)	2586
Coastal	1269	25	4	1	92	(56)	109	1557
Northwest	1622	58	16	39	134	(40)	(121)	2029
Southern	964	1	14	39	113	38	115	1284
Central	1505	2	11	72	125	278	296	2289
Northeast	1750	0	29	36	146	1	(10)	1972
	Rural Average	1953						

( ) indicates that figure may be based on too few cases to yield reliable results.
Source: CPO Family Budget Survey and University of Sana'a surveys.

3.8 **Cooking**, as noted earlier, accounts for over 92 percent of final energy consumption in households in the northern governorates. Most cooking (including virtually all baking, the most energy intensive cooking task) is done with firewood and almost all firewood is used for cooking. Nonetheless, dung and crop residues are important cooking fuels in certain rural areas, particularly the Central region where wood resources have been substantially depleted. LPG is a common cooking fuel in urban areas, primarily because it is more readily available in cities. Kerosene is also used for certain cooking tasks such as boiling, but not to the extent that LPG or even dung and crop residues are used. Electricity is virtually never used for cooking.

3.9 The staple food for the Yemeni meal is bread which is most frequently baked with firewood in a vertical cylindrical oven called a *tannur*. Some typical tannurs are depicted in Figure 3.1. They are usually between 45-70 centimeters in height and 25-60 centimeters in diameter. Tannurs found in the Coastal region are typically smaller than those in other regions of the country reflecting lower consumption of flour breads. Traditional tannurs are made of clay or a mixture of mud, dung and shale, and are sometimes surrounded by a metal casing (as in the figure). In urban areas, they sell for YR 300-600 (depending on the size, quality and retailer) while village prices are less at YR 100-200. Installation in the home kitchen is done either by the household or by a mason who may charge as much as YR 350 for the service.

3.10 The most common bread (*khubz*) is made of flour, yeast and water. Other cereals are also used for breads and porridges. The principal side dishes of a meal include rice, vegetable stews, and meat, chicken or fish. Because cooking and baking often take place simultaneously on the same appliance, it is difficult to separate the two from an energy standpoint. The cooking process on the tannur is as follows:

(a) while the tannur is heating up, a meat stew may be put on the fire along with water kettles;

(b) when the walls of the tannur are sufficiently hot, dough is placed on the inside wall to bake. Baking takes 1-3 minutes per bread, and 5-15 breads are usually baked per tannur/household/day;

(c) during baking, other dishes (e.g., sorghum gruel, vegetable stew, rice, sauces or meat for grilling) may be placed on top of the tannur to be cooked;

(d) fish may be baked in the tannur and bread-based dishes may be put in a stone pot and heated for a few minutes on the glowing embers on the bottom of the tannur;

(e) at the end of baking, the tannur is often covered, with the top being used to heat water, keep food warm or complete the stewing of meat.

3.11 Recently, an all-metal LPG-fired tannur has appeared on the market along with gas burners that can be used for pots and pans or retrofitted (rather ineffectively) in the wood-burning clay tannur. In addition, an increasing number of people are buying their bread from bakeries which primarily use LPG or diesel as a baking fuel.

3.12 Households will seldom use only one fuel or stove type. A charcoal stove (*mawgid*) or an open wood fire may also be used to simmer dishes or keep food warm. The mawgid is principally used to hold burning charcoal for use in water pipes. Dung and residues are typically burned in three-stone stoves, while kerosene is typically used in "Primus"-type pressure stoves. These stoves are also used for water heating for bathing, etc., although electric water heaters are found in urban areas in wealthier households. The types of stoves used, cooking practices, and the particular dishes prepared vary from region to region in Yemen. Throughout the country, though, cooking is done with aluminum or clay pots and aluminum, clay or stone pans, often in a poorly ventilated indoor kitchen.

3.13 The range of biomass-using appliances and their frequency of ownership in urban and rural areas are presented in Table 3.3. The most commonly-owned appliance is the tannur, followed by the mawgid and, lastly, the three stone stove. All three of these appliances are relatively inefficient. For instance, to bake bread alone, an LPG tannur may operate at an efficiency of 13 percent whereas the traditional wood-fired tannur may operate at only 4 percent efficiency; an LPG or a kerosene pressure stove may yield efficiencies on the order of 50 percent compared to three-stone stove efficiencies of around 10 percent. (Efficiencies are given on the basis of heat required for the task divided by energy content of the fuel consumed). Consequently, given the higher use of these appliances for energy intensive tasks in rural areas, it is not surprising that rural energy consumption is so much higher than urban consumption.

<u>Table 3.3</u>: BIOMASS APPLIANCE OWNERSHIP BY LOCATION
(Average number per household including non-users)

Appliance	Rural	Urban	Nat'l Ave.
Tannur	1.55	0.57	1.45
Mawgid	0.42	0.56	0.44
3-stone stove	0.40	0.09	0.36

<u>Source</u>: University of Sana'a survey #1.

Figure 3.1: THE TRADITIONAL TANNUR

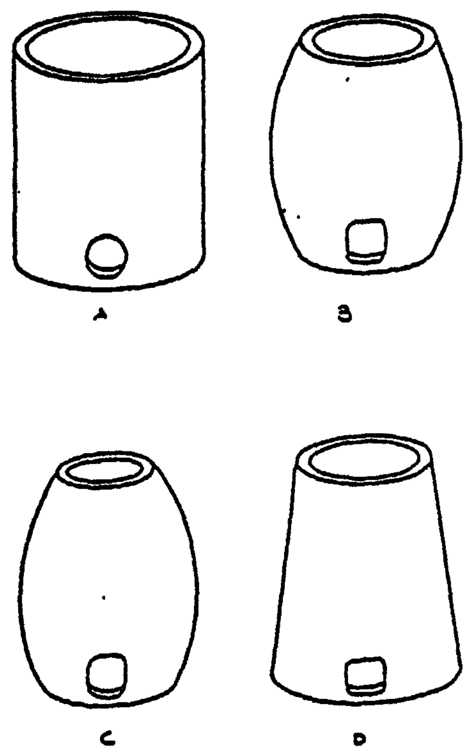
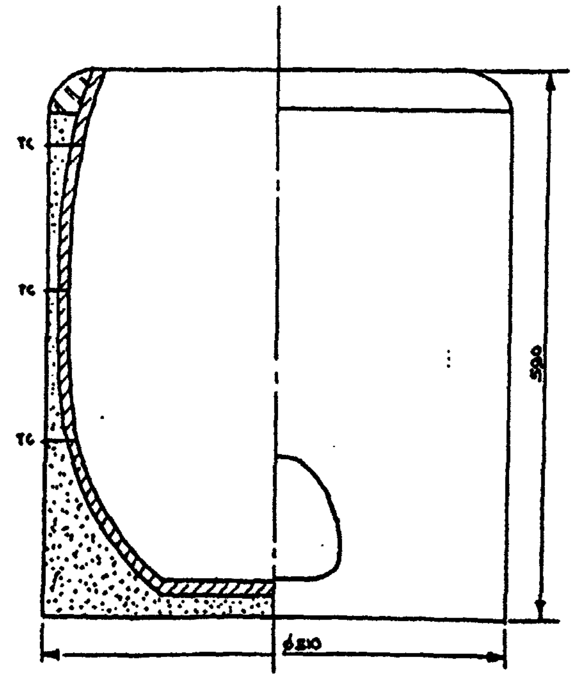


Fig. 1
tannur inserts (Source: D. Champault)



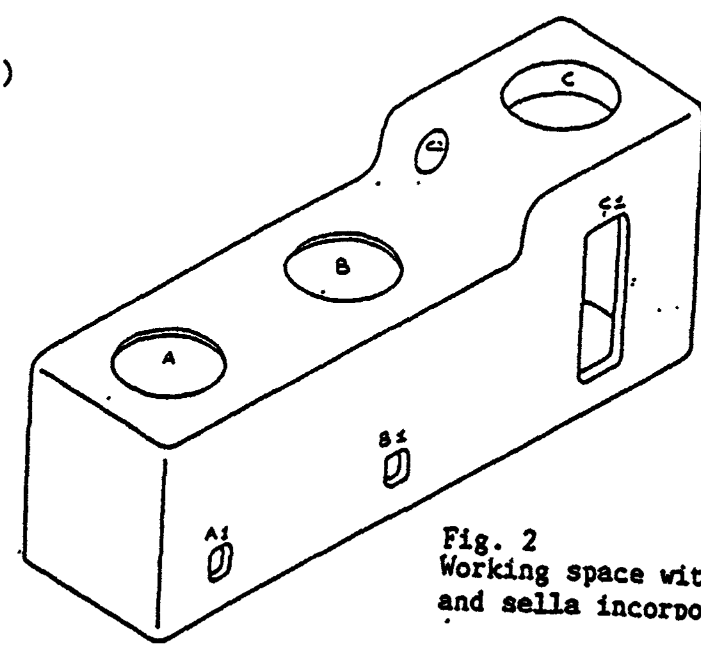


Fig. 2
Working space with tannur and sella incorporated.

Source: Visser, "Test Results on Tannurs and Cookstoves," prepared for ESMAP, December 1988, and Dominique Champault "Espaces et materiels de la vie feminine sur les Hauts Plateaux du Yemen," 1985.

3.14 **Lighting** is the second largest end-use in terms of household final energy consumption, although it accounts for only 2.5 percent of total household consumption. The importance of lighting from a household welfare standpoint far outweighs its representation in the household energy balance.

3.15 Electricity and kerosene are the primary lighting fuels, although candles are also used. Nearly 63% of all households use electricity (not including dry cell flashlights); of these, approximately 83% use electric lights (those who use electricity but not electric lighting are by and large households that use liquid batteries for television only). Both incandescent and fluorescent lamps are used, although fluorescent tubes are used in more households.

3.16 Although the use of electric lighting is relatively widespread, kerosene remains a common lighting fuel, even in houses which use electric lighting. About 87% of households use kerosene, of which over 94% use it for lighting. Nearly two-thirds of all kerosene consumed in households is consumed for lighting, while most of the rest is used for cooking. Wick lamps are far more common than pressurized lamps. The use of kerosene and electric lighting together is easily explained by the fact that over three-fourths of household electricity users rely on intermittent private generation for their electricity; kerosene lighting provides light during periods when electricity is unavailable.

Fuel Prices and Equipment Costs

3.17 The differences in rural/urban and regional energy consumption patterns reflect differences in fuel pricing. Although official prices have been set for modern fuels such as kerosene, LPG, and electricity, the Government is only able to effectively control the retail price of grid electricity. The prices for all other fuels, both modern and traditional, are set in the market. Given the vibrant private sector found in Yemen, fuel retailing monopolies are uncommon. Fuel prices may be high relative to other countries, but this is not due to monopoly rents. Rather, prices seem to represent high producer costs, limited supply, and a high willingness to pay. Given the liquidity of both the rural and urban household economies, the barriers to entry in the retail market for household fuels are few. Woodfuel trading requires only a small truck, and electricity sales a small generator. Although these investments would be prohibitively expensive in many other countries, the relative wealth and liquidity of the Yemeni economy enables an open and dynamic market to operate.

3.18 **Woodfuel** is highly commercialized in Yemen. The first University of Sana'a survey indicates that approximately 40% of all firewood consumed in households is purchased. The retail value of 1988 Woodfuel sales in the northern governorates alone was around US$380 million, making the woodfuel trade by far the largest commercial domestic energy supply activity in the country. Woodfuel prices reflect not only local availability, but also location relative to woodfuel transportation routes. For instance, firewood is less expensive in the urban centers of the Central region because they serve as transhipment points between the northern and the Southern regions. Charcoal prices also exhibit regional and rural/urban differences, but not as large (in percentage terms) as those found with firewood. Average retail firewood prices (weighted by the quantity of wood traded in each of the following categories: headload, camel load, small pick-up truck load, and lorry load; the small pick-up truck dominates), and average retail charcoal prices per sack, i.e. about 18 kg, are given in Table 3.4.

Table 3.4: REGIONAL RETAIL WOODFUEL PRICES
(YR/kg)

Region	Firewood Urban Price	Firewood Rural Price	Charcoal Urban Price	Charcoal Rural Price
Sana'a	2.22	1.04	8.62	6.20
Coastal	2.17	1.32	7.29	8.14
Northwest	1.85	1.76	8.35	7.20
Southern	2.33	1.98	6.84	7.66
Central	1.91	2.05	5.90	N.A.
Northeast	1.41	1.49	6.15	7.10
N. Governorates Average	2.19	1.81	7.79	7.34
N. Governorates Average (rural & urban):	1.85		7.49	

Source: University of Sana'a Survey #1.

3.19 Using the range of retail prices given above, purchased firewood costs between YR 0.06 to YR 0.15 per MJ on a final energy basis (or a northern governorates average of YR 0.11 per MJ), whereas charcoal costs YR 0.19 to YR 0.29 per MJ (a northern governorates average of YR 0.25 per MJ). On a useful energy basis, assuming a tannur fuel-to-bread efficiency of 4%, firewood costs between YR 1.50 to YR 3.75 per MJ for baking. These prices are far higher than urban fuelwood prices in similar agro-ecological zones such as the Sahel, where wood retails for the equivalent of between YR 0.50 to YR 1.00 per useful MJ.

3.20 Firewood is collected on private or common lands and sold to wholesalers who operate roadside markets. The wholesalers in turn sell to transporters who then sell it to retailers and final consumers in urban centers. Some firewood traders may be vertically integrated, taking on collection, transportation, and retailing themselves. Wood from private land generally comes from intensively managed natural wood- or scrubland, and represents a smaller share of the market, while wood from common lands generally represents a larger share of the market. In fact, firewood trading is perhaps the major source of income for bedouin, who still live in tents but frequently have replaced the camel with a four-wheel drive truck to facilitate the collection of dead- and livewood from *wadis*. Data collected from the household surveys and the woody biomass resources assessment suggest the price structure found in Table 3.5. After taking into account transportation costs, the retailer and transporter share a markup equivalent to between 30 to 55% of the retail price (although this does not represent pure profit to the retailer, as his costs have not been included). A markup of this magnitude is typical of many countries where a commercial wood trade is found; it reinforces the assertion that the relatively high fuelwood prices found in YAR are not due to excessive markups or monopoly rents.

3.21 LPG prices are characterized by large differences in rural and urban pricing; regional differences, on the other hand, are less pronounced than with firewood prices. Table 3.6 gives average prices for LPG on a regional and rural/urban basis. These prices include the cost of bottle filling as well as transport from the retailer to the household; the transport component typically accounts for around 7% of the total cost. These actual prices are 16% to 100% higher than the official retail price of YR 40 per bottle, depending on the region. (Although it nominally contains 12.5 kg, a bottle, on average, actually contains 10.7 kg of LPG. This is due to the numerous tare weights of bottles in circulation and the absence of any practice to standardize bottle filling by tare class). The lowest prices are found in urban areas of the Coastal region, presumably because of the proximity to the Hodeida bottling plant (However, LPG use in this region is the lowest of all regions, probably due to the lower incomes of this region.). Despite retail price markups, LPG is competitive with firewood on a final energy basis, particularly in urban areas: YR 0.13 per MJ vs. YR 0.11 per MJ for firewood for the northern governorates as a whole, and YR 0.10 per MJ vs. YR 0.14 per MJ in urban areas. When cooking efficiency is taken into account, LPG is a much better buy than firewood: using national average costs, an LPG ring (50% efficiency) provides energy at YR 0.26 per useful MJ vs. YR 1.10 per useful MJ for a three-stone stove (10% efficiency); a metal LPG tannur (13% efficiency) provides energy for YR 1.00 per useful MJ, whereas a wood-fired tannur the cost is YR 2.75 per useful MJ.

Table 3.5: EXAMPLES OF FIREWOOD PRICE STRUCTURE

Case #1
Wholesale Market: Al Harf (Northwestern Region, Saada governorate)
Wholesale Price: YR 650 per small pick-up truck (960 kg); YR 0.68/kg a/
Transportation Cost: 300 km roundtrip at YR 1.93/km: YR 0.60/kg b/
Wages: YR 200 per trip; YR 0.21/kg
Retail Market: Sana'a
Retail Price: YR 2.22/kg
Markup: YR 0.73/kg; 33% of retail (for both transporter and retailer)

Case #2
Wholesale Market: Al Bareh (Southern Region, Taiz governorate)
Wholesale Price: YR 630 per small pick-up truck (960 kg); YR 0.66/kg a/
Transportation Cost: 150 km roundtrip at YR 1.93/km; YR 0.30/kg b/
Wages: YR 150 per trip; YR 0.16/kg
Retail Market: Taiz
Retail Price: YR 2.33/kg
Markup: YR 1.21/kg; 52% of retail (for both transporter and retailer)

a/ Weight of pick-up truck load estimated by mission.
b/ Full roundtrip distance is considered; no backhauling assumed. Cost per km is calculated assuming YR 3/li fuel costs, consumption of 9 km/li, used pick-up truck cost of YR 160,000, used vehicle life of 5 years, and travel of 20,000 km/yr.

Table 3.6: REGIONAL RETAIL LPG PRICES a/

	(YR/bottle)	
Region	Urban Price	Rural Price
Sana'a	47	68
Coastal	43	N.A.
Northwest	53	63
Southern	49	70
Central	58	68
Northeast	54	75
Norther Governorates Average	48	69
Average for all locations: 64		

a/ Includes cost of bottling filling and transport.
Source: University of Sana'a Survey #1

3.22 Although there is no explicit Government pricing formula, the current official retail price of YR 40 per bottle, or YR 3738/mt (based on a 10.7 kg. bottle), corresponds fairly well to the actual economic cost of about YR 3200/mt for imported LPG. Table 3.7 provides an LPG cost build-up. The economic cost of domes' ' LPG, which will be available upon implementation of the LPG Crash Program, would exclude .ne insurance, freight, dock and duty charges, and would therefore be on the order of YR 2,000/mt (YR 0.04 per MJ on a final energy basis, significantly less than kerosene).

Table 3.7: LPG COST BUILD-UP a/

	Per Tonne		Per Cylinder b/
LPG fob Ras Tanura	$100	= YR 975	10.43
Freight Ras Tanura to Hodeida	$112.50	= YR 1097	11.74
Price cif Hodeida	$212.50	= YR 2072	22.17
Insurance	$ 0.16	= YR 1.56	.02
Duty and Dock Charges		YR 100	1.07
Laid down Product Cost Hodeida Terminal		YR 2173.56	23.26

OPERATING COSTS TO POINT OF SALE
YR per Cylinder

	To Sanaa/Taiz	To Mareb
Cylinder handling - loading/offloading	1.85	1.85
Plant Employee Wages	0.70	0.70
Various Employee Wages-Overtime etc.	1.15	1.15
Plant Depreciation	0.25	0.25
Cylinder Depreciation	0.13	0.13
Transport Return Trip - Filled/Empty	4.80	7.20
YPC Depot/"Shop" Rental	0.13	0.13
Total of Above Costs	9.01	11.41
Administration and Overheads (10%)	0.90	1.14
TOTAL COSTS	9.91	12.55

TOTAL COSTS AND PRICES OF FILLED CYLINDERS AT POINT OF SALE

	YR per Cylinder	
	To Sanaa/Taiz	To Mareb
Product Cost	23.26	23.26
Operating/Transport Cost	9.91	12.55
TOTAL COST	33.17	35.81
YPC Official Selling Price	40.00	40.00
Government Tax	6.83	4.19

a/ Product cost based on exchange rate of YR9.75 = US$1. The more current rate of YR 12.50 = US$1 would result in a subsidy of YR2.07 per bottle for Mareb deliveries and a small tax of YR.057/bottle for Sana'a/Taiz deliveries.

b/ Based on 10.7 kg per cylinder.

Source: Modified from Pencol, "Development of LPG. Resources: Techno-Economic Justification Report", November 1989.

3.23 Although the economic cost and official price of imported LPG are comparable, the difference between actual retail prices and official prices are striking. LPG is sold to private agents at YPC depots in Sana'a, Taiz, and Hodeida at official prices. Nonetheless, in rural Sana'a, the average retail price is over 80% higher than the official price in Sana'a. LPG retailers and transporters realize higher markups than in the fuelwood trade.

3.24 The large difference between the official LPG prices and actual retail prices (in effect, the large markups of LPG retailers) can be attributed to the scarcity of LPG and the inefficiency of the distribution system. Although the Hodeida bottling plant is operating at full capacity and domestic bottling has been augmented with bottle shipments from Aden, shortages of LPG persist. Households prefer LPG to other fuels, and their demand exceeds the existing supply; queues for LPG are common. This strong demand allows retailers to set prices that are comparable to competing fuels such as kerosene and fuelwood, and capture higher profits; the prices of competing fuels are well above the official LPG prices on an energy basis. Furthermore, most LPG is bottled in Hodeida (some LPG consumed in the northern governorates is bottled in Aden), so transport is also expensive.

3.25 Distributing LPG throughout Yemen in bottles is inefficient and costly when compared to bulk distribution to consumers or local bottling plants. Like the fuelwood trade, there are a large number of LPG transporters and retailers throughout the country. In addition to its own stores, YPC has over 500 private agents who are authorized to return empty bottles to the main YPC depots in Sana'a, Taiz, and Hodeida and purchase filled bottles at the official price. Although this suggests healthy competition on the retail level, all of these retailers are nonetheless constrained by inefficient distribution methods imposed by YPC and a lack of supply which enables them to maintain high prices without being undercut by competitors. However, with proper management and implementation of the LPG Crash Program, and operation of the Sana'a bottling plant, this situation should change.

3.26 **Kerosene** prices are also marked-up over the official retail price of YR 2.30/li. Regional kerosene prices are somewhat more consistent throughout all regions and rural/urban areas, as indicated in Table 3.8. One notable exception is the urban areas of the Coastal region (primarily Hodeida), where kerosene is much cheaper. LPG use is minimal in the Coastal region and the low kerosene prices found in the urban areas there may reflect the operation of very competitive distribution systems and adequate supplies as well as the proximity to Hodeida port where kerosene is landed and initially stored. At around YR 0.14 per MJ, kerosene is priced competitively with LPG and firewood on a final energy basis, and remains competitive with imported LPG on a useful energy basis. The financial price of kerosene is higher than its economic cost of YR 0.07 per MJ (US$210/t plus 40% inland markup) on a final energy basis. The economic cost of domestic LPG is considerably less than the economic cost of kerosene; from a national economic standpoint, domestic LPG should be encouraged over kerosene.

Table 3.8: REGIONAL RETAIL KEROSENE PRICES (YR/li)

Region	Urban Price	Rural Price
Sana'a	3.84	5.12
Coastal	3.00	4.97
Northwest	N.A.	4.54
Southern	4.99	4.64
Central	4.09	5.25
Northeast	5.42	5.49
N. Governorates Average	3.97	4.89
N. Governorates average for all locations: 4.86		

Source: University of Sana'a Survey #1.

3.27 **Electricity** prices vary considerably by whether one is connected to the YGEC grid or instead purchases power from a private generator. YGEC connection fees are YR 2,000 for single phase and YR 3,000 for three phase power. Electricity is priced at YR 1.50/kWh in rural areas and YR 1.10/kWh in urban areas. Prices for privately produced power are much higher. Most households purchasing private power pay a monthly fee for each type of appliance they have. Based on these fees and appliance stocks and utilization, the average price of privately produced power is YR 5.93/kWh. The prices of YGEC and privately produced power are not comparable in that the level of service each source provides is different. YGEC power is available 24 hours per day, while private power is available only 5 to 6 hours per night and is used for only the most important, relatively low-power services such as lighting. The light private power price should not be construed as the consumer's willingness to pay for 24 hour per day service, or for any but the most basic, low power service.

3.28 Energy prices are summarized below in Table 3.9, and suggest the following conclusions:

(a) On a final energy basis, firewood, kerosene, and LPG are competitively priced. However, when end-use efficiencies are taken into account kerosene and LPG are less costly than firewood;

(b) The Government's official pricing scheme for kerosene and LPG is ineffective; markups in the LPG trade, after taking into account transportation costs, are higher than in the fuelwood trade, where supply is relatively unconstrained at the present time. The high cost of LPG and the high markups are facilitated by constrained LPG supply, a high willingness to pay, and a poor distribution network; and

(c) The economic cost of domestic LPG is far less than that of kerosene.

Table 3.9: FUEL PRICE SUMMARY

Fuel	Official Price (physical units)	Retail Price (physical units)	Retail Price YR/MJ (final energy)	Retail Price YR/MJ (useful energy)	Economic Cost YR/MJ a/ (final energy)
Firewood	N/A	YR 1.85/kg	0.11	1.10	N/A
Charcoal	N/A	YR 7.49/kg	0.25	1.00	N/A
LPG	YR40/bottle b/	YR 64/bottle	0.13	0.26	0.04 c/
Kerosene	YR 2.30/li	YR 4.86/li	0.14	0.28	0.07

a/ Assuming an exchange rate of YR9.75 = US$1.
b/ A bottle is nominally 12.5 kg, but actually contains 10.7 kg on average.
c/ This assumes domestically produced LPG, not imported LPG.

3.29 Naturally, the cost of end-use equipment is often as important as the cost of fuel itself for determining the affordability of switching to particular fuel. For instance, LPG is relatively cheap in the Tihama, but the low incomes of households in that region seem to prevent fuel switching, since they do not allow households to purchase the necessary equipment. Approximate prices for several types of end-use equipment are given below in Table 3.10. LPG appliances typically are the most expensive. Empty LPG bottles, like the fuel itself, are sold for far more than their official deposit of YR 150. Nonetheless, LPG remains a preferred fuel.

Table 3.10: END-USE EQUIPMENT COSTS, 1987

Equipment	Price Range, YR	Typical Price, YR
LPG metal tannur	1300 - 2500	1500
12.5 kg nominal LPG bottle	300 - 1000	400
LPG burner ring	200 - 700	350
Traditional wood tannur	100 - 200 (rural)	150 (rural)
	300 - 600 (urban)	350 (urban)
Kerosene pressure lamps		500
Kerosene wick lamp	50 - 250	0.25 li: 60
		0.50 li: 200
Mawgid charcoal brazier		150
Incandescent bulbs		5
Fluorescent lamps		20W: 25
		40W: 30
Fluorescent fixtures		20W: 125
		40W: 200

Source: University of Sana'a survey #1 and mission observations.

Household Expenditure on Fuels

3.30 On average, Yemeni households in the northern governorates spend approximately 7.6% of their family budget on fuels 8/. This is typical of many developing countries. Disaggregating household expenditure data by expenditure quartile and rural/urban location provides additional insights into the structure of household energy consumption in the northern governorates.

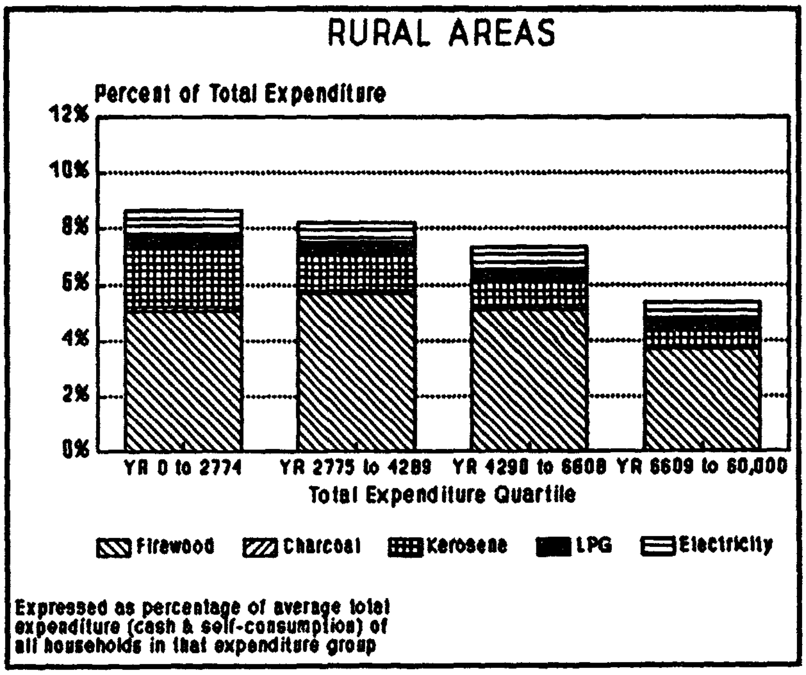
3.31 Figure 3.2 shows household fuel budget shares by rural/urban location and expenditure group. As expected, in both rural and urban areas households in lower expenditure categories spend higher proportions of their budget on fuels, 9 to 10% in the lowest categories compared to 5 to 6% in the highest categories. This suggests that the changes in fuel pricing (such as an increase in fuelwood prices due to resource depletion) would have the greatest impact on those who could least afford it, the low expenditure households.

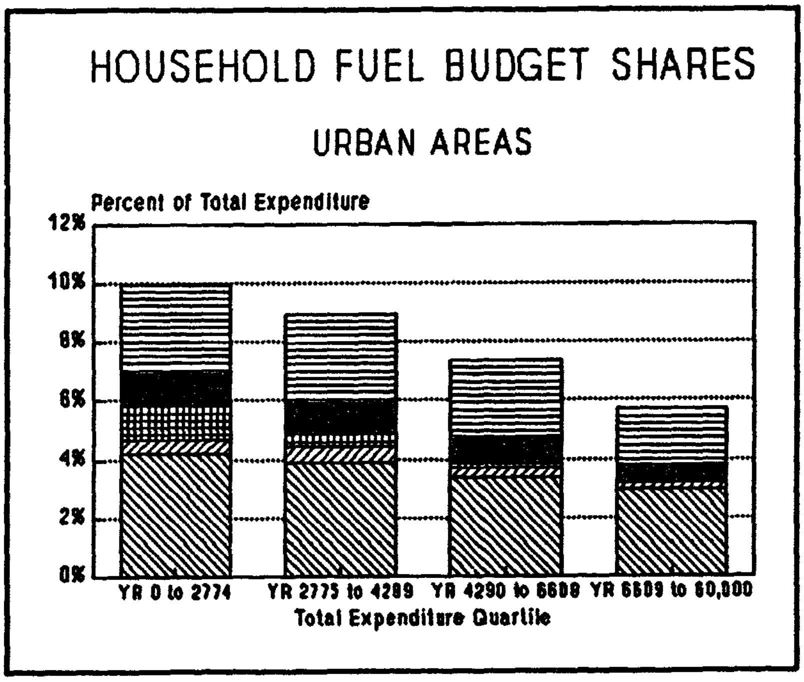
3.32 As in the regional and household sector energy balances, firewood is the predominant fuel in expenditure terms as well. Interestingly, the firewood budget share is fairly consistent across all expenditure categories, indicating the prevalence of traditional bread baking even in urban high expenditure households. Likewise, the LPG budget share is also consistent over all expenditure categories; unlike many developing countries and despite the constrained supply, LPG is not only a "rich man's fuel." This observation is consistent with the relatively low expenditure elasticities, i.e. less than 0.5, for LPG consumption which were derived from the CPO Family Budget Survey. These low elasticities and the uniform budget shares across expenditure groups may be due to the following: (a) Even with high markups, LPG is priced competitively with other fuels, so that low and high expenditure groups alike have no disincentives towards LPG use; (b) the inflow of remittances may allow households to afford the initial cost of fuel switching easier than in many countries for low expenditure groups; (c) the unavailability of low-cost baking appliances results in rapid saturation, even in high expenditure households, and (d) supply constraints affect all expenditure groups, and do not allow the income effect to be discussed more clearly.

3.33 Whereas fuel budget shares are fairly uniform across expenditure categories, the most striking differences occur between rural and urban groups. Charcoal expenditure is insignificant in rural areas, most likely because of the greater use of embers from the firewood used in tannurs in rural areas. Kerosene consumption, and hence expenditure, is greater among those low expenditure households where electricity is used less, and much greater in rural areas where intermittent private generation is the dominant mode of power supply for all expenditure groups, necessitating the use of kerosene for lighting when the power is off. Although LPG budget share is consistent across expenditure categories, the share is much larger in urban areas where baking is less frequent and LPG more readily available and cheaper. Similarly, the electricity budget share is consistent across expenditure categories, reflecting the widespread use of electricity in both rural and urban areas; however, despite the cheaper prices associated with YGEC power, the share is far greater in urban areas and actual consumption is proportionally much greater than in rural areas. These differences in rural and urban consumption patterns for even high expenditure groups are most likely due to the intermittent generation provided by private sources, which does not allow the use of refrigerators, air conditioners, and other appliances which may operate 24 hours per day.

8/ *The fuels accounted for include firewood, charcoal, kerosene, LPG, and electricity; dung and residues are not included. "Family budget" refers to the value of total cash expenditure plus the market value of own-consumption of goods produced, grown, or collected by the household.*

Figure 3.2: FUEL EXPENDITURE BY LOCATION AND GROUP





3.34 In fact, the household budget for all energy-related expenditure is somewhat higher than expenditures for fuel alone. These can be significant, depending on fuel availability, income level and energy preferences. For example, an urban household might purchase an LPG tannur (YR1800-2000), electric appliances, lightbulbs and a kerosene primus stove, all of which might add up to annualized energy equipment costs of over YR 1000. Rural equipment costs are of a lower order because fewer appliances are used and tannurs are less costly than in the cities. The major exception would be for households which purchase their own generators, though this cost would not be charged to the household budget if power is sold to neighbors.

Household Fuel Preferences

3.35 In addition to the previous section on energy-related behavior, the household fuel marketing surveys generated information on consumer preferences for different household energy sources and gave some indication as to how residential consumption patterns might change with price increases. In Table 3.11, preferences are examined by expenditure category. The key inferences that can be drawn from these opinions are: (a) LPG is the preferred substitute for wood at all income levels, (b) the majority of consumers would retain their primary fuel if prices rise, and (c) kerosene is not a preferred substitute fuel, probably because it cannot be used for the most important household energy end-use - baking bread.

3.36 More specifically, it is worth observing that fuel utilization and preferences are fairly consistent across all expenditure groups. The majority of households also stated that they would not switch fuels if prices increased, and this too holds across expenditure groups. LPG consumers are the most loyal, indicating the durability of LPG market penetration which has already occurred. Kerosene demand does not exhibit such resilience, suggesting the status of a less preferred fuel and hence limiting its potential as a substitute fuel. For instance, though wood consumers are loyal, over one-third would make the transition to LPG when wood becomes more expensive, with kerosene forming a secondarily preferred fuel. Results were also disaggregated by household location (rural or urban). Slightly more rural households (35%) would be willing to switch fuels if prices rise compared to their urban counterparts (29%). If LPG prices rose, the first choice for both urban and rural dwellers would be to continue using LPG but more rural consumers would switch to fuelwood while urban users preferred kerosene. For kerosene users who would switch fuels with a price hike, more rural households would move down to fuelwood while urban consumers would move up to LPG. While 61% of rural households would continue to buy more expensive fuelwood, only 35% of urbanites would do so, with 38% switching to LPG and 27% to kerosene.

Energy Decision-making and the Role of Women

3.37 Nearly three-quarters of Yemeni women over the age of 10 are economically active, mostly in agriculture and livestock herding. Women may acquire personal income through inheritance (e.g. land, cattle, jewelry), cattleherding on a share-basis with the owner, purchase and resale of sheep, goats and chickens, sale of fodder and dairy products, handicraft production or sale of baked bread. Also, a substantial number of women manage their own lands and property. They also have custody of traditional forms of savings and "liquid capital" like grain stores, cattle and jewelry which can be sold when there are economic problems. Rural women are typically not veiled and play an important role in agriculture while women in the cities are veiled and generally do not engage in agricultural and market activities. A sizable number of women work in the informal sector, selling home-baked bread, sewing dresses, embroidering, or washing clothes. Their earnings are usually controlled by them, with part being reserved for household expenses.

Table 3.11: FUEL PREFERENCE BY INCOME QUINTILES

(% of households using the fuel specified in that income category, unless noted otherwise)

	Total Monthly Expenditure a/ (YR/month)				
	25-500	501-1258	1259-2000	2001-3000	3000-40200
Mean income	286	926	1704	2581	5325
PRIMARY COOKING FUEL (% in each income category using fuel)					
LPG	23	15	31	42	30
Kerosene	12	14	9	3	10
Fuelwood	65	71	60	56	60
WILL SWITCH IF FUEL PRICE RISES (% of all households in each income category)					
No	59	62	68	76	64
Yes	41	38	32	24	36
PREFERRED SUBSTITUTE FOR LPG IF LPG PRICE WERE TO RISE					
keep using LPG	90	91	82	80	75
switch to kerosene	5	6	5	11	9
switch to fuelwood	6	3	13	9	16
PREFERRED SUBSTITUTE FOR KEROSENE IF KEROSENE PRICE WERE TO RISE					
keep using kerosene	19	59	67	67	67
would switch to LPG	24	2	5	33	2
would switch to wood	57	39	28	0	31
PREFERRED SUBSTITUTE FOR FUELWOOD IF PRICE OF WOOD WERE TO RISE					
keep using fuelwood	57	58	63	73	58
would switch to LPG	36	32	31	19	31
switch to kerosene	8	8	6	9	10
would switch to dung/ ag. residues	0	2	0	0	0

a/ Expenditure is based on total cash and farm expenditure, with 20% of all Yemeni households falling into each category.

Source: University of Sana'a survey #1.

3.38 Generally, it is the man's duty to purchase basic household furniture and equipment (including stoves and tannurs), food, clothing, water and fuel. The collection of fuel and water is the responsibility of rural women and constitutes one of their most demanding tasks. Decision-making about the choice of energy equipment and fuels is, however, more complicated than this simple division of labor and power.

3.39 From the University of Sana'a surveys, it is women who mostly decide which cooking equipment should be purchased (66% of households) but, in most cases, the husband is responsible for actually purchasing the equipment (81% of households). In urban Sana'a, husband and wife generally make a joint decision on energy equipment purchases and, in rural areas, women have greater decision power in this respect than in cities. Installation of the tannur in the kitchen is done by women in 65% of the cases, by the husband (10%) or by an artisan, the seller, a friend or another family member (25%).

3.40 While women are primarily responsible for collecting wood, it is the husband's duty to purchase firewood and charcoal. In rural Taiz and Hodeida, husband and wife jointly share the responsibility for purchasing fuelwood. LPG is generally bought by the male head of the household. The Yemeni family depends on the woman or women of the household (the mother, grandmother, wife and daughter(s) are all expected to participate) for its cooking needs and, hence, they control the use of cooking fuels and equipment.

3.41 Naturally, new and improved cooking appliances must take into account women's preferences and needs. Consumer acceptance testing of new or improved appliances, such as LPG tannurs, must involve women. However, the above observations suggest that promotion and marketing of fuels and appliances, even those used for cooking, must be directed at men as well as women.

IV. WOODFUEL DEPLETION: ISSUES AND OPTIONS

4.1 Three key household energy issues emerge from the Household Energy Strategy Study:

(a) the likelihood and consequences of fuelwood depletion;

(b) the potential role for LPG and impediments to LPG substitution; and

(c) the widespread use and economic costs of electricity in rural households.

In the three following chapters, these issues are discussed in turn and possible strategies are proposed.

Fuelwood Depletion

The Resource Base and Supply System

4.2 As no reliable data existed on fuelwood availability in the northern governorates, a woody biomass resource assessment was undertaken as part of the Household Energy Strategy Study. Measurements of trees and shrubs were made in all of the land-use zones identified in the 1983 USAID/YAR Land-Use Inventory. Fifty-three plots were randomly selected from the 14 non-urban land classes identified in the inventory. At each site, trees and shrubs were classified, all woody biomass was measured, evidence of wood utilization was sought and the local environment was described. The data collected were converted into estimates of woody biomass growing stocks (both as total above-ground volume and wet weight) using equations developed in areas of North East Africa with similar ecological conditions. Wood productivity was estimated using Clement's equation 9/ and local precipitation data, with adjustments for frost and occult precipitation. Time series analysis of aerial photographs for the Jebel Bura area, commonly thought of as one of the last forest regions in Yemen, was carried out in order to assess actual long-term changes in standing stocks. No quantitative estimate was made on the stock or productivity of roots. Dead wood stocks were evaluated along with the mechanisms by which these stocks are replenished. Interviews were held in seven wood markets throughout the northern governorates and information gathered during these interviews was combined with data on woody biomass stocks to identify fuelwood supply regions. These findings were reinforced with observations of fuelwood transport along major roads. Gap analysis was used to assess the long-term sustainability of woody biomass supplies. Data on current stocks (both live and dead wood), woody biomass productivity and household consumption (both current and projected, to account for population growth) were combined. A more detailed description of the assessment methodology is presented in Annex 4.

9/ *Food and Agriculture Organization, Etudes sur les volumes et la productivite des peuplements forestiers tropicaux. 1: Formations forestieres seches, 1984, Etude FAO, Forets 51/1. Clement's equation is a regression relating biomass productivity to annual precipitation based on studies on low rainfall areas (<800 mm/yr) in the Sahel.*

4.3 The current level of total above-ground woody biomass growing stock in the northern governorates was calculated from data gathered during the assessment and is presented in Table 4.1. For each land-use unit, the mean and mid-range values were multiplied by the areal estimates to obtain weighted totals of above-ground stocks for each unit. These were then summed to obtain the total stock for the region. The mean weight was chosen over the median value as it is likely to give a better representation of the variability of woody biomass in any land-use unit. Natural wood productivity potential was then calculated, adjusted for occult precipitation and frost on a regional basis. The weighted average for the northern governorates was calculated to be **0.38 t/ha/year**, or 4.7 million air-dry tons (13% of standing stocks) annually. For mature natural woodlands, one would typically expect productivity to be on the order of 5 percent of standing stocks rather than 13 percent. This suggests that if the assessments of standing stocks and productivity are accurate, biomass resources in the northern governorates are intensively exploited, and perhaps being rapidly depleted. In any case, using the 5% productivity value as a lower bound, the current annual productivity of above-ground woody biomass in the northern governorates is probably in the range of **1.8 to 4.7 million air-dry tons.**

Table 4.1: ESTIMATES OF LIVE WOOD RESOURCE BASE

Parameter Used	Live Wood Growing Stock
Median values:	
Total above-ground wet weight	71.72 million tons
" " dry weight*	48.05 " "
Mean values:	
Total above-ground wet weight	53.84 million tons
" " dry weight*	36.07 " "

* Air-dry weights were calculated using a conversion factor of 1.49 dry t per wet t.

Source: Millington, "YAR Household Fuel Marketing Study, Phase 2: Woody Biomass Resource Assessment", ESMAP, 1989.

4.4 Traded fuelwood consists not only of cut live wood, but also roots and dead wood. Roots appear to be a relatively insignificant portion of the trade, and what roots are traded are more properly classified as dead wood, since they have for the most part been washed out of *wadis* by flooding rather than dug up by tree cutters. Dead wood is an important, but declining component of the fuelwood trade. In several markets, fuelwood wholesalers indicated during interviews carried out during the study that live wood did not even appear in fuelwood markets until as recently as 1984. Mission visits to the markets of Al-Harf and Al-Amar revealed that about half of the fuelwood offered for sale consisted of dead wood. This dead wood was often encrusted with dried mud, suggesting that it had been washed out of *wadis*. A separate estimate of dead wood stocks was made based on data recorded from plots during the inventory. The weighted average total for the region is **1.2 million tons.** However, the contrast between the relative abundance of dead wood in the markets and its relative dearth on sample plots suggests that deadwood is intensively harvested. As noted earlier, it is probably the largest source of cash income for bedouin. Nothing is known of the rates of tree and shrub mortality in the different land-use units so it has not been possible to account for this in the calculation.

4.5 As noted in paragraph 3.18, fuelwood is a highly commercialized commodity; approximately 40% of firewood (by weight) consumed by households is purchased. Roughly two-thirds of households collect at least some of their firewood; on the other hand, nearly half of all households buy at least some of their wood. To better develop a picture of the fuelwood supply system, data were analyzed to identify the wood surplus, equilibrium and wood deficit areas of the northern governorates. The following information is depicted in Figure 4.1: (a) known fuelwood supply areas, (b) possible fuelwood supply sites, (c) charcoal production zones, (d) regions which produce construction timber, (e) the location of wood markets, and (f) known and possible fuelwood supply routes. Referring to Figure 4.1, the **wood surplus regions** (where current production exceeds local demand) are: the mountains and *wadis* to the east and west of the Saada-Sana'a road (in the west, this area extends down into the escarpment but it is unknown how far the area reaches to the east); the lower escarpment region, e.g., to the east of Hajja, the Bani Sad region, and between Jebel Bura and Jebel Raymah; the southern Tihama; the northern Tihama; Wadi Al-Jawf and tributary wadis; and Wadi Arhana. The **areas in equilibrium** (where current demand is met by local supply) are: the higher parts of the Western Highlands, e.g., around Hajja and Manaka; the low population density rangelands, cultivated volcanic areas and cultivated highland plains adjacent to mountains in the Central Highlands; the area south of Taiz around Al-Turbah; and the area around Al-Beida. **Wood deficit areas** (where local demand can only be met by wood importation or fuel-switching) are: in the Central Highlands around densely populated areas and in lower-density areas distant from the mountains; the southern cities of Ibb, Jibla and Taiz; and the low tree density areas on the Tihama, e.g., around Al-Marawa'it.

4.6 The main areas of wood markets which sell fuelwood to be transported to the wood-deficit areas are found in four distinct clusters in:

(a) Saada and Sana'a governorates (on the Saada-Sana'a road at Al-Harf, Al-Amar, Al-Hayrah, Huth, and Suq Al-Talh/Saada);

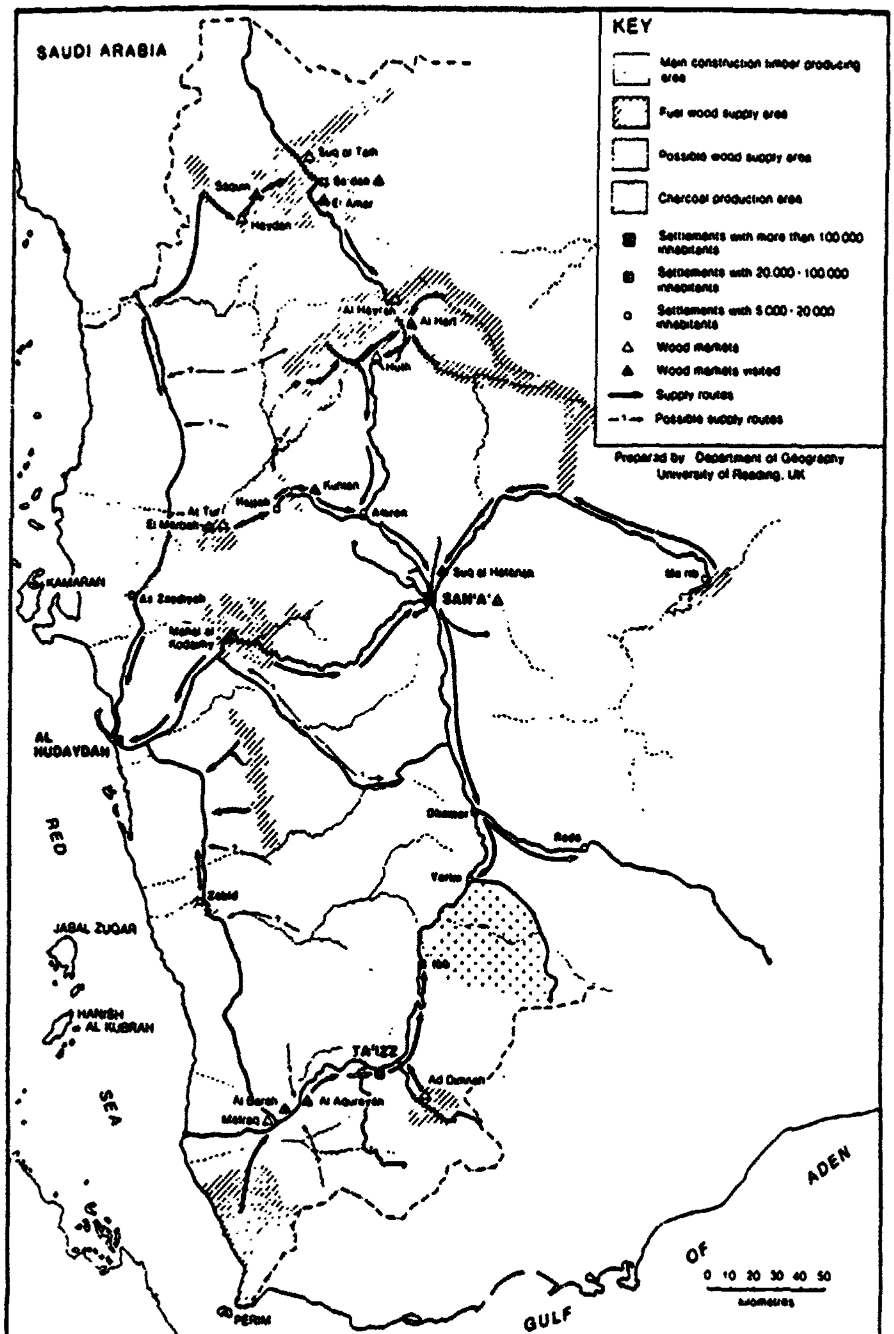
(b) Hajja and Hodeida governorates (on the Hajja road between Al-Merba and Al-Tur);

(c) Hodeida and Al-Maweet governorates (on the Hodeida-Sana'a road in the Bani Sad region, e.g., Mahal Al-Kodaimy); and

(d) Taiz governorate (on the Taiz Mokha road at Al-Barah, Al-Ayrayeh, Hasi Ben Alwan, Jebenara, Mafraq and Al-Hamali, and at Al-Dimnah on the Taiz-Aden road).

All of these markets are found in, or adjacent to, wood supply areas. There is some trading between markets within each cluster. For instance, some of the wood at the Saada market comes from Al-Harf, and some of the wood at Al-Harf comes from Al-Amar. However, the local trade is probably small and the bulk of the wood in these markets is exported from the supply areas.

Figure 4.1: WOOD SUPPLY AREAS OF THE NORTHERN GOVERNORATES



Source: Millington, "YAR Woody Biomass Resource Assessment," ESMAP, July 1989.

4.7 Each of these clusters of wood markets has a discrete supply area. For the **Saada and Sana'a governorate** markets, these are (a) the mountains and *wadis* to the east and west of the Saada-Sana'a road, and (b) the woodlands in western Wadi Al-Jawf. For the **Hajja and Hodeida governorate** markets, wood comes from the lower escarpment region to the east of Hajja. For the **Hodeida and Al-Maweet governorate** markets, supplies come from the lower escarpment region in the Bani Sad region. For the **Taiz governorate** markets, fuelwood is collected from the southern Tihama and the area around Al-Dimnah. The most frequent destinations for fuelwood purchased at these markets are:

(a) the farmed areas of the Central Highlands south of Huth, including the cities of Amran, Dhamar, Raydah, Sana'a and Yarim;

(b) the main southern cities and towns (Ibb, Jibla, and Taiz); and

(c) on the Tihama around Hodeida, in the areas of intensive agriculture, and in some of the bare and rangelands areas.

These, then, are the centers of high demand and lower supply, i.e., the wood-deficit areas.

4.8 The charcoal-producing area extends northwards from Wadi Surdud to Wadi Mawr, and is centered around Al-Zaydiya. The area has been producing charcoal since before the Hodeida-Jizan road was built, and prior to the road, charcoal was transported to Hodeida by camel. Semi-pit kilns are used, with tops constructed of sheet metal and sand; efficiencies of such kilns are generally good, typically between 20 and 25%. Charcoalers often dig up roots as well as cut down trees. The concentration of charcoal-making in this area leads one to suspect that trees are being exploited at a far greater rate than their apparent productivity would allow, and that the practice of removing roots as well accelerates topsoil erosion. However, site visits suggested tree regeneration at rates far greater than regional productivity estimates. Although there is mobile sand in this area, it cannot necessarily be used as evidence of sand encroachment due to deforestation from charcoal-making. Furthermore, given the limited use of charcoal in Yemen, it is unlikely that there will be any large-scale increase in charcoal production in the near future unless rapid interfuel substitution for firewood reduces the amount firewood embers available for waterpipes. (Although charcoal exports to Saudi Arabia have not been quantified, they too are unlikely to increase).

Fuelwood Consumption and Resource Sustainability

4.9 Standing wood stocks may be reduced through agricultural land clearing, fuelwood extraction, or extraction of construction timber. (It is assumed that grazing and browsing decrease productivity, but do not directly reduce existing standing stocks). Most of the construction timber used in Yemen is imported; woodlots which provide local timber have not been included in the biomass resource assessment, so timber extraction is not an issue in this analysis. Agricultural land clearing also does not have a significant effect on standing stocks in Yemen except perhaps in limited areas of the Tihama. Yemen has been settled for thousands of years; most potential agricultural land has already been exploited. In fact, when seedlings appear on cultivated land in the Tihama, and perhaps elsewhere in Yemen, they are not removed. Trees are a valued resource and crops will be planted around the seedling. Therefore, the major pressure on wood resources comes from fuelwood extraction. Although most productive land in the northern governorates is privately owned (there are few arable common lands) and land holders seem to practice good biomass resource management, traditional resource management methods may be breaking down due to recent social changes (export of male labor, receipt of overseas remittances, etc.) and increasing woodfuel consumption pressure.

4.1 As suggested in Table 3.2, annual firewood and charcoal consumption vary between rural and urban areas, and between regions according to: (a) regional cooking habits, including the use of prepared foods from bakeries and restaurants, (b) the cost and availability of fuelwood, (c) regional income, and (d) the cost and availability of substitute fuels. Annual household consumption of firewood by rural and urban areas for each region is presented in Table 4.2.

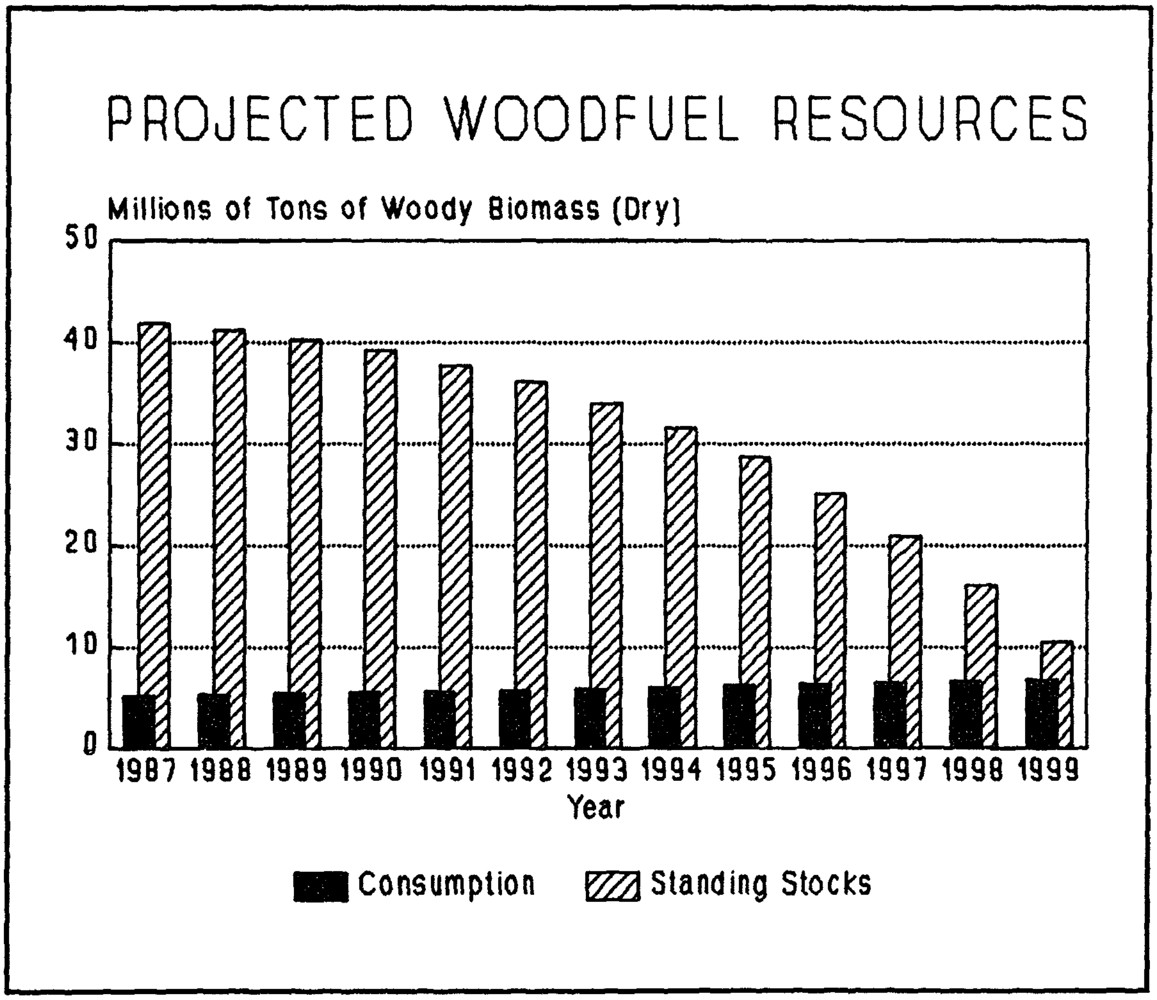
Table 4.2: AVERAGE ANNUAL FIREWOOD CONSUMPTION BY REGION (kg/yr/user household)

	Urban		Rural	
	% Users	User Average Consumption	% Users	User Average Consumption
Sana'a	52.5	1228	97.6	5997
Coastal	8.3	(1854)	97.2	3436
Northwest	77.0	(4267)	99.1	4309
Southern	47.4	2201	97.5	2604
Central	81.7	2881	98.0	4041
Northeast	64.1	(3904)	98.4	4679
N. Governorates Average	44.6	1916	97.8	3879
National average for all locations: 92.4% users consuming 3675 kg/yr				

() indicates that figure may be based on too few cases to yield reliable results.
Source: University of Sana'a survey #1 and CPO Family Budget Survey.

4.11 Woodfuel consumption in 1987 totaled about 5.2 million t of air dry wood, consisting of nearly 4.8 million tons of firewood, 260,000 t of wood for commercial charcoal, and 173,000 t for household charcoal. Wood availability was estimated to be nearly 42 million t, consisting of 36 million t of standing stocks, 1.2 million t of dead wood, and an annual increment of 4.7 million t. A simple projection of woodfuel resources and consumption is given in Figure 4.2. Despite the intensive tree management practices observed throughout the northern governorates, fuelwood resources could be depleted by the turn of the century if current trends continue. The cause of this would not be poor resource management per se, but rather increasing demand, which even at the present time exceeds annual productivity. Some caveats regarding these projections are discussed in Annex 4. Most importantly, as resources are depleted, consumption will decline due to scarcity and higher prices. These control mechanisms will, however, have detrimental impacts on household welfare, as discussed in the following paragraph.

<u>Figure 4.2</u>: PROJECTED FUELWOOD STOCKS



4.12 In an effort to validate these projections, the rates of wood exploitation between 1973 and 1987 were examined in the Jebel Bura area. From this there is corroborating evidence that consumption already greatly exceeds productivity. Analysis of aerial photographs taken 15 years apart indicates that some of the best woodland areas in Yemen have undergone a net *reduction* in standing stocks equivalent to 0.14 t/ha/year (air dry). The projections are further supported by market observations which indicate that dead wood has been increasingly replaced with cut live wood at the retail level. The additional evidence cited here of decline in standing stocks suggests that while the exact year of depletion is questionable, the general trend is not. Suffice it to say that the decline will accelerate once stocks reach 25 to 30 million t, and that without intervention, stocks will decline to a serious level within the next one to two decades. Further work must be done to better estimate woody biomass standing stocks and productivity in Yemen. In the meantime, energy policies and programs must be designed on the assumption that current fuelwood supply and consumption patterns are unsustainable.

4.13 A decline in woody biomass stocks is not a problem in and of itself. Rather, the issue is the effect this decline will have on people. In Yemen, a decline in standing stocks could have two effects on people: indirectly, through environmental degradation, and directly, through welfare impacts resulting from the increases in woodfuel prices which will likely accompany a reduction in supply.

Environmental Effects

4.14 Fuelwood exploitation in Yemen is undoubtedly a contributing factor to environmental degradation but it is not the sole cause of environmental problems. Use of wood energy must be seen within the context of the Yemeni environment as a whole in order to understand that large-scale afforestation by itself is not likely to be the answer to reversing ecological decline. Furthermore, as woody biomass supplies diminish over the remainder of the century, the most immediate problem will not be a widespread environmental disaster but, rather, a decline in the welfare of individual households caused by an increased use of inferior fuels, higher woodfuel prices than at present, a lower per capita consumption of cooked food, and/or less space heating during the cold season. The following paragraphs review five major areas of environmental concern related to woody biomass exploitation: (a) soil erosion and terrace degradation; (b) groundwater recharge; (c) wind erosion and sand encroachment; (d) microclimatic change; and (e) declining agricultural productivity.

4.15 Soil Erosion and Terrace Degradation. The dominant environmental conditions in many parts of Yemen (short-duration, medium-intensity rainfall, silt-loam and silty clay-loam soils, steep slopes, and sparse vegetation cover) mean that rates of soil erosion are extremely high, ranging from 60 to 200 tons/acre per year. To counter the soil erosion hazard and manage spate (*sayl*) irrigation, impressive stone-wall terraces have been built in many parts of the Western and Central highlands for thousands of years. Providing they are maintained each year, these terraces are very effective soil conservation measures. In a number of areas of the country, terraces have recently been abandoned, initially because of the exodus of migrant labor to the employment opportunities in the Gulf and, more recently, because of migration to towns and cities. The lack of annual maintenance caused by this abandonment has led to terrace degradation, increased rates of soil erosion, more frequent flash flooding, and sediment-rich floodwater. This causes soil loss from previously terraced areas, less-predictable and controllable spate irrigation, and increased risk of severe flooding. Siltation in reservoirs and irrigation systems downstream is also increased.

4.16 In erosion-prone areas with no terraces, soil erosion is pervasive. In all of the plots sampled in the woody biomass resource assessment, there was evidence of soil erosion by water, even in the escarpment woodlands where there was a significant amount of rilling and sheetwash under the trees. From observations, it is apparent that the sparse vegetative cover neither intercepts significant amounts of rainfall nor creates an effective barrier to surface runoff. Roots hold the soil together but often, plant spacings are so wide that the amount of soil bound by roots on a slope is minimal.

4.17 Although uncontrolled exploitation of the remaining woody biomass resources in Yemen will no doubt lead to increased soil erosion and the consequent downstream damage, afforestation alone will not significantly reduce the current high rates of soil erosion. In agricultural areas, the most effective method of controlling erosion is well-maintained terracing and any policies which encourage terrace agriculture will be more effective than woodland management or afforestation in reducing erosion in farmed areas. However, terrace maintenance could involve agroforestry practices, particularly tree planting along terrace walls to bind the soil at the terrace edges. In non-agricultural areas improved rangeland management, particularly livestock management, will likewise be more effective than afforestation in arresting soil erosion.

4.18 Groundwater Recharge. Evidence from wells in the Dhamar region shows that groundwater levels have been dropping by 30 cm/yr for the past decade. Three factors could account for this decline:

(a) increased groundwater extraction rates due to greater diesel pump use;

(b) a reduction in available rainfall; and/or

(c) decreased soil infiltration rates in groundwater recharge areas due to increased surface runoff associated with the removal of vegetation.

Given the drought conditions which much of Yemen has experienced during the past several years and the expansion of irrigated agriculture (due to the increased opportunities to purchase pumps because of remittances from Yemenis working abroad), the reasons for a decline in the groundwater levels can mainly be attributed to (a) and (b).

4.19 It is unlikely that the current levels of groundwater extraction can be significantly reduced in agricultural areas and, therefore, the solution to this problem appears to lie in increasing infiltration in groundwater recharge areas. This involves either managing the existing vegetative resources in an effective manner or altering land-use practices. The objective is to reduce surface runoff and increase retention of water on the soil surface (depression storage) long enough for it to infiltrate into the soil. Increasing the infiltration capacity of the soils is most effectively achieved by having a well-developed vegetative cover with extensive root systems. Alternatively, a series of normal or above-normal rainfall years would also ameliorate the effects of continued high levels of pumping.

4.20 Efforts to expand infiltration capacity may or may not involve woody biomass management because in many recharge areas the woody biomass resources are very low and better range management may be the solution to the problem rather than afforestation. Nevertheless, the groundwater depletion problem is partly a function of woodland conversion and possibilities for woody biomass management and afforestation exist within the context of this environmental problem.

4.21 Wind Erosion and Sand Encroachment. Sand encroachment and the consequent loss of agricultural land is a problem in many parts of the Tihama and on the Eastern plateau. Large expanses of mobile sand exist in the Tihama and around Mareb. This problem may have grown in the Tihama due to tree clearance for charcoal production but most of the expansion is probably due to past agricultural landclearing and to overgrazing. A more common situation in these areas is a sparse tree and shrub cover. In such areas, a high proportion of bare soil is exposed which increases the potential for topsoil to be easily eroded by wind.

4.22 In these areas of bare soil, topsoil is mobilized due to strong winds and the aridity of the area. The two most cost-effective and commonly-used solutions to the problem of sand encroachment are stabilization of sand by mat-like vegetation (especially grasses) and the planting of windbreaks to reduce wind velocities. Windbreaks are uncommon in the central and northern Tihama regions but, in other parts of the Tihama and around Mareb, there is currently an emphasis on establishing windbreaks and sand stabilization to counter wind erosion and sand encroachment. Windbreaks not only provide a means of reducing wind velocity, they also have roles in microclimate amelioration, provision of leaf fodder and browse, supply of poles for viticulture, and maintenance of agricultural production. From the energy viewpoint, they can provide a source of harvestable fuelwood.

4.23 Microclimate Degradation. Good tree cover provides several microclimatological advantages in arid and semi-arid regions: (i) decreased daytime temperatures, (ii) shade (less direct insolation), (iii) increased humidity and occult precipitation, and (iv) decreased wind velocity. The value of microclimate amelioration has been know to the coffee farmers of the Western highlands for a long time. Tall trees with wide crowns were left when fields were originally cleared or specifically planted to shade coffee bushes. Evidence suggests that these shade trees are carefully managed as timber resources, with some ancillary fuelwood use. Cutting extends only to pollarding useful branches from the crown.

4.24 Trees could be introduced to other agricultural areas to provide a suitable microclimate for crops which would benefit from such conditions. While this is done to a certain extent in the southern highlands and on the plains of the northern Central highlands, it could be introduced into the plains of the Central highlands south of Huth. Apart from the advantages of microclimate improvement, there is the potential for wood harvesting from shade trees for a variety of end-uses, including fuelwood.

4.25 Declining Agricultural Productivity. The problems outlined above point to excessive wood exploitation adversely affecting agricultural productivity through:

(a) loss of fertile topsoil (wind and water erosion, sand encroachment, and terrace degradation);

(b) declining groundwater resources; and

(c) microclimate deterioration which affects both plant metabolism and soil-forming processes.

In addition, browse and grazing resources are directly affected by the exploitation of certain trees and shrubs. It appears that a strong economic argument for managing woody biomass resources and, in certain cases, afforestation, may be to maintain or increase levels of agricultural productivity in addition to maintaining fuelwood stocks.

4.26 Furthermore, although dung is still mainly used as a manure and the first use of crop residues after harvest in most areas is for livestock, further reductions in the amounts of woody biomass available to rural communities will lead to diversion of dung and crop residues to fuel. Evidence from neighboring Ethiopia suggests that this will result in a decline in crop production unless fertilizers are imported and a decline in livestock production due to the shortage of productive rangelands, i.e., grasses and browse.

4.27 Human Health. An additional issue of environmental concern, though not related to fuelwood depletion, is the impact of cooking practices on household health. Typically, cooking in Yemen is done indoors in a cramped and smoky kitchen. In other countries with similar cooking practices, e.g., India, indoor air pollution from fuelwood combustion has been linked to higher incidents of respiratory infection, particularly in women and children. In developing countries, respiratory ailments are a major cause of infant mortality and contribute to significant reductions in life expectancy. Therefore, household energy consumption patterns may have important consequences for the overall health of the Yemeni population.

Welfare Impacts

4.28 Although the environmental impacts of fuelwood depletion are serious, the direct impacts on household welfare may be greater and more immediate. Increasing wood scarcity would result in higher woodfuel prices which households would likely adjust to by changing their dietary and cooking habits, using less desirable fuels, or spending more cash or collection effort on woodfuels. It is difficult to assess the changes in dietary and cooking habits that may occur and the consequences of such changes. It is also difficult to assess the consequences of increased use of lower quality fuels such as dung and residues, since the role of these by-products in agriculture in Yemen is not well understood; nonetheless, some comments are made below. However, a cross-sectional analysis of the data collected in the course of this study can provide a better understanding of the welfare effects of such scarcity in terms of the additional financial burden that would be placed on the household budget.

4.29 In this regard, the governorate of Dhamar can provide a picture of what the future may hold in store for the rest of Yemen if actions are not taken to facilitate the transition to LPG. Dhamar is commonly (and correctly) thought of as an area where fuelwood resources have already been seriously depleted. Nonetheless, the vast majority of households in Dhamar continue to use wood, as in most of Yemen. Households in Dhamar which use only wood spend more than twice the northern average on energy and those which use a mix of wood and LPG spend 35% more on these than the governorate average. This appears to have induced many more households in Dhamar to switch to LPG when compared with regional usage, despite the initial high cost of switching.

4.30 What would be the impact on household welfare if the fuelwood situation in Dhamar were to spread to the rest of the northern governorates, assuming that the supply of substitute fuels such as LPG was not increased? For the 36% of households which use both wood and LPG, expenditure on firewood might increase about 5%, assuming that the ratio of average expenditure to the average amount of firewood consumed were to reach the level found in Dhamar for the same consumer group. For the poorest households (those who do not use LPG), the situation is more severe. Due to increased scarcity and consequently higher prices, the average amount of firewood consumed would fall to about 2.2 t/household/yr, assuming that the ratio of firewood consumed by households using LPG to the consumption of those who don't reaches the level found in Dhamar. Use of inferior fuels such as dung and residues would likely grow significantly to make up for the lower firewood consumption, as it has in Dhamar. Although consumption of wood would decrease, expenditure would increase by over 60% if the ratio of average expenditure to the average amount of firewood consumed were to reach the level found in Dhamar for that consumer group.

4.31 Aggregating these effects to the regional level, annual household expenditure on firewood would increase by YR 1.1 billion, or an additional YR 820 per household per year on average. Moreover, most of this extra expenditure would be made by those who can least afford it. While this analysis is crude, it illustrates the magnitude of the consequences of continued reliance on firewood by households. This assessment does not take into account the additional household welfare issues of convenience and health benefits accruing from cleaner LPG cooking, nor the increased wood collection times that would result from further depletion.

4.32 Households compensate for the effects of fuelwood depletion in Dhamar not only by spending more on firewood and consuming more LPG, but also by using more dung and crop residues. Cattle are kept near the household and are generally not grazed, while sheep, goats, donkeys, and camels roam the rangelands (which reduces biomass productivity in these rangelands). Consequently, cattle are the major source of dung. The cattle population in the northern governorates is estimated at 1 million head, and assuming 1 ton of dung per head annually implies a dung resource of 1 million t/yr. Currently, nearly one-third of this amount is consumed as fuel, and given that 76% of farms use dung as fertilizer, one can infer that most of the remainder is used for fertilizer. Clearly, increasing the use of dung as fuel will decrease its use as fertilizer, with direct effects on agricultural productivity and farm income.

4.33 Like dung, crop residues also have competing uses, not only as a soil conditioner but also as fodder. Total residue availability is estimated at 2 million t/yr, of which fodder consumption by cattle represents 850,000 t/yr and fuel consumption about 500,000 t/yr. Although the situation may not be as critical as with dung, increasing use of crop residues as fuel may have negative consequences for livestock health and agricultural productivity, which both affect farm income. Information on the current availability and use of dung and crop residues can be found in Annex 5.

<u>Current Policies and Programs</u>

4.34 One strategy for avoiding the environmental and welfare consequences of fuelwood depletion is to increase supply. The Government's basic strategy for forestry development, as reflected in First (1977-81) and Second (1982-86) National Five Year Development Plans of YAR has been to provide a source of seedlings through establishing forest nurseries in strategic locations. Seedlings are issued free or sold at less-than-cost price to farmers for planting on their own lands or to LDC's, the army and youth groups for planting in public places. Limited provision has been made for institution building, forestry training and research. The existing forestry nurseries could produce several million seedlings each year but, in the absence of a concerted extension effort, there is insufficient demand for even the half million actually produced. The aims of YAR's Third Five Year Plan (1987-91) cover provision of qualified forestry staff, management of natural forests, further expansion of seedling nurseries, establishment of legislation, anti-desertification projects, training of extension staff and finding substitutes for fuelwood.

4.35 Forestry operations in regional projects have been limited. The Tihama IV project contained a sand dune fixation/windbreak component which, following several delays, began in 1985. Shortage of finance has delayed establishment of large shelterbelts but establishment of windbreaks by farmers has been successful, with over 200 kms. built to date. The forestry component of the Southern Uplands Rural Development Project (SURDP) II was eliminated by the Regional Authority as lacking priority. The Central Highland Agricultural Development Unit has an active forestry/range management development project in Dhamar. The scope for sand dune fixation in the 1988 Northern Regional Development Authority project was considered but rejected. The Eastern Region Agricultural Development Authority 1988 project will include a sand dune stabilization and afforestation component primarily to safeguard irrigation development and agricultural production. A UNDP-financed sand fixation project, to be executed by FAO, was to begin in the Tihama plains in 1989.

4.36 Bilateral aid projects have also made useful contributions to wood supply development. The German (GTZ) forestry project in Al-Haraz (1980-86) focused on experimental afforestation of abandoned terraces, species trials, training and forestry education. The United Kingdom's agricultural and forestry research project in Dhamar (1981-86) initiated studies in tree plantation establishment for fuelwood, poles, fodder and windbreaks in the Central Highlands. The FAO Fuelwood Development Project, financed by the Swiss, is primarily concerned with institution-building (despite its name). It has financed training for all the Yemeni forestry graduates and technicians from the northern governorates since 1985, established and equipped five new forest nurseries, supported several others with irrigation and equipment, and provided technical assistance. A project aim is to initiate the management of some 15,000 ha. of natural woodland in the fuelwood supply regions. Two Dutch-supported projects -- the Rada'a Integrated Rural Development Project and the Range and Livestock Improvement Project at Dhamar -- have involved management of marginal land. The latter has started a tree planting campaign in 1987, involving 18 nurseries. USAID has undertaken soil and land use surveys and, more recently, made proposals for future management of horticulture.

4.37 After 17 years of forestry interventions, forest management has made only limited progress. The first major constraint to remedying this situation is the absence of firm Government directives on forest management. Effectively, Government-based forest management programs have not been applied to any woodland in the northern governorates and traditional conservation systems are breaking down due to increasing shortages of wood and labor, and rising prices for forest products. The continued absence of a forest law and enforcement mechanism to provide some simple regulation of wood usage is a major stumbling block to organized management. The task of reestablishing the Yemeni woodlands is far too great to be met by afforestation alone; the introduction of management (or reinforcement of traditional tribal laws) of existing woodland demands high priority. At the present, however, there is no readily available database on the extent and status of existing forest, its area, density, species composition or condition. Thus, the introduction of forest development in Yemen is a national priority demanding a national solution and strong central support to translate policy into action. However, the Directorate of Forestry lacks adequate staff and facilities, and has no development plan or programs that address current needs.

4.38 To remedy this situation, the Bank is initiating a forestry component of the National Agricultural Sector Management Project which will fund: (a) institutional development of the central and regional forestry organizations; (b) a survey and plan of action, continued work in the Tihama and Mareb, and research; (c) a national aerial survey and development of simple plans for management of the indigenous forest; and (d) promotion of tree planting by private landowners and LCD's. In addition, the Government is being urged to adopt a forestry policy which recognizes the functions of the forest and the constraints to forest development, develop legislation or reinforce traditional tribal laws in support of the policy, and promote an active implementation program.

Additional Options

4.39 Some additional steps which should be considered are (a) developing an improved woody biomass database on resources and management practices, (b) assessing, and if necessary improving the efficiency and sustainability of carbonization methods, (c) supporting appropriate indigenous management methods, where possible, and (d) developing effective community and household agroforestry progress. These activities should be undertaken, either in parallel with existing and proposed forestry projects, or should be incorporated directly in planned programs, such as the Bank's proposed Land and Water Conservation Projects.

4.40 Information Development. In order to better understand the fuelwood production system so that it can be managed on a sustainable basis, the following activities are envisaged: (a) land-use conversion analysis, (b) detailed investigation of the woody biomass supply mechanism, (c) additional wood inventories, and (d) further research on biomass productivity. The land-use conversion analysis done for Jebel Bura as part of the household fuel study can be extended to other areas of Yemen where time series aerial photography or satellite imagery is available. This should be combined with a ground survey to examine the environmental impacts of deforestation in these areas. This extended analysis can provide a far better appreciation of: (i) the rates of wood loss in different land-use units in Yemen, (ii) the total wood loss over the time period which is considered, and (iii) the processes leading to woodland, shrubland and bushland destruction.

4.41 Only a cursory examination of the wood supply system, including the functioning of wood markets, was conducted during this study. The woody biomass supply mechanisms have not yet been studied in detail. Important aspects of the system which require investigation are: (a) the role of the bedouin in the wood trade; (b) detailed analysis of the temporal trends in wood trading, especially the current decline, to provide a better estimate of the long-term trends in fuelwood supply; (c) the relationship between wood supply mechanisms and areas that are opened up by new road construction; and (d) species preferences. This will provide useful information on how to provide wood suppliers with incentives to engage in better, more sustainable practices.

4.42 To get an improved picture of fuelwood availability, a detailed inventory of the actual and potential wood supply areas (see Figure 4.1) should be undertaken. In these areas, the density of trees and shrubs is very variable. Therefore, a level of sampling is required within these areas which could be best achieved by the utilization of remotely sensed data. If Landsat TM or SPOT-HRV data were acquired for the identified supply areas, those with the highest densities of woody vegetation could be mapped. In the high tree density areas, detailed aerial photography should be taken. This could then be used to (a) construct the sampling plan for the forest inventory, and (b) extrapolate the results of the tree and shrub mensuration exercises carried out by field teams. Trees and shrubs on farmland and less well-wooded rangelands should also be included in the inventory. In addition to providing information on the standing stock of live trees, this wood supply inventory should also pay particular attention to dead wood stocks and their replenishment, and wood productivity. This could be best achieved by combining measurements of dead wood on sampled field plots with an assessment of tree mortality-environmental disturbance relationships (e.g., droughts, extensive flooding, widespread disease, forest fires, etc.).

4.43 There is an urgent need to investigate wood productivity in Yemen. To gain a better idea of existing wood productivity, research needs to address the following aspects where productivity probably deviates from predicted values:

(a) the role of occult precipitation;

(b) productivity of *wadi* bottom woodlands;

(c) productivity of mangroves; and

(d) productivity depression caused by frost.

These studies ideally need to be long-term experimental efforts. They would be of use to a variety of natural resource inventories, not just in energy planning.

4.44 Assessing and Improving Carbonization Methods. To determine whether charcoaling induces environmental degradation, and if so, to improve the productivity of carbonization and conserve wood feedstocks, the charcoal industry of the north-central Tihama needs to be studied in some detail. The following activities are proposed:

(a) an assessment of land-use in this area of the Tihama to determine the environmental effects (e.g., wind erosion, sand encroachment, salinization and loss of farm land by desertification) of land clearance by charcoal makers. This could be done using a combination of aerial photography and multi-temporal high spatial resolution satellite imaging, with validation by observation of wind erosion and salinization processes on recently cleared land;

(b) an ecological study of the unusually rapid regeneration mechanisms of the main trees used for charcoal making, which appear to be far in excess of productivity estimates for the area;

(c) an inquiry as to why the Tihama carbonizers use roots as well as above-ground woody biomass. The fast rates of wood growth and the fact that the land is not usually used for farming after roots have been pulled up suggest that root clearance is not economically viable unless the charcoal produced by roots is of exceptionally high value; and

(d) introduction, if warranted, of more efficient carbonization techniques. This would involve an assessment of the efficiency of existing conversion processes, development of affordable and acceptable techniques to improve carbonization efficiency and reduce production time, and training/dissemination efforts. In determining whether improved carbonization methods are called for, one must keep in mind the effects on resource extraction rates. For instance, it is possible that improved methods would stimulate greater demand by virtue of the resulting production cost reductions. However, given that charcoal is used primarily for water pipes, consumption is relatively price inelastic, i.e. price changes that could be brought about through improved production would not significantly affect demand.

4.45 Indigenous Resource Management. Little of detail is known about traditional woodland management practices in different areas of Yemen. One such management method is the *heema* system which was once common throughout the Arabian Peninsula. This system involves classifying land into different *ahmia* (managed areas) according to types of protection where:

(a) animal grazing is prohibited but cutting of grasses is permissible during specified periods and droughts, or

(b) grazing or wood cutting is permitted but restricted to certain seasons of the year, or

(c) grazing is allowed year-round but the kind and number of animals are specified, or

(d) the reserve is kept for beekeeping, with use restrictions being relaxed after the flowering season, or

(e) the reserve aims to protect forest trees. These *ahmia* are usually the common property of a village or a tribe. Tree-cutting is prohibited except in emergencies, e.g., rebuilding a destroyed house or raising funds for the benefit of the village or tribe.

There are undoubtedly other similar management systems which have fallen into disuse or neglect for a variety of social and economic reasons. An investigation should be conducted to identify existing and past management practices with an eye towards revitalizing those that could be integrated into modern Yemeni society, possibly with the help of technical, economic and legal provisions.

4.46 Community and Household Agroforestry. Agroforestry techniques, e.g., use of shade trees, field boundary planting and pollarding, have also been well-developed or adopted in certain parts of Yemen, most notably the Hajja, Saada and Ibb-Taiz regions. Other farmed areas, such as the plains of the central highlands and parts of the Tihama, have less agroforestry. The effectiveness of these techniques should be evaluated and introduced into these latter areas as appropriate. This type of follow-up activity could also investigate the unusual cropping practices on the Tihama where cereal plants are stripped at specific intervals so that there is excessive stem thickening which enhances the fuel value of the crop residues. Certain agroforestry techniques from outside Yemen may also be appropriate.

4.47 Once successful practices have been identified, extension offices and the media, primarily radio and television, will be needed to disseminate these practices. Agroforestry programs should target the household and community levels, as these are the levels at which resource management decisions are now taken. Of course, households and communities will adopt new agroforestry interventions on a permanent basis only if they are clearly aware of the incentives to do so. Given the high prices commanded by firewood, and forest products in general, in Yemen, market incentives are probably the most promising. Further work should be done on the impediments to commercially-oriented agroforestry.

V. LPG SUBSTITUTION: ISSUES AND OPTIONS

5.1 Although woodfuel supply development and improved management are important components of any comprehensive strategy to bring about environmentally and economically sustainable household energy consumption patterns in Yemen, supply oriented activities alone are not enough. First, supply activities will not yield results for at least 5 to 10 years after they have been initiated. Given the rapid resource depletion expected in Yemen, reliance on such strategies alone will not avert the environmental and welfare consequences of fuelwood depletion discussed above. Secondly, the expectations held for any supply development program must be tempered by the past experience in Yemen. Many projects have been ongoing for the last several years without achieving the level of success that would be necessary to avert the effects of fuelwood depletion, even if time were not an issue. Although further supply development efforts are needed, they cannot be relied on alone.

5.2 Demand reduction through end-use efficiency improvements is another strategy. Improved stoves have been introduced in many countries to help prevent fuelwood depletion. However, the effectiveness of these programs is questionable and is currently a topic of research throughout the world. Furthermore, unlike many other countries, baking is the primary use for fuelwood in Yemen. The tannur offers little if any potential for efficiency improvements. Large tannurs have been successfully replaced by more efficient dome ovens (similar to European pizza ovens) at bakeries in Afghan refugee camps in Pakistan, but this is impractical at the household level. In Yemen, woodfuel costs represent only around 5% of the bakery costs. Under these circumstances bakeries would not have much incentive to switch to dome ovens. Moreover, many larger bakeries have already switched to diesel or kerosene-fired ovens.

5.3 The most promising strategy for enhancing woodfuel sustainability appears to be interfuel substitution. By encouraging households to switch to kerosene or LPG for cooking, pressure on fuelwood resources can be reduced. Electricity is not an option at the current time since most households that use electricity rely on intermittent private supply which is unsuitable for cooking. In fact, less than 3% of electricity consumers (less than 2% of all households) in the northern governorates use electricity for cooking. In comparison, over 42% of all households already use LPG for cooking.

5.4 Typically, households move up the "fuel ladder" from firewood to charcoal to kerosene to LPG. However, households in the northern governorates appear to be jumping a few rungs from firewood directly to LPG. Charcoal is a natural step in countries where the depletion of peri-urban woodlands necessitates costly transport from distant areas, thus rendering charcoal cheaper. However, in Yemen most firewood demand is rural and the distances are not large enough (nor will they ever be given the geography of Yemen) to stimulate household use of charcoal as a primary cooking fuel. Kerosene is also being skipped by most households; 37% of rural households and 87% of urban households in the northern governorates use LPG for cooking compared to kerosene use for cooking by only 31% of rural households and 6% of urban households. This is due in large part to the labor migration of the late 70's and early 80's. Yemeni men were exposed to the convenience of LPG and were provided with the financial means to afford the relatively high initial cost of switching to LPG, which retards LPG substitution in many other countries. In Yemen, LPG substitution is far more promising than kerosene substitution for the following reasons:

(a) Domestically produced LPG is both financially and economically less costly than kerosene;

(b) LPG is preferred to kerosene across all expenditure categories and rural/urban locations even at high current market prices;

(c) Unlike kerosene which is used most by low-expenditure rural households, LPG is currently used in all expenditure groups and rural/urban locations; and

(d) Unlike kerosene, LPG can be used to fuel low-cost tannur burners, so that it can directly substitute for wood used for baking.

Therefore, a strategy to bring about economically and environmentally sustainable household energy consumption patterns in Yemen must emphasize the substitution of LPG for fuelwood.

Impediments to LPG Substitution

5.5 The preceding section argued that woody biomass in Yemen is being rapidly depleted due to household firewood consumption. Fuelwood depletion will result in some environmental degradation, and more immediately, a direct reduction in household welfare. A strategy oriented towards increasing fuelwood supply will not alone arrest these undesirable environmental and welfare effects. Likewise, end-use efficiency programs to reduce fuelwood consumption could only be marginally effective, since tannur efficiency cannot be substantially improved. The strategy must therefore also focus on interfuel substitution. Since LPG is preferred to kerosene, is already used more commonly than kerosene, is no more expensive than kerosene when domestically produced, and can be used for household bread baking whereas kerosene cannot, LPG is the most promising candidate for an interfuel substitution program. The impediments to LPG substitution are discussed below, and programs and policies to overcome them are suggested.

Resource Base, Supply System, and Demand Patterns

5.6 LPG resources in the northern governorates were discussed briefly in paragraphs 2.22 through 2.25. Known LPG resources are large enough to provide 300,000 t per year for the next fifty years and can therefore offer a long-term alternative to fuelwood.

5.7 The supply system for LPG currently consists of importation and domestic production, bottling, transportation and distribution. Of the 96,000 tons of LPG consumed in 1988 in the northern governorates, approximately 82,000 tons were imported by sea in bulk and bottled in Hodeida by YPC 10/. With the expansion of the Hodeida facilities, imports reached an annualized rate of over 100,000 tons per year by late 1990. Bulk importation through the port is limited by

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10/ The remaining 14,000 tons were transported from Aden in bottles and sold to YPC at a price of US$3.50/bottle, equivalent to US$327/t. The Aden bottling plant has a capacity of around 70,000 t per annum.

the capacity of off-loading, storage and bottling facilities, and is expensive due to high freight costs that result from the use of small 3,000 t tankers. Despite the recent expansion, these facilities are already operating at capacity. The current composition of imported LPG is 85% butane, 15% propane.

5.8 The c.i.f. price for LPG is now around US$212/ton, whereas the ex-field economic cost for domestically produced LPG would likely be on the order of US$47/ton 11/. The use of indigenously produced LPG could replace US$15 to 20 million per year of LPG imports. The LPG Crash Program was initiated in 1989 with the assistance of the Bank to help develop domestic resources. By late 1990, approximately 30 tons per day of LPG were being trucked from the C5+ facility in Safer to Hodeida for bottling 12/. Expansion of domestic production capacity is underway.

5.9 Bottles filled at the Hodeida plant are transported by private contractor to YPC regional depots in Hodeida, Sana'a and Taiz 13/. The bottles are then either collected at the YPC depots by retailers, who receive a credit of YR 1.50 per bottle for collecting it themselves, or are delivered to agents at a price of YR 36 per bottle. There are over 500 private agents in the northern governorates in addition to over 50 YPC agents who are permitted to return empty bottles to these depots and receive full bottles for retail sale. There is currently no mechanism for controlling the prices charged by retailers.

5.10 LPG bottles are imported and distributed by YPC. The official deposit on bottles is YR 150, although in reality bottles are traded in the market for YR 300 to YR 1,000; YR 400 is the average price in the northern governorates. Approximately 1 million 12.5 kg bottles are currently used by households there, with another 400,000 to 800,000 either in use by commercial establishments or in circulation in the transport/filling system. The CPO Family Budget Survey revealed no evidence of bottle hoarding by households; in 1987, average bottle stock among users was 1.4 bottles per household. Given the high value of bottles, there appears to be a high opportunity cost of hoarding them. Many of the bottles in use, however, are damaged and in need of repair or replacement. Overall, it is estimated that there are about 1.4 million bottles in acceptable condition which are being used by residential and commercial consumers.

5.11 Total LPG consumption in the northern governorates increased from an estimated 27,000 tons in 1982 to about 84,000 t in 1987 and 96,000 t in 1988. Consumption in 1991 will likely exceed 130,000 t. Approximately 70,000 t were consumed by households in 1987, with the balance used primarily by poultry farms and the service sector. In 1987, about 42% of all households in the

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11/ *"Development of LPG Resources Techno-Economic Justification Report", Pencol Engineering Consultants for MOMR, November, 1989. The actual economic cost will depend on the purchase price ultimately agreed to between GCOMR and YHOC.*

12/ *The most recent negotiations indicated that GCOMR would pay about 50% of the Gulf f.o.b. price for LPG ex-Safer to the Yemen -Hunt Oil joint venture planned for LPG development.*

13/ *60% of LPG passes through the Sana'a depot, 30% through Taiz, and 10% through Hodeida.*

northern governorates used LPG (37% of rural and 87% of urban residences). Average consumption for users was 123 kg/year/household (109 kg/yr for rural and 176 kg/yr for urban residences). While urban household market penetration in different governorates ranges from 67 to over 95%, it ranges from 1 to over 60% by governorate in rural areas.

5.12 One cause of higher average urban consumption is the greater consumption of bakery bread in urban areas, which reduces the need for tannur baking. Instead of using firewood in a tannur for both baking and cooking, households opt for purchasing bakery bread and using LPG to cook. Regional differences in LPG consumption may be accounted for by variations in dietary habits and household expenditure. For example, the lowest LPG consumption is found in the rural Tihama where only about 1% of household use LPG. Average total household expenditure in that region is about 40% less than the rural average for the northern governorates, suggesting a reduced ability to switch to LPG in the first place. Of course, differences in LPG availability throughout the northern governorates also affect consumption patterns.

5.13 With respect to interfuel substitution strategies, Yemeni households may be disaggregated into three categories: those which use LPG only, those which use LPG and firewood, and those which do not use LPG. While the first group serves as an example of consumption patterns that might occur if LPG completely displaces firewood (and rural cooking practices become more urban), any strategy must be based upon considerations of how it will increase substitution in the other two groups. The characteristics of these three groups are summarized below in Table 5.1. Although rural households exhibit significant LPG utilization, the greatest use is associated with urban areas. As Figure 4.3 indicated, in terms of household budget shares, differences in LPG utilization are more pronounced between rural and urban households than across expenditure categories.

Table 5.1: LPG PENETRATION

Category	% of all households	% of urban households	% of rural households
LPG only	5.8	45.7	1.1
LPG & firewood	36.4	41.5	35.9
No LPG	57.8	12.8	63.0

Source: CPO Family Budget survey and University of Sana'a survey #1.

5.14 Queues to purchase LPG are common in the northern governorates, and together with the observation that LPG importation and bottling is operating at full capacity, suggest that consumption is severely supply-constrained due to limited storage, bottling, and distribution infrastructure. Increasing fuel and bottle availability would presumably result in (a) more households switching to LPG (12% of households not using LPG stated they were not doing so because of unavailability); (b) greater consumption of LPG by households already using LPG (43% of households using LPG indicated that bottle availability was a major difficulty with LPG use); and (c) an increase in consumption brought about by lower prices resulting from greater supply (although the own-price elasticity for LPG appears to be low suggesting that this effect may not be significant; however, a low own-price elasticity may be expected simply due to constrained supply).

5.15 Several activities have already been initiated by MOMR, GCOMR, and YPC, mostly under the LPG Crash Programme, to improve LPG supply in Yemen, including:

(a) **Production**: Assuming the current gas reinjection rate of about 400 mmscfd, 330 days/yr of operation, and no further spiking of crude oil with butane (which would be justified given that the value of domestically consumed LPG is greater than the value of butane in spiking), 90,000 to 100,000 t of LPG will be available annually from the existing C5+ plant at Safer; increasing the gas reinjection rate would increase LPG availability proportionately (a total capacity of 650 mmscfd is in place). Facilities are being designed for storage and bulk loading of LPG from this existing plant; some were already operational by late 1990, allowing truck loading and transport to Hodeida of 30 t/day. It is estimated that LPG production from the Asad Al-Kamil field could provide an additional 700 t per day.

(b) **Transport**: In order to transport recovered LPG to bottling plants and bulk consumers, bulk delivery trucks and/or a pipeline will be required. GCOMR currently has seven tractor-trailers capable of hauling 20 t each, and is considering the acquisition of 40 more for bulk transport from Safer to the bottling plants. These trucks would cost about US$175,000 each. An unspecified number of smaller "bobtails" (5 to 8 t bulk delivery trucks) may also be procured for bulk delivery to consumers. There are also plans to conduct a feasibility assessment of an LPG pipeline from Safer to Sana'a; and

(c) **Bottling**: The Hodeida bottling plant has recently been expanded to a capacity of 130,000 t/yr on three shifts. Small bottling stations 14/ are planned for four towns: Sa'ada, Amran, Mareb, and Dhamar. Installations of small stations is expected in 1991. A 135,000 t per year plant (based on 2.5 shift/day average) has been proposed for Sana'a, with financing by the German government. A private company, Mareh Co., has established a bottling plant in Ibb reported to have a three shift capacity of 20,000 bottles per day. Mareh Co. has also purchased two 20 t tractor-trailers to transport LPG to the plant. The Government has been considering several possible arrangements for the operation of this plant, e.g. under contract to YPC, leased by YPC, or as an independent bottler.

5.16 Of course, operation of these facili .s presupposes an agreement with YHOC regarding the offtake of LPG from the gas stream. The Parliament recently turned down a proposal which would have included downstream involvement of YHOC. Operation of these facilities nonetheless continues while a new proposal is formulated. LPG is loaded onto road tankers at Safer and transported to the large bottling plant in Hodeida, four small regional bottling plants, and later, the large plant at Sana'a. Bottles are distributed from these plants; in addition, some of these plants will have facilities to load bobtails for bulk delivery to consumers such as poultry farms and hotels. Imports by sea could still be accommodated to meet any shortfall in supply since production capacity at Safer rather than bottling capacity would constrain domestic demand.

14/ Each plant will have a capacity of 1,000 to 2,000 bottles per day (3,500 to 7,000 t per year), and will be moveable.

5.17 In Sana'a and Mahweet governorates, the area that would be served by the proposed Sana'a and Amran bottling plants, approximately 46,000 t of LPG was consumed in 1987. By 1990, it is estimated that consumption had grown to 57,000 t annually. Simple demand projections based on population growth and moderate increases in LPG penetration and average consumption per user suggest that consumption may reach 96,000 t by 1997 and over 120,000 t in 2002 15/. Given that the Amran plant would supply no more than 7,000 t, the sizing of the proposed 135k tonnes/yr is believed to be too large. A smaller plant should be considered with the option of increasing its size when justified, over time as the market dictates.

Overcoming Impediments to Substitution

5.18 Although the planned improvements in the LPG supply system discussed above are necessary to stimulate LPG substitution, they are not alone sufficient. Table 5.2 outlines the required action. In addition to the on-going activities described above the LPG substitution strategy should contain three basic elements which are discussed in more detail in the paragraphs which follow:

(a) improving LPG production, bottling, and delivery infrastructure, i.e., increasing the supply of fuels, bottles, and trucks, particularly to rural areas, beyond current efforts;

(b) improving the management of LPG operations; and

(c) commercializing low-cost LPG appliances, especially tannurs.

Improved Infrastructure

5.19 Fuel Supply. As long as importation of LPG by sea remains necessary, YPC should ensure that gas return lines are connected to LPG delivery ships while they are at berth. The advantage to YPC of not connecting gas return lines is that the receipt of LPG is greater than recorded, but the disadvantage is that the vessels, berth, and discharge systems are occupied for unnecessarily long periods. With the increase in bottling capacity at Hodeida, it will be necessary for delivery ships to unload as quickly as possible to maximize LPG availability. Furthermore, not connecting gas return lines may have a detrimental impact on safety.

15/ *These projections are based on 1.6% annual rural population growth and 8.9% urban growth. Actual values for 1987 and projections for 1997 for relevant parameters are given below:*

	Sana'a		Mahwheet	
	1987	1997	1987	1997
Percent urban users	96.8	99	66.7	90
Urban user avg. consumption, kg/yr	188	200	136	175
Percent rural users	62.9	75	67.2	79
Rural user avg. consumption, kg/yr	159	175	96	140

Table 5.2: LPG - STRATEGY OBJECTIVES AND ELEMENTS

OBJECTIVES	ACTIONS TO BE TAKEN
1. Encourage households using LPG + firewood to use less firewood and more LPG	- Increase the supply of LPG bottles and fuel - Improve LPG marketing and distribution - Commercialize low cost LPG baking appliances - Encourage the development of community bakeries
2. Encourage households not using LPG to adopt it	- Same steps as above - Reduce the costs of bottles, regulators, and appliances (i.e. the initial switching costs) by cross-subsidizing these items from fuel sales.

5.20 Although the on-going development of infrastructure for the use of domestic LPG may seem sufficient to meet demand for the next several years, it is anticipated that demand will again outstrip this capacity in only a few years. (See the section below, "Impacts of a Managed Fuel Transition"). The cost of LPG imports that will be necessary due to domestic undercapacity makes temporary overcapacity relatively cheap. **RECOMMENDATION:** Consequently, planning should already begin for a cryogenic extraction facility at Safer. This could boost LPG supply by as much as an additional 180,000 t/yr. The cost of such a facility would be on the order of US$ 24 million. Planning for LPG extraction from Asad Al-Kamil should continue.

5.21 Although the use of tanker trucks is expedient, it may not be the least-cost transport option, particularly as demand grows. **RECOMMENDATION:** A detailed feasibility study for an LPG pipeline from Safer to Sana'a should be carried out 16/. If a pipeline is constructed, the road tankers can be used for delivery to bulk consumers and the small regional bottling plants.

5.22 Bottle Supply. Three measures can greatly increase consumer access to cylinders which, in turn, will remove one of the key barriers to accelerated LPG penetration of the household fuel market. First, YPC can increase its imports of cylinders to meet projected demand for newly-available domestic LPG. Alternatively, assuming the Government implements the recommendation in paragraph 5.28 below urging a greater role for the private sector in LPG operations, the private sector would be responsible for augmenting cylinder supply. Up to the present, YPC has been restricting bottle imports because LPG availability has been constrained. This has resulted in a black market for cylinders and average prices paid by consumers of three times the official price. As supply expands, more cylinders are needed and should be made available on the marketplace in a timely fashion. Table 5.3 provides an estimate of the number of new cylinders which will be required on an annual basis. **RECOMMENDATION:** YPC, and/or the private sector, should import 450,000 bottles as soon as domestic LPG is available to meet pent-up demand, and augment

16/ *A preliminary assessment of an LPG pipeline was carried out by Fluor Daniel as part of the Gas Utilization Study. That evaluation concluded that a pipeline would be economically attractive. Other benefits of a pipeline not considered in the Fluor Daniel analysis include: (i) reduction in wear on the road between Safer, Sana'a, and Hodeida together with the propensity for accidents and congestion; (ii) greater flexibility in matching supply to demand without idle tankers; (iii) greater security against natural disasters or anti-government activities; and (iv) lower operating costs, which would save future foreign exchange.*

the stock with between 160,000 to 210,000 bottles annually over the next 10 years. In addition, a bottle reconditioning plant should be constructed and operated by YPC. These actions should bring market prices for bottles into line with official prices.

Table 5.3: PROJECTED DEMAND FOR NEW LPG CYLINDERS

Year	Households Using LPG ('000)	Households LPG Consumption '000 tons	No of Bottles required a/	Extra 5 days Supply b/	Total	Existing Bottle stock	Required Purchases c/ '000 bottles
1988	656	84	1050	92	1142	1000	142
1989	733	96	1173	105	1278	1119	159
1990	808	110	1293	121	1413	1252	161
1991	857	120	1371	132	1503	1385	118
1992	907	128	1451	140	1591	1473	119
1993	1001	142	1602	156	1757	1560	198
1994	1094	156	1750	171	1921	1722	199
1995	1185	170	1896	186	2082	1883	199
1996	1275	184	2040	202	2242	2041	201
1997	1363	198	2181	217	2398	2197	201
1998	1451	212	2322	232	2554	2350	204
1999	1538	226	2461	248	2708	2503	206
2000	1624	240	2598	263	2861	2654	207

a/ Assumes 1.6 bottles per household, the current average for households using more than 150 kg/year.
b/ In addition to bottles held in households, a supply of 2 days of bottles is assured for the YPC depots and private agents, and a 1 day of supply for the bottling plants.
c/ Assumes 2% of the bottle stock must be replaced each year.

5.23 The second cylinder-related measure which can make LPG accessible to more consumers is to reduce the cost of a bottle and thereby ease the price barrier to using LPG. If cylinders cost YPC an average of 200 YR over the decade 1991-2000 and if it charged a nominal fee of 50 YR per new bottle, this would cost YR 81.7 million for a five-year program (1991-1995), or YR 169.5 million over ten-years (1991-2000). This could be financed by a surcharge of less than 7 YR per 12.5 kg cylinder filling during the promotional period. The program would be relatively simple to administer if YPC continues to have a monopoly on official imports of cylinders and it would remove one of the important barriers to new consumers who would like to enter the LPG market but are hindered by the start-up costs of bottles. RECOMMENDATION: The price for LPG bottles should be subsidized with the proceeds from fuel sales.

5.24 The third action would be for the YPC to standardize and enforce tare weights. Currently, the tare weights of YPC bottles vary between 13.6 and 16.3 kg. The gross weight of full bottles needs to be set at a common figure which is currently 26 kg. The net weight of LPG in the filled bottles now varies between 9.7 and 12.4 kg and averages 10.7 kg. The effects of this are:

(a) transportation capacity of the bottles is not fully used;

(b) customers are paying more for their product than they believe and may be overcharged up to about 30%; and

(c) statistics relating to consumer demand may be overstated by 10-15% if this is not factored in.

RECOMMENDATION: A standard tare weight for all future bottle purchases should be selected and adhered to. All new bottles (standard tare) should be purchased already painted in a distinctive color and all existing bottles of the same tare weight should be painted in the same color. Bottle filling can then be undertaken by batching common-colored (i.e., common tare weight) cylinders and adjusting the gross filling weight according to the tare weight of each batch.

Improving Management

5.25 Simply augmenting the infrastructure for LPG supply and distribution alone will not maximize interfuel substitution. Achieving the best use of the fuel delivery infrastructure requires a supportive policy environment and sound management that can direct operations smoothly and efficiently. The responsibility for establishing a policy environment conducive to LPG substitution should lie with MOMR. Production operations, on the other hand, should lie clearly with GCOMR, and downstream operations with YPC. Three issues which MOMR should address immediately are private sector participation, LPG pricing and safety of operations.

5.26 Private Sector Participation 17/. Given the active private sector in Yemen, the success of the LPG substitution strategy will be enhanced by the involvement of the private sector wherever possible. Naturally, private sector operations will be subject to safety inspection and code enforcement, but gradually allowing private participation further upstream over time may relieve the Government of the burden of commercial management and result in more efficient operations to the benefit of the consumer.

5.27 It is assumed that the Safer facilities will remain either in the hands of the Government (GCOMR), or with a joint venture with Hunt Oil Co. There are numerous scenarios for private participation in LPG transport, bottling and distribution. Some of the more basic ones are given below:

(a) All transport, bottling, and distribution operations downstream of the Safer production and loading facility lie with the private sector;

(b) Transport and bottling remain the domain of YPC, but the private sector is responsible for bulk and bottles distribution to consumers. Private firms may be licensed for bottling. In this way, the private sector can build and operate small bottling plants, e.g. 1000 bottles per day, in more remote areas, and supply these plants through their own bulk deliveries; or

(c) YPC maintains responsibility for transport, bottling, and distribution. It may contract with private firms for bulk or bottle distribution as necessary.

17/ *Private Sector participation in LPG distribution is also discussed in Pencol Engineering Consultants, "LPG Crash Programme Privatization Report", January 1990.*

Option (c) would require additional investment and management by YPC. Given the anticipated growth in the LPG market, such a strategy may overwhelm YPC's administrative and managerial capacity, and may limit penetration to only those areas where YPC could operate. Option (a) may not generate required bottling and distribution capacity, since the private sector may wish to invest only gradually, as GCOMR and YPC demonstrate the ability to provide a steady LPG supply. Furthermore, it may be difficult to prevent an unmanageable monopoly situation from developing in the long run, to the detriment of the consumer.

5.28 **RECOMMENDATION:** Option (b) is strongly recommended. YPC may maintain its own retail agents, but private retailers would be allowed to compete, regulated only by safety codes. GCOMR would only set wholesale prices; retail prices would not be controlled. This should allow sufficient competition to ensure relatively low consumer prices. The barriers to market entry by retailers would remain basically as they are now, i.e. the need to have a truck and a place to sell bottles. Private sector mobilization would help ensure distribution to all parts of the country, something which would be very difficult for YPC to accomplish on its own given the anticipated increase in LPG volume. Over time, YPC may wish to sell off parts of its bottling or transport facilities to the private sector.

5.29 Pricing Policy. The only effective retail pricing mechanism in Yemen is market competition; price controls are ineffective on a retail level. Naturally, GCOMR, with the guidance of MOMR, can influence retail prices through the bulk sale price of LPG to private parties. If GCOMR wants the retail price to be as low as possible (i.e. for the markup on its bulk price to be kept at a minimum), it must ensure adequate supply of LPG along with easy entry for private parties into the market (while not sacrificing inspection and enforcement of codes).

5.30 Paragraphs 3.21 to 3.24 note that the current official LPG retail price is slightly above the economic cost of imported LPG. However, once domestic LPG production begins, the economic price will be substantially below the current retail price. It has been suggested by some that the pricing be reduced to reflect the Gulf f.o.b. price for LPG, e.g. to YR 24/bottle. However, it is strongly recommended that pricing remain equivalent to at least the current official level of YR 40/bottle for the following reasons:

(a) Even at YR 40/bottle LPG will remain the cheapest household fuel on both a final and useful energy basis;

(b) There is no evidence that a fuel price reduction will stimulate interfuel substitution. Statistical analysis suggested a negative but very small own-price elasticity for LPG; however, due to supply constraints this result is expected and may not hold as supply increases. Perhaps more importantly, high fuel cost was seldom given by households as the primary reason for not using LPG, and for those who have already made the switch to LPG (generally in conjunction with other fuels), fuel cost was not a major problem associated with LPG use. The initial cost of switching to LPG and the unavailability of bottles, fuel, and appliances are the primary impediments to substitution;

(c) Maintaining ex-plant LPG prices above economic cost will provide a source of revenue that can be used to subsidize bottle and appliances prices, and thereby enable more households to switch to LPG.

(d) With the reduction in private remittance income it will be necessary to increase public sector development efforts to maintain the momentum of development which has built up over the past 10 years. This will require additional Government funds, although any windfall from maintaining LPG prices at their current level should first be applied towards improving LPG availability and safety, and enhancing interfuel substitution. For example, funds generated from this windfall could be used to improve safety in so far as they can finance LPG bottle and facility inspection and code enforcement (see below). Remaining funds could then be applied to other projects;

(e) Since the fall in remittance income will have the greatest impact in rural areas, the tax revenue received from the sales of a fuel used most in urban areas would result in a transfer of wealth back to the rural areas, at least until the rural use of that fuel reaches a level comparable to urban areas, and assuming the cross-subsidization of bottle and appliance costs. The cross-subsidization benefit households that do not have LPG equipment but switch to LPG after program implementation (i.e. rural household) at the expense of those who already do (i.e., urban households); and

(f) Recently there has been some devaluation of the Yemeni rial, which, if sustained, would oblige a higher domestic retail price.

5.31 A sensible approach which would at the same time encourage interfuel substitution is to apply the fuel sale windfall as a cross subsidy to decrease the cost of bottles and appliances, i.e. to reduce the primary barriers to switching to LPG in the first place. Since the percentage of households using LPG in rural areas is about one-third of that in urban areas, this will benefit mostly rural households in addition to encouraging substitution. Since GCOMR would be the monopoly producer/wholesaler of LPG, it could set the bulk price for LPG and implement the cross subsidy in several ways:

(a) reducing the bottle deposit further below cost, but not so low that there would be no incentive to properly care for bottles, say YR 50/bottle;

(b) licensing manufacturers of LPG tannurs for quality control, and providing these manufacturers with radiator materials at concessionary prices which would encourage lower retail appliance prices (these materials do not appear to be available in YAR, and hence could be imported by YPC for distribution); and

(c) a promotional campaign whereby if a household buys an LPG tannur, they will receive a free bottle of LPG.

5.32 RECOMMENDATION: GCOMR and YPC should maintain an LPG pricing structure which encourages retail pricing of around YR 40/bottle. YPC could sell bottles directly to consumers through its agents at this price. Assuming that LPG transport, bottling, and distribution costs YR 10/bottle, based on Table 3.7, the bulk price for LPG should be no more than YR 2,800/t (calculated on the basis of a retail price of YR 40/bottle less transport, bottling, and distribution costs of YR 10/bottle) and no less than YR 2,000/t (based on the economic value 18/ of approximately YR 1,400/t and including a bottle cross-subsidy equivalent to YR 7/bottle, i.e. YR 560/t). The actual price for bulk LPG as well as wholesale bottle prices should be set within these limits, but at a level which will encourage private sector involvement and at the same time help guarantee the financial health of YPC.

5.33 Assuming that domestically produced LPG is priced at its economic value of around YR 1,400/t 19/ and bottling, transportation, and distribution costs of YR 10/bottle, a retail price of YR 40/bottle would generate a windfall of approximately YR 15/bottle for YPC. Two-thirds of this could be applied towards bottle and appliance subsidies, while the remaining third could be spent on safety and code enforcement. Allowances could also be made for road maintenance or other development projects which indirectly support LPG marketing and distribution. Even though the retail price would be much higher than economic cost, LPG would nevertheless become less costly in financial terms than competing fuels. Furthermore, since the implicit tax on the fuel would be used to subsidize bottle and appliance costs, LPG would in effect become the cheapest household fuel in Yemen.

5.34 Improving Safety. As suggested above, the tax revenues generated by maintaining LPG prices at their current level could be used in part to finance the adoption and enforcement of standards and codes covering both YPC operations and consumer installations. This includes appropriate siting of bottles depots and filling plants, and the regular inspection of bottles and facilities. These responsibilities would be most effectively adopted by YPC itself, since it will already be familiar with LPG facilities and will have the opportunity to inspect bottles as part of normal operations. Fortunately, there have been no large scale LPG accidents to date, but this has simply been a matter of luck given the deplorable condition of many bottles and LPG facilities in Yemen. In the long run, a safer LPG industry will not only save lives and property, but will also reassure consumers and stimulate interfuel substitution. Some key safety recommendations are listed below.

5.35 Safety needs to be enhanced throughout the chain of LPG supply by developing and enforcing safety codes, attending to damaged equipment and decentralizing large, potentially dangerous distribution depots. Of four sales outlets visited, only one had a fire extinguisher, none had suitable ground-level ventilation, two had steel thresholds to the store which could be spark-inducing and visitors were not informed not to smoke. **RECOMMENDATION:** Standard codes for equipment, construction, operations and safety need to be developed and instituted immediately. One area of particular danger is the manner by which bottles are recklessly handled at present. As a first measure, operators should be instructed: (a) never to drop bottles unless the fall is cushioned by an old tire and then never more than 30 cm.; (b) where a wooden ramp is used to move bottles, the cylinders should be stopped at the end of the ramp by a tire, not another bottle; (c) bottles should be moved by holding the collar and rolling on the base ring; and (d) bottles should be piled manually and carefully, preferably upright on pallets. To enforce the new codes, a safety commissioner should be appointed, perhaps with a small inspectorate, to develop, implement and

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18/ Assuming a Gulf c.i.f. price of US$100/t and an exchange rate of YR 12.5 = US$1.

19/ GCOMR may actually pay less than YR 1,500/t for domestically produced LPG depending on the purchase agreement reached with YHOC. However, given that the f.o.b. value of LPG would be around YR 1,500/t, it should not sell it for less.

enforce, as well as educate employees about, safety regulations and practices. Safety codes and standards will be established during the LPG Crash Program.

5.36 The problem of damaged cylinders is a safety issue which will only get worse with inattention. An estimated 250,000 to 500,000 damaged bottles await repair which could be undertaken at about one-quarter the YR 150 cost of importing a new cylinder. RECOMMENDATION: All bottles with dents greater than 5 mm deep should be set aside for expert testing before being readmitted to active bottle stock. All bottles, damaged or not, should be tested before their fifth anniversary of manufacture and thereafter once each year. Testing dates should be stencilled on cylinders. Once color-coding of bottles by tare weight has been put into effect, bottles of the standard tare weight should be selected for first repair. In a related vein, safety problems may develop with the pressure regulators. Because LPG produced from field gases will differ in butane/propane proportion from the current imported mixture (i.e. domestic LPG will have a butane/propane composition of approximately 70/30 as opposed to 85/15 for current imports) , there will be an increase of pressure within all vessels holding LPG. It is likely that existing bottles will be suitable for the higher pressure but pressure regulators and other equipment may need to be entirely replaced. RECOMMENDATION: Pressure regulators and other equipment should be tested prior to marketing domestic LPG and replaced if necessary. The cost of replacement could be absorbed as part of the refilling price.

5.37 The current system of operating large retail sales outlets in densely populated areas with many stored bottles in dwellings which are not built specifically with LPG hazards in mind is dangerous. RECOMMENDATION: Properly built storage and selling facilities should be installed in YPC's gasoline stations. This would provide a number of advantages over the present system, including:

(a) the storage and handling of cylinders can be made inherently safer;

(b) the task of collecting full and delivering empty bottles would be much more convenient for customers;

(c) a ready-made network of distribution points could be employed with the small extra cost of constructing suitable stores on YPC property; and

(d) training of operating staff would be simplified as existing gasoline station personnel have respect for hazardous products.

Similar storage standards and practices would apply to private retailers.

5.38 Development of both LPG and natural gas are important topics at the current time. These activities should be organizationally segregated since LPG is much more similar to petroleum products than to natural gas in terms of marketing and distribution. RECOMMENDATION: In light of this, LPG would naturally fall under the control of YPC, while natural gas development would be relegated to the portfolio of another agency such as GCOMR. Given the limited number of qualified staff at YPC, GCOMR, and MOMR it is likely that for the time being the same staff will be involved in both LPG and natural gas development. These agencies should endeavor to attract other qualified individuals to these positions, so that these activities may proceed independently in the future.

Commercialization of Appliances

5.39 If LPG is to substitute for woodfuels, LPG appliances that satisfy the same end-uses must be affordable and widely available. Virtually all firewood is consumed for baking and cooking. Although small LPG burner rings are readily available for cooking, the prevalence of bread in the Yemeni diet requires LPG baking equipment. Until now, large expensive metal LPG tannurs have been available in larger cities. Even at a cost of YR 1300 to YR 2500 each, sales have been rapidly growing. Nonetheless, at these prices it is unlikely that these appliances will be widely accepted. Furthermore, although urban areas manifest the highest population growth rates and the lowest firewood consumption, to a large extent due to the availability of bakery bread, one cannot rely on urbanization to obviate the need for bread baking equipment. 90% of households in the northern governorates are rural, and most will remain so. Even most urban households continue to bake at least some bread. Affordable LPG baking appliances are as important as increasing fuel and bottle supply to bring about interfuel substitution.

5.40 Results from the University of Sana'a and CPO surveys support the assertion that LPG and firewood are currently not substitutes; firewood consumption is positively correlated with LPG consumption. Given the lack of LPG baking appliances, this is understandable; as households cook and bake more, they will use more of both LPG and fuelwood since no technologies are widely available to allow substitution between them for baking.

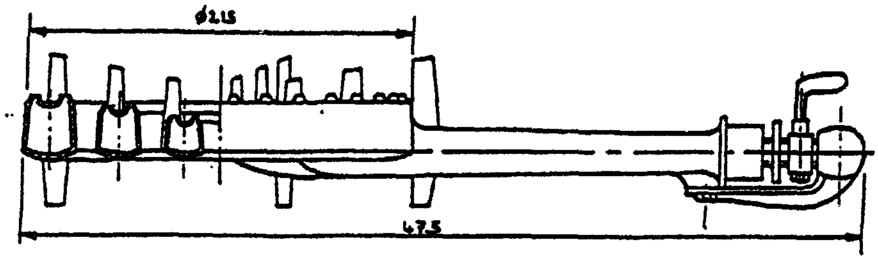
5.41 Tests were conducted under the Household Energy Strategy Study to determine the performance, efficiency, and specific fuel consumption of LPG baking appliances, including the clay tannur retrofitted with a disk burner, a ring burner and a radiator, as well as the metal tannur. These appliances are shown in Figure 5.1. The specific fuel and energy consumptions, and lifecycle costs for each oven were calculated based on a series of baking trials and measurements conducted at the University of Sana'a, and are compared in Table 5.4. The methodology and more detailed test results are presented in Annex 6. On fuel and lifecycle costs, the metal tannur turns out to be the least expensive LPG appliance, though start-up costs are much more prohibitive than the retrofitted woodburning tannur.

Table 5.4: COMPARATIVE BAKING COSTS, LPG AND WOOD

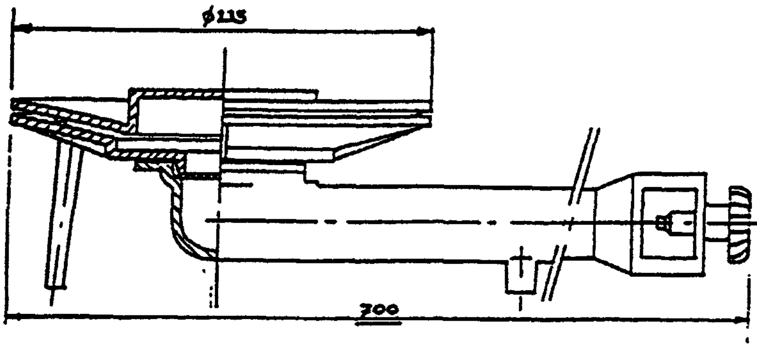
Stove Type	Fuel type	Power kW	Lifetime a/ yrs.	SFC b/ kg/kg	SEC c/ MJ/kg	Fuel Costs (YR/kg)	Lifecycle Costs d/ (YR/kg)
Clay tannur	wood	29	3	2.7	35	3.9	4.0
Clay tannur w. ring burner	LPG	12	3	0.5	22	1.5	1.8
Clay tannur w. radiator	LPG	13	3	0.4	18	1.3	1.6
Metal tannur	LPG	12	5	0.2	10	0.7	1.3

a/ Estimated.
b/ Specific fuel consumption (kilos of fuel per kilo of bread baked).
c/ Specific energy consumption (megajoules of energy per kilo of bread baked).
d/ Based on wood priced at YR 0.11/MJ and LPG at YR 0.07/MJ (this assumes the recommended retail price of YR 38/bottle and 12.5 kg/bottle). The life-cycle costing assumes that a wood tannur costs 200 YR, a clay tannur with ring or radiator YR 550 and a metal LPG tannur 1500 YR. 700 kg/yr bread consumption and 10% discount rate assumed.
Source: Visser, "Household Energy Options in the Yemen Arab Republic: Test Results on Tannurs and Cookstoves", ESMAP, 1988; Zabarah, "Field Study for the Substitution of the Traditional Tanoor for the LPG Tanoor", ESMAP, 1988; and mission estimates.

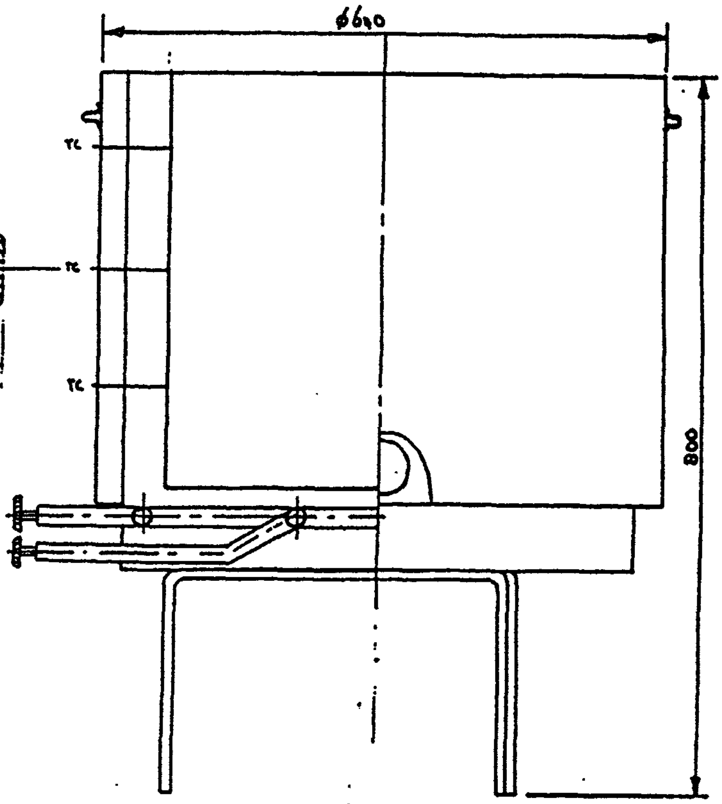
Figure 5.1: LPG APPLIANCES



The Ring Burner



The Disk Burner.



The Metal Tannur.

Source: Visser, op. cit.

5.42 The LPG radiator for retrofitting existing clay tannurs represents the most promising LPG baking appliance, on a cost and performance basis. The disk burner tended to burn the bread, and the initial costs of the metal tannur are too high for most households. A preliminary design has been developed as part of the household fuel marketing study. It is strongly recommended that the Government initiate a follow-up activity to commercialize this design. This activity would comprise the following tasks:

(a) identification of appropriate materials for the radiator, taking into account cost, availability in Yemen, lifetime, etc.;

(b) local construction of prototype burners (including the radiator);

(c) testing of the prototypes on technical aspects such as power, controllability, and lifetime, as well as on consumer acceptability; and

(d) once an appropriate design is found, organization of production and marketing of such burners on a commercial basis in cooperation with a local manufacturer.

The most appropriate Government counterparts for this activity would be GCOMR and YPC.

The Effects of a Managed Transition

5.43 With even the most sophisticated market forecasting techniques, it is unlikely that sales forecasts will be reliable. Even if an accurate figure of the market potential can be deduced, the speed of market penetration will depend on the skills employed in tackling the market and on suitable supply and distribution systems. With these caveats in mind, the benefits of implementing the recommendations made above are estimated.

5.44 With improvements in the availability and delivery of LPG and other measures which are recommended in this chapter, household demand for LPG could reach 240,000 tons/year by 2000; in addition, a potential demand of nearly 30,000 t/yr could be tapped in other sectors such as poultry farms and large service sector consumers, e.g., hotels. Market penetration is expected to gradually increase as locally produced LPG becomes available at a price competitive with that of increasingly scarce and expensive fuelwood.

5.45 In order to project LPG demand, two scenarios have been analyzed which are based on different proposed Government strategies. In the "natural substitution" scenario, no Government action is taken beyond making domestically produced LPG available in an accelerated way; this Government program was described in paragraph 5.15 above. Should the current trends in household energy consumption continue, total fuelwood stocks in the northern governorates would be depleted in about ten years to the level currently found in fuelwood deficit areas such as Dhamar. This scenario assumes that, at that time, national household LPG consumption reflects the consumption pattern currently found in Dhamar. Non-household LPG demand growth is assumed to grow at 5% annually and includes the demand by commercial farms which is expected to reach 29,000 t/yr by 2000. In the "managed transition" scenario, the Government would, in addition to the measures mentioned above, undertake the following: (a) increase the availability of LPG cylinders to ensure their adequate supply at a more affordable price; (b) mobilize the private sector by allowing private LPG marketing and distribution, including bulk supply, at all stages downstream of extraction; (c) develop and disseminate low-cost LPG tannurs; (d) subsidize LPG bottles and appliances with extra revenues from the sale of LPG fuel; (e) formulate and enforce codes and standards to help ensure product safety and the smooth operation of production, bottling and distribution; and (f) establish a separate agency or unit within YPC that would be responsible for LPG promotion and code enforcement.

5.46 These two scenarios were then compared with a theoretical "maximum potential" of market penetration which establishes the upper bound for future growth in domestic LPG consumption. This is characterized by steady growth in LPG demand such that, at the end of 15 years, all households consume LPG at the average rate of those who today use only LPG and no kerosene or wood, i.e., 176 kg/yr. Non-household demand is assumed to grow at 10% annually. The estimated demand under the two scenarios and the maximum potential are enumerated in Table 5.4 and depicted in Figure 5.2.

Table 5.5: LPG DEMAND ESTIMATES

Scenario	Actual 1987	Projected 1990	1995	2000	1988-2000 Growth Rate
		('000 tons/year)			
Natural substitution	84	108	144	193	6.0
Managed transition		114	193	268	8.9
Maximum potential		119	201	340	11.1

5.47 Government actions can make a significant difference in demand growth. According to these estimates, the difference in consumption under the two scenarios after 12 years is estimated at 75,000 t/yr, which is equivalent to nearly 1 million t of fuelwood, or 20% of present fuelwood demand. Figure 5.3 shows the effects of the managed LPG transition on woody biomass standing stocks. The impact of increased LPG substitution becomes apparent after about 5 years, when the rate of depletion does not accelerate as quickly compared to the depletion shown in Figure 4.2 for the natural transition scenario (i.e. the line for "stocks w/o mngd tran" shown in Figure 5.3). At the end of 10 years, sturdy stocks are nearly twice as great with the managed transition than without. Although the managed transition alone will not prevent fuelwood depletion, it will allow additional time to implement effective fuelwood supply programs.

Figure 5.2: LPG CONSUMPTION SCENARIOS

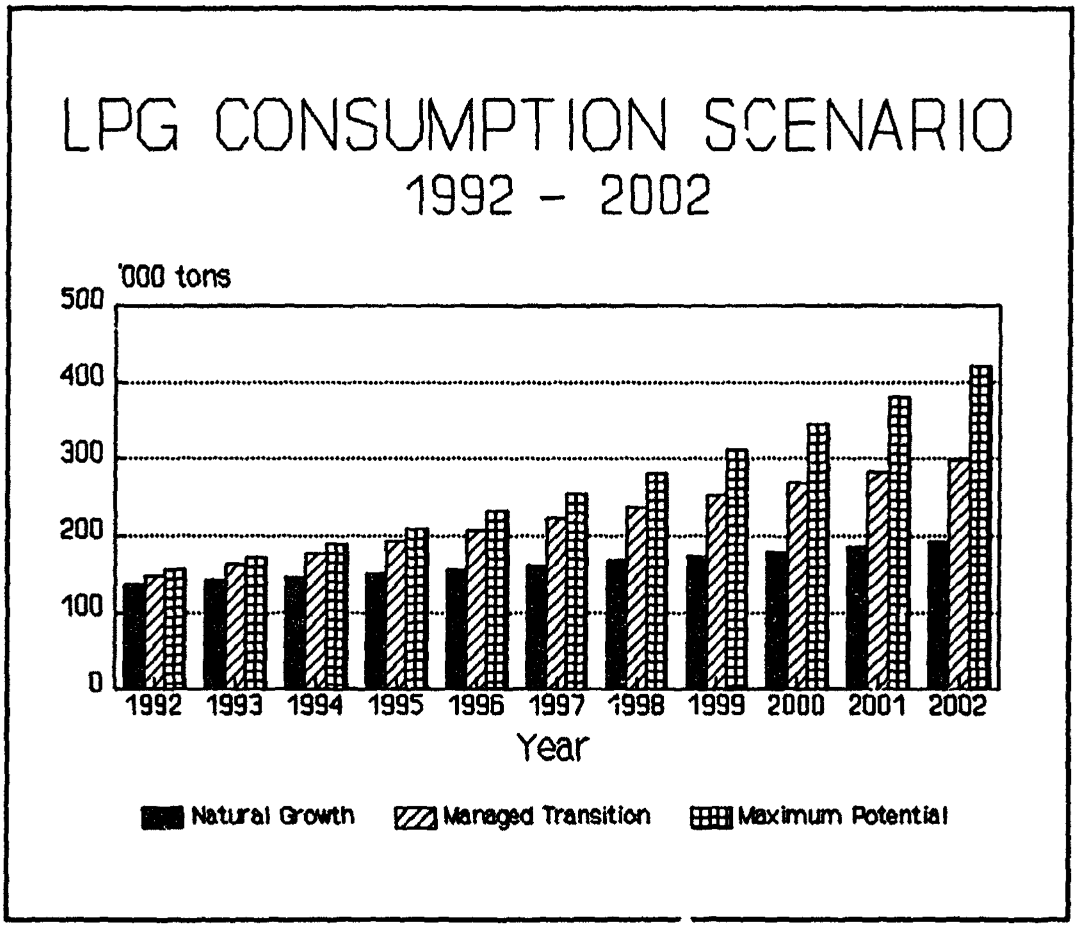
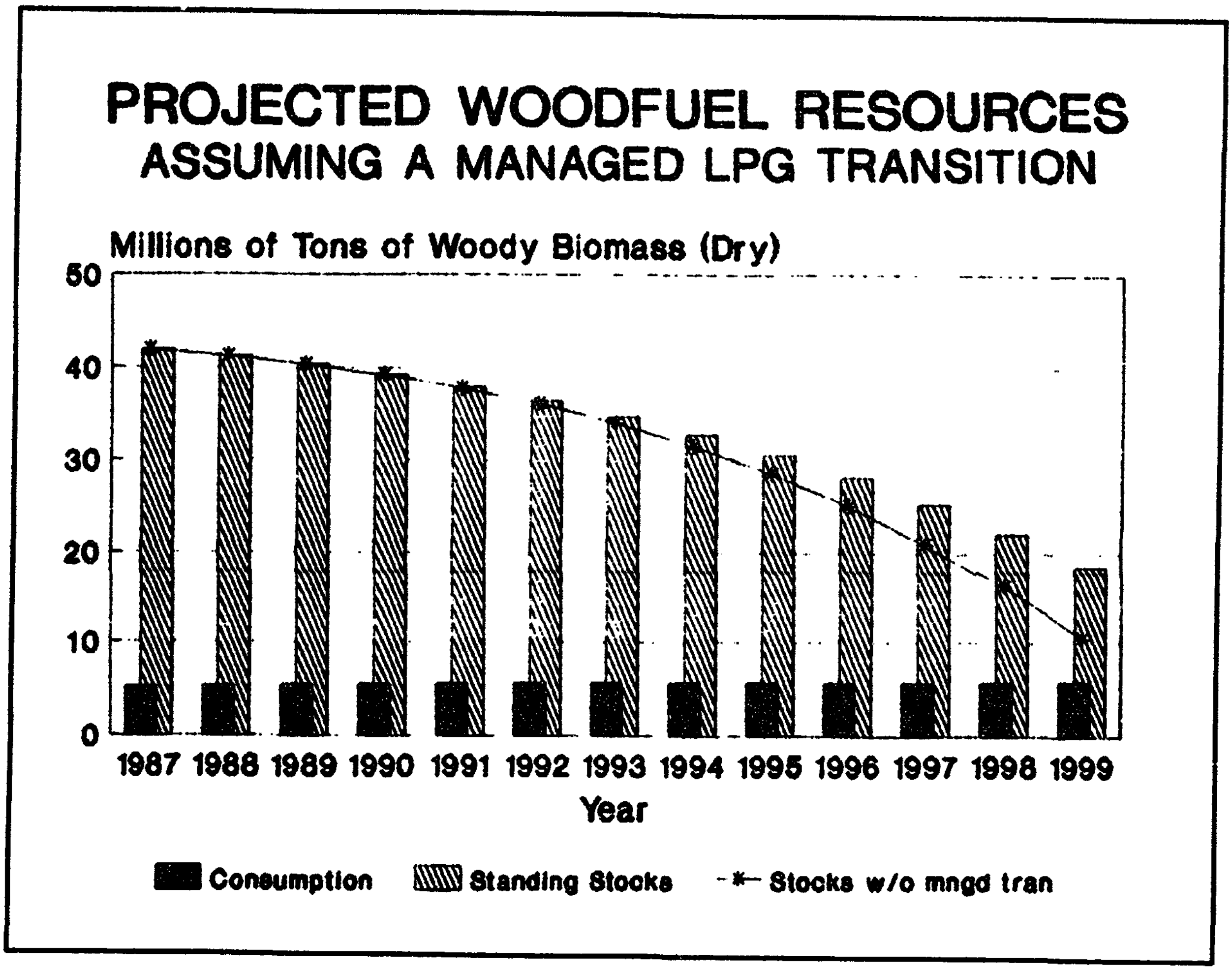


Figure 5.3: THE EFFECT OF A MANAGED TRANSITION ON WOODFUEL RESOURCES



VI. RURAL POWER SUPPLY: ISSUES AND OPTIONS

6.1 Household electricity use is remarkably widespread in the northern governorates. Nearly 63% of all households use electricity from sources other than dry cell batteries, including 96% of urban households, and 59% of rural households. The high incidence of rural use is extraordinary when compared to middle income countries (such as in South America), where only 30 to 50% of rural households may be expected to use electricity. What is even more remarkable is the fact that the majority of households in the northern governorates using electricity obtain it from sources other than YGEC; in fact, users of non-grid electricity outnumber grid connected users by almost four to one. While this unprecedented use of electricity has no doubt benefitted rural households, it has done so at great cost, economically and financially. In fact, there appears to be considerable scope for reducing the costs of rural power supply.

Existing Rural Power Systems

6.2 Among the power systems found in the northern governorates are: (a) the grid and numerous isolated systems operated by the public utility (YGEC); (b) autogeneration (and in many cases local distribution) by a large number of private households and industrial operators throughout the country; and (c) lead-acid car or truck batteries used by many households for television. Based on information from YGEC and the Household Fuel Marketing Surveys, it is estimated that, out of 769 Gwh supplied in the northern governorates in 1988, 545 Gwh (71%) was generated by YGEC, and the remaining 224 Gwh (39%) was privately produced for own-consumption or sale.

6.3 Of the 769 GWh consumed in 1988, 46% was consumed by households, 27% by industrial users, 14% by the commercial sector, and the remainder by the military, agriculture, water supply, hotels and street lighting. Consumption characteristics of rural and urban households are given in Table 6.1 by source of generation; this data leads to the following observations:

(a) Autogeneration is an entirely rural phenomenon which accounts for virtually all household electricity consumption in rural areas, while the public utility meets virtually all of urban electricity demand;

(b) As with the consumption patterns of other fuels, there are striking differences between rural and urban consumption of YGEC electricity. Urban consumption per household is more than twice as great as rural consumption. Since rural/urban income and expenditure differences are not as great as one would normally expect (average total rural expenditure is about 70% of the average urban total), this disparity may be in large part attributable to the length of time connected. On average, urban households have been connected to the grid five times longer than rural households;

(c) As with LPG, households exhibit a high willingness to pay for electricity, at least for low-power basic needs such as lighting; in rural areas, households pay on average over US$ 0.60/kWh; and

(d) Average consumption for rural YGEC households is about twice as great as for households relying on autogeneration, most likely because autogeneration is much more expensive and is only available during limited periods of the day, which reduces the usefulness of appliances such as refrigerators and water heaters. In fact, whereas there is an incidence of 0.5 refrigerators per household and 0.3 water heaters per household in YGEC households, the incidence of these appliances in households relying on autogeneration is statistically insignificant. Rural households are apparently unwilling or unable to pay the high costs of additional autogeneration to enable the use of these "luxury" appliances. Furthermore, they are less likely to be able to afford the appliances themselves.

Table 6.1: HOUSEHOLD ELECTRICITY DEMAND, 1987

Source of Electricity	Urban	Rural	Total
A. No electricity			
# of households	6000	498,000	504,000
% of all HH	4	41	37
B. YGEC			
# of households	133,000	49,000	182,000
% of HH in group	94	4	14
average kWh/yr.	1311	588	1116
yrs. connected	9.4	1.9	7.0
avg. price, YR/kWh	1.36	1.82	1.49
C. Own-generated			
# of households	-	85,000	85,000
% of HH in group	-	7	6
average kWh/yr.	-	386	386
years owned	-	2.8	2.8
D. Private generation			
# of households	-	464,000	464,000
% of HH in group	-	38	34
average kWh/yr.	-	235	235
avg. price, YR/kWh	-	5.93	5.93
E. Battery			
# of households	3,000	124,000	127,000
% of HH in group	2	10	9
average kWh/yr.	23	23	23

Sources: Data on average consumption and years connected from University of Sana'a survey #2, except for YGEC figures, which were provided by YGEC; all other figures from CPO Family Budget Survey.

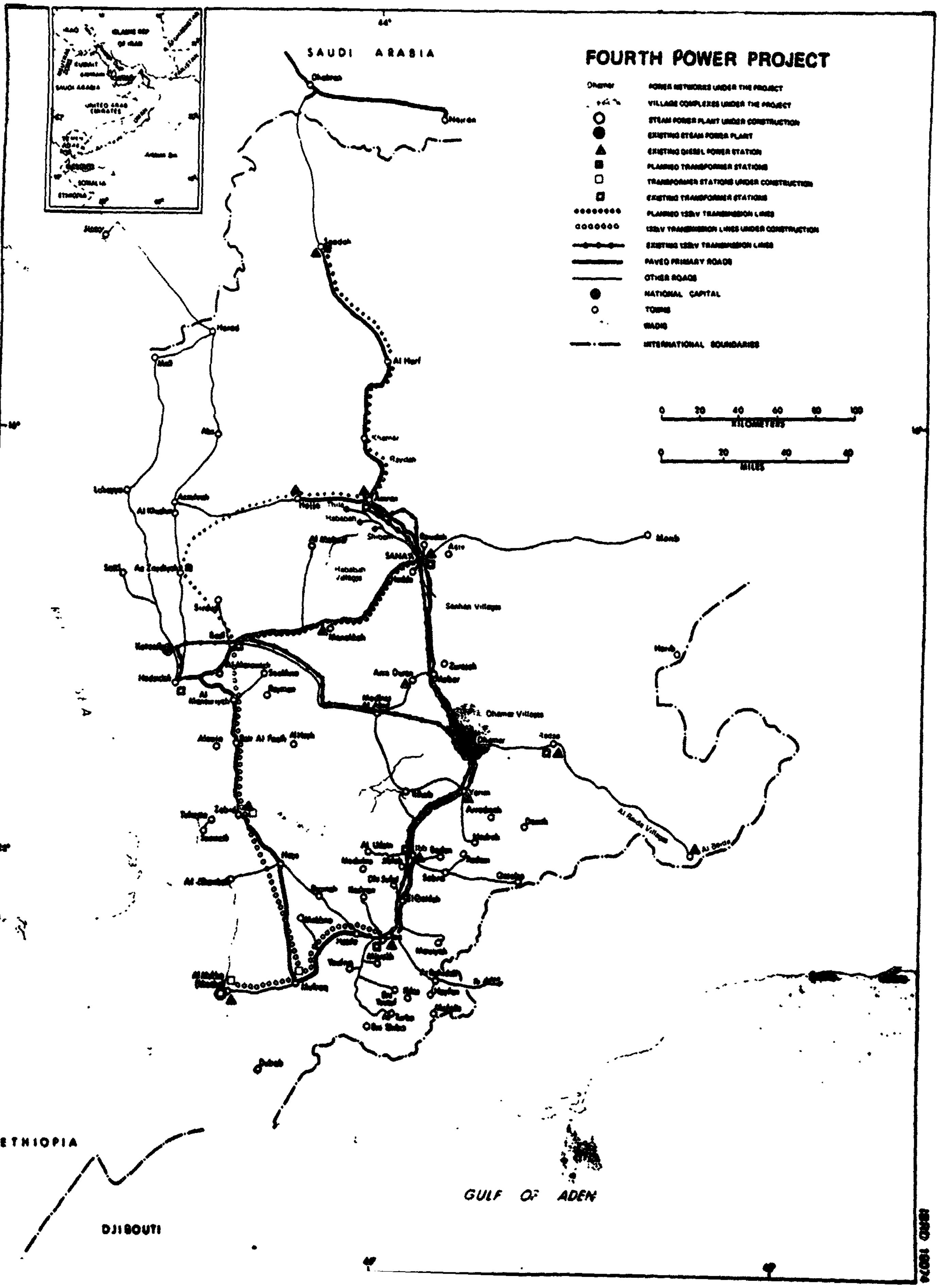
6.4 The YGEC system in the northern governorates, which is depicted below in Figure 6.1, consists of two components: the interconnected grid (comprising the thermal power stations at Ras Khatenib and Mokha, and the major diesel stations in the urban areas of Sana'a, Hodeida and Taiz, all connected to the 132-kV network), and about 33 isolated systems throughout the country, consisting of diesel units and associated distribution networks. The interconnected system has an installed capacity of 372 MW, of which 310 MW are in the two thermal plants and 62 MW in the city diesel units. In 1988, the interconnected system accounted for about 93% of YGEC's electricity sales and generation. At present, this system has excess generating capacity. In 1988, maximum demand of the grid was 143 MW, leaving a reserve margin of 160%. However, given general demand growth, and once the Amran and Bajil cement plants (which now generate their own power) and other industrial users are linked to the interconnected system during the next few years, this reserve margin is expected to disappear in 1993; by 2000, YGEC is expected to increase its generation threefold. The World Bank Energy Strategy Review has recommended that future capacity expansion utilize domestic natural gas as fuel.

6.5 Only 4% of rural households in the northern governorates rely on YGEC for electricity; the remaining 55% of rural households which use electricity obtain it from private generation or liquid batteries. If the number of rural households grows 2% annually over the next 15 years, by 2004 there will be nearly 1.8 million rural households. If implementation of the current and proposed power projects (Power III, IV, and V) as well as the Earthquake Reconstruction Project proceed as planned there will be approximately 370,000 rural households connected to YGEC, suggesting that the portion of households connected will increase to 21% by 2004. On the other hand, if the fraction of rural households using their own generators or purchasing power from private producers remains constant at 45% of all rural households, there will be over 800,000 rural residences using electricity generated from sources other than YGEC, plus those using lead-acid batteries.

6.6 The prospects for increasing the portion of grid-connected rural households beyond 21% in the next 15 years are poor. The costs of rural electrification are increasing as the most accessible rural communities have already been connected. The Power V Rural Electrification Feasibility Study estimated that the average costs of distribution (from the 11kV level downwards) and connection for households under that program would be $933 per household (1987$); the most expensive connections considered in the study were $1300 each. Considering these costs, the financial resources required to accelerate rural electrification are immense. If another 1 million rural households were to be connected for a conservative average cost of $1500 each, resulting in connection of nearly 80% of all rural households by 2004, the additional cost would be $1.5 billion.

6.7 YGEC tariffs contain cross-subsidies between consumer categories. Most industrial consumers and some hotels and agricultural enterprises are subsidized, while the highest rates have been set for rural households, which pay YR 1.50/kWh or as much as twice the rate paid by subsidized consumers. Urban residential consumers pay YR 1.10/kWh, reflecting the lower distribution costs in urban areas. When fixed monthly service costs are taken into consideration, the average urban rate is YR 1.36/kWh and the average rural rate is YR 1.82/kWh. Even though tariffs exceed the long-run marginal cost estimated in a 1984 World Bank study, this tariff structure does not provide adequate revenues to cover the financial requirements of YGEC in the short-run due to underutilized capacity, technical losses and administrative inefficiencies. The Government and YGEC are aware of the need to restructure electricity tariffs and have already appointed consultants to carry out the study under the Bank's Third Power Project (Cr. 1361-YAR).

Figure 6.1: THE YGEC SYSTEM IN THE NORTHERN GOVERNORATES



6.8 Although YGEC may generate more energy than any other electricity source, autogeneration provides power for nearly four times as many households and represents more installed capacity. In 1987, residential autogeneration represented 416.5 MW of installed capacity (about 83% in diesel units) which produced 28 Gwh for own-consumption and 110 Gwh for sale through private networks to other households. Average generator size is about 4.9 kW and average monthly generator fuel consumption (mostly diesel) is 196 liters. In addition, some 4 Gwh of electricity was supplied by liquid batteries for residential use. Battery power is not included in the demand and supply figures to avoid double-counting as it is assumed that the preponderance of cells are charged by power from autogenerators or YGEC.

6.9 Total installed generator capacity comprises numerous small gasoline and diesel generators in the 500 W to 7 kW range. A smaller proportion of total capacity comprises the 5 to 80 kW range, while 80 to 200 kW units may make up the largest single portion of capacity. These large units are virtually all diesel. All households in University of Sana'a survey #2 which reported owning a generator indicated that they also provided power to other households. In fact, only about 8% of households buying power from non-YGEC sources obtain it from cooperatives; approximately 90% buy it from individuals who produce and distribute it as a business. The smallest generators are used by individual households and provide electricity to a few nearby neighbors. The larger generators, on the other hand, represent a significant business activity in which electricity is sold to many households in the vicinity. During missions to the northern governorates, private, household-based enterprises were visited which supplied electricity to over 200 households and which operated fairly sophisticated billing systems.

6.10 Results from University of Sana'a survey #2 indicate that rural consumers of privately produced power pay approximately YR 5.93/kWh. Site visits confirmed that consumers of privately produced electricity pay considerably more for power than YGEC consumers, though there is a high degree of variability. One shop owner paid YR 50 per month for a single 20W tube lamp operated only 5 hours per night, implying a cost of nearly YR 17/kWh. In a private 225 kW system which included metering at each connection (unlike most small diesel systems which charge monthly by the appliance), consumers were charged a fixed fee of YR 80 for up to the first 15 kWh per month, YR 3/kWh for the next 10 kWh, YR 2/kWh for the following 10 kWh, and YR 1/kWh thereafter. Average consumption per connection was approximately 17.4 kWh/month, suggesting that consumers were paying on the order of YR 5/kWh.

6.11 Even at these prices, private generation and distribution is not excessively profitable. The relatively high prices consumers pay simply reflect the high costs of this technically inefficient power supply source. A properly sized 5 kW system providing power to 17 households may produce electricity at a levelized cost of around YR 5.20/kWh, whereas a 60 kW system supplying 200 households produces electricity at a levelized cost of nearly YR 4.00/kWh. However, private generation capacity in Yemen is often oversized, in several observed cases by a factor of three, resulting in poorer fuel-to-electricity efficiency and higher levelized production costs than suggested above.

6.12 Conservatively assuming a fuel-to-electricity efficiency of 0.5 li of diesel per kWh consumed for private generation in Yemen, and that all private generation is diesel, approximately 68,000 t of diesel was consumed in 1987 for private household generation at a total economic cost of YR 106 million. Although grid extension throughout rural Yemen would be prohibitively expensive, continued reliance on private generation will also remain costly. There appears to be considerable scope for reducing the costs of rural household power supply and improving service.

The Potential for Alternative Technologies

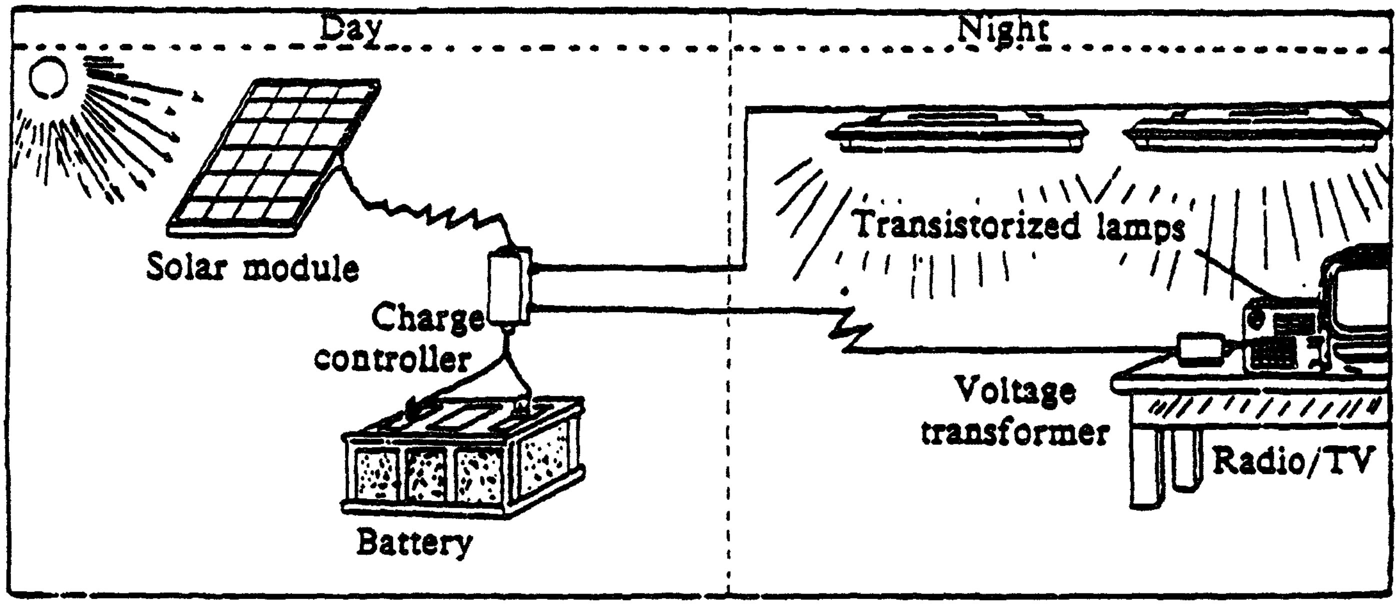
6.13 The preceding section shows that rural non-YGEC electricity consumption is widespread for low power, basic needs such as lighting and television reception, and that non-YGEC generation will remain significant over at least the next 15 to 20 years. Non-YGEC consumers have demonstrated a very high willingness and ability to pay for this service, paying on average over US$ 0.60/kWh. This price reflects the high costs of small diesel generation.

6.14 The high costs of grid extension and rural private generation in Yemen render alternative electricity supply technologies very attractive. The most promising alternative is the household photovoltaic (solar electric energy) system. These systems comprise photovoltaic (PV) modules which convert sunlight into DC electricity, batteries for storing this energy for use during the night or cloudy periods when there may not be sufficient sunlight to meet all loads, a voltage regulator to prevent excessive overcharging or discharging of batteries, and appropriate DC appliances such as high efficiency fluorescent lamps. (DC fluorescent lamps, televisions, and radios are already widely available in Yemen). A generic depiction of this system is shown in Figure 6.2.

6.15 Photovoltaic technology has proven reliable and cost-effective for providing small amounts of power at remote sites. PV modules are perhaps the most reliable part of these systems, and module cost reductions over the past decade have allowed PV to become competitive with conventional technologies for remote telemetry, telecommunications, cathodic protection, and vaccine refrigeration. More recently, several projects worldwide have demonstrated the potential for commercially viable dissemination of household PV systems in rural areas. GTZ has financed such projects in Peru, Tunisia, and Philippines, the French government has undertaken a widespread though heavily subsidized program in French Polynesia, and an American non-profit organization has developed a sustainable dissemination program in the Dominican Republic. These projects have demonstrated the importance of appropriate balance-of-system design (i.e. all system components other than the PV modules) and the need for financing schemes if systems are to be commercially disseminated beyond the wealthiest few percent of rural households. Most importantly, though, these projects have illustrated the technical maturity of the technology and the feasibility of commercially viable system dissemination.

6.16 Based on the experience in other countries, the potential for these systems in Yemen appears to be very good. Most rural households in Yemen cannot expect grid connection in the next two decades, rural household income and liquidity are relatively high, rural households have already demonstrated a willingness and ability to pay for electricity for low power basic needs, the cost of conventional rural power supply systems now used in Yemen is high, and the private sector is active and motivated. The confluence of these factors, together with the good solar resource in Yemen, suggests that Yemen may indeed be the most promising location for widespread commercial dissemination of household PV systems in the world.

Figure 6.2: HOUSEHOLD PHOTOVOLTAIC SYSTEM COMPONENTS



Source: Interdisziplinare Projekt Consult GmbH

6.17 The cost breakdown for a complete PV system that could meet the average daily load of households currently purchasing power from private generators is as follows (profit margins and other overheads have not been included):

	in US $
90 Wp of modules	495
Batteries	70
Charge controller	75
Three fluorescent lamps and fixtures	90
Wiring and installation	30
Total System Cost	$ 760

6.18 Smaller systems with fewer lighting points which may be acceptable to lower income households or those with more modest needs could be configured to include only 50 Wp of module, half as much battery storage, and fewer lamps and fixtures. The cost of such a system would be on the order of $450.

6.19 In order to better evaluate this potential, grid extension, diesel generation, and PV systems were compared economically. These results, discussed in detail in Annex 7, indicate that PV is economically less costly than grid connection or diesel generation for settlements where there are fewer than 20 to 45 households with electricity located more than 2 to 4 km from the existing 11 kV grid, i.e. areas in which there are fewer than 12 to 16 low-power connections per kilometer of 11kV line. The precise criteria depend on site specific conditions such as the economic cost of delivered fuel, local terrain which may result in higher costs for grid extension, etc.

6.20 On the basis of these results and observations, a follow-up activity for the development of appropriate household PV systems and a commercial infrastructure for dissemination and maintenance of such systems is recommended. Since the activity would complement conventional electrification, the appropriate government counterpart would be MEW. However, a private sector firm should be selected as an operational counterpart; YGEC and University of Sana'a could provide technical support and monitoring assistance.

6.21 This commercialization activity could be structured as a joint venture between the a foreign donor and a local private firm. The foreign donor would provide foreign exchange items such as international consultancy and an initial supply of system components, while the local firm would cover local costs, and in particular, would provide staff. Selection of the local firm would be based on business plans submitted in response to a request for proposals. The activity would include the following components:

(a) the technical testing of household PV systems and the specification of appropriate system design;

(b) consumer acceptance testing over a period of at least one entire weather cycle during which time systems will be installed and monitored in rural households. Criteria for selection of villages for system testing would be mutually agreed to with the government counterparts. The effects of competition with private power distributors who currently sell power to rural households will also be assessed. At the end of this period, the systems will be offered for sale to the households in order to judge actual consumer acceptance;

(c) the development of effective financing mechanisms, if necessary, which will make the systems affordable to more households; and

(d) the development of local private sector capability, particularly through training of local staff, to carry on the assembly, marketing, dissemination, and maintenance of the systems on a sustainable, widespread, and commercially viable basis.

<u>The Need for a Rural Power Strategy</u>

6.22 The development and introduction of less costly alternative rural power supply options recommended above should be part of an effort to formulate a broad rural power strategy. With the decline in remittance income, the ability of rural household to purchase these alternative systems may diminish somewhat. Despite their costs, social and political pressure for grid extension will remain and diesel generation will continue to supply most rural households with electricity. It is recommended that the Government, through YGEC and MEW, formulate a rural power strategy to minimize economic and financial costs and improve service by conducting the following activities:

(a) The formulation of a strategy to improve the service and reduce the costs of private power generation. In effect, this requires the Government to acknowledge the vital role of the private sector in providing power to rural areas and to create an environment where rural consumers and the economy as a whole can benefit as much as possible from private sector activity in this area.

Site visits and survey results suggest that capacity is not properly sized to demand, equipment operation is sub-optimal, proper safety and maintenance procedures are often lacking, and generator output is probably highly underutilized. Even if PV systems were to rapidly penetrate the rural autogeneration market, small generators will likely continue to dominate rural power supply. Therefore, it is important to evaluate the potential for more efficient operation of this source of energy in Yemen and develop mechanisms to promote efficient operation of private generation. To do so, this component would comprised of the following activities:

(i) an inventory of the most common diesel and gasoline generators used in Yemen (power rating, estimated lifetime, purchase price, operating costs, etc.);

(ii) an evaluation of generator efficiencies under a range of typical operating conditions;

(iii) a description of the supply systems for generator and spare parts importation; and

(iv) recommendations on import standards, dissemination of information on efficient operations and maintenance, and other institutional mechanisms, as well as safety considerations, to promote efficient private power supply.

One approach for realizing the potential of improvement in private power generation may be to develop a scheme for licensing private generators. In order to obtain a license, private parties would have to meet certain technical generation and distribution standards. License holders would be entitled to technical extension services that may help them operate, maintain, and expand their systems at least cost. A further (and probably greater) incentive for private generators to seek licensing would be to offer license holders a ready supply of spare parts at appropriate costs (perhaps subsidized if it is shown to be justified), or perhaps even vouchers for the purchase of fuel at discounted prices. Pressure for operators to share the rents of more efficient operation with consumers might come from the availability of alternative power supply sources, such as the household PV systems described above.

(b) A thorough evaluation of the costs and benefits of rural grid extension, the identification of criteria which determine whether grid extension is justified in particular cases, and development of a detailed rural electrification plan using these criteria which takes into account the results of the PV commercialization activity and the rural private power assessment described in (a).

VII. A HOUSEHOLD ENERGY STRATEGY

Strategic Principles

7.1 The formulation of a household energy strategy for Yemen is guided by the following strategic principles:

(a) **Welfare Improvement**: As Yemen enters the era of domestic oil production, it is important to maintain the momentum of development which has built up over the past two decades. An important aspect of this development is the improvement of household welfare. The Government now has a greater responsibility to invest resources in rural development to improve rural household welfare, particularly since villages are no longer benefiting from remittance income to the extent that they used to. The Government also has a greater ability to make investments which benefit rural inhabitants, who constitute the bulk of the population (including the poorest segments), because it is the recipient and allocator of oil earnings. The household energy strategy seeks to improve household welfare in the short run through interfuel substitution and the efficient use of energy and, in the long run, through minimizing further environmental degradation caused by woodfuel harvesting.

(b) **Resource Sustainability**. The improvement of household welfare is intertwined with the issues of resource use and environmental impact. Clearly, if a resource such as woodfuel is depleted, household welfare will decline unless appropriate substitutes are made available and affordable. Although Yemen currently faces depletion of woody biomass resources, it enjoys a supply of LPG adequate for several decades of domestic consumption. The household energy strategy stresses the prudent use of indigenous energy resources to promote resource sustainability.

(c) **Institutional Viability**. The Government of ROY faces an enormous task in managing the recently discovered petroleum resources and maintaining the momentum of development. Its skilled human resources are at a premium. Therefore, the household energy strategy does not rely primarily on government resources for strategy implementation. Yemen has always been characterized by a buoyant private sector, and the household energy strategy aims to mobilize this resource through a market approach to policy and program implementation.

Elements of the Strategy

7.2 Chapters 4-6 developed the individual recommendations which comprise the household energy strategy for the northern governorates and provide a basis for formulation of a strategy for the entire country. The key elements are: (a) options to improve woodfuel resource management; (b) measures to accelerate LPG substitution; and (c) activities to enhance rural power supply. These are summarized in Table 7.1, along with information on implementation, estimated cost and status of the recommendation.

Table 7.1: SUMMARY OF STRATEGY ELEMENTS

Activity	Proposed Implementing Agency	Approximate Cost (US$)	Status	Paragraph References
WOODFUEL OPTIONS				
Information development	Forest Department	400,000	Could be part of Bank's Nat'l. Ag. Mgmt. Project	4.40 to 4.43
Improved Carbonization	For. Dept./LCD	150,000	"	4.44
Indigenous Res. Management	For. Dept./LCD	100,000	"	4.45 to 4.46
Community and household agroforestry programs	For. Dept./LCD	500,000	"	
LPG SUBSTITUTION				
Improved Infrastructure				
Fuel Supply	YPC/GCOMR	9 million	Main component of LPG Crash Program	5.15, 5.19 to 5.21
Bottle Supply	YPC	9 million initially and 3.5 million per year thereafter	Could be funded by YPC from extra fuel revenues	5.22-5.23
Improved Management				
Involve private sector	MOMR/YPC/priv.	N.A.	Could be follow-up to Crash LPG Prog.	5.26-5.27
Pricing policy	MOMR	N.A.	"	5.29-5.33
Safer operations	YPC/priv.	N.A.	"	5.34-5.38
Commercialize LPG Appliances	GCOMR/YPC/priv.	85,000	ESMAP activity	5.39-5.41
RURAL POWER SUPPLY				
Photovoltaic market testing	MEW/Priv.	305,000	ESMAP activity	6.20-6.21
Rural Power Strategy Formulation	YGEC/MEW	500,000	potential ESMAP	6.22

Strategy Management

7.3 Organizational Responsibilities. Yemen's household energy strategy should ideally be developed within the context of a coherent national energy policy. However, the development of a national energy strategy requires an institutional framework capable of carrying out planning and implementation tasks, a well-defined division of responsibility between sectoral institutions, and basic tools such as databases and evaluation mechanisms. At present, proper energy planning and coordination do not exist in Yemen for strategy formulation, project selection or general programming. RECOMMENDATION: To implement the household energy strategy, the Government will need to designate an existing agency as a centralized energy planning and coordinating agency and provide for qualified staff, including expatriates, or, at a minimum, an interministerial energy committee with an operational staff to coordinate the components of the strategy which will involve several different Government entities. This action has also been recommended by the Bank's Energy Strategy Review. The Planning Department of MPD appears to be the best suited to this task.

7.4 Seven different Government organizations will be primarily responsible for strategy implementation. It is anticipated that much of this work will be done by non-governmental Yemeni experts and foreign consultants. As part of accelerated LPG substitution, YPC will need to upgrade its LPG unit to the status of a Department with more personnel and an improved budget. In addition, the respective roles of YPC, GCOMR, and MOMR need to be clarified so that YPC has more autonomy to develop LPG as a household fuel but also so that GCOMR and MOMR account for and coordinate YPC decisions on LPG utilization with overall gas and oil policies and investments. The rural electricity supply strategy formulation should be managed by the YGEC, in cooperation with the planning section of the MEW. Private sector counterparts would be operationally involved in the LPG tannur and household PV system projects; government supervision of the LPG tannur project could be carried out by GCOMR and YPC; MEW could supervise the household PV project. Finally, elements of the natural resource management component can be jointly or separately prepared by the Forestry Department of the Ministry of Agriculture and the Land Survey Authority.

7.5 For specific activities, other Government and non-governmental organizations may be involved in implementation and evaluation, with overall management by one of the institutions mentioned above. For example, development of improved LPG tannurs and household PV systems may involve development of the University of Sana'a for technical and monitoring support and local women's councils for determination of social acceptability.

7.6 Financing. Financing requirements were roughly outlined in Table 7.1. As noted above, some of the recommended activities can be or will be financed under the LPG Crash Program or the National Agriculture Sector Management Program. For activities that do not fall under these projects, Yemeni authorities can follow two broad avenues for mobilizing necessary funds for components which cannot be self-financing. The Government may wish to organize an Energy Sector Donors' Meeting which brings together the principal bilateral, multilateral and NGO organizations which are or would like to be active in the Yemeni energy sector. The household energy strategy would then be one element in a portfolio of projects and programs for the sector which would be presented for discussion and financing. This would entail a good deal of preparation to assemble the portfolio and schedule the meeting, but could have important benefits not only in the enhanced mobilization of funds but also in efficiency gains from improved coordination of donor activities. Alternatively, the household energy strategy could be circulated to the donor community for financing in its entirety, or on the basis of individual components or even specific activities. Full financing would increase the likelihood that an integrated strategy would be implemented (something that would be hard to achieve through piecemeal implementation) but may be more difficult to accomplish than farming segments out to donors with parochial interests.

7.7 Training Needs. Yemeni officials clearly need training in data collection and analysis, planning, project selection, monitoring and evaluation for the entire energy sector. Beyond this, specific training is recommended for skills related to the acceleration of LPG market penetration and improved natural resource management. For the substitution component, training is needed for (a) the development and enforcement of safety procedures, and (b) the education of operators in safe cylinder handling and filling practices. For the forest energy management component, training of relevant Yemeni staff would be helpful in (a) interpretation of aerial photography and remotely-sensed images, (b) the development and analysis of a database on woody biomass supply and demand, and (c) dissemination of improved agroforestry techniques.

7.8 Monitoring and Evaluation. As the strategy is implemented, two types of monitoring and evaluation can provide useful feedback to the central body which will coordinate the effort, as well as to the relevant authorities which will be responsible for managing each separate component. First, regular collection of data on relative fuel prices, quantities purchased and collected, energy equipment purchases, behavioral changes, etc. should take place to determine how effective different measures are in reducing woodfuel consumption and improving household welfare. Some of this can be obtained through market surveys while much of it should be developed from periodic surveys of randomly selected control households throughout the country. Second, a mid-term and final assessment should be conducted by experts (local and/or international) who are not directly concerned by the success or failure of strategy implementation. Assuming that the strategy is implemented over a ten-year period from 1991 - 2000, then these in-depth reviews should occur in 1995 and 2000.

Expected Results, Costs and Benefits

7.9 Expected Results. Implementation of the strategy will result in significant financial savings to households. Table 7.2 provides an estimate of household fuel consumption and expenditure trends with and without strategy implementation. Calculations were made assuming that:

(a) increased LPG consumption will directly substitute for woodfuel;

(b) the price of woodfuel will not escalate as rapidly with strategy implementation due to reduced demand pressure;

(c) LPG costs will be lower with the strategy due to lower prices for cylinders, appliances, and fuel; and

(d) electricity consumption and total expenditure will not grow as rapidly due to the implementation of efficiency measures and dissemination of household photovoltaic systems.

The results of the rural power strategy study and the improved carbonization activities have not been considered.

7.10 Even with successful execution of all strategy components, wood will continue to play a vital role in the Yemeni energy economy, dropping from 6.7 million tons in 2000 to a little over 6.0 million tons when the strategy is followed. Thus, the strategy can slow the growth in woodfuel demand but not prevent it. Nonetheless, given the precarious status of woodfuel resources in Yemen and the deleterious effects of resource depletion on household welfare, interfuel substitution efforts are justified. Widespread woodfuel resource depletion would likely lead to more rapid growth of LPG consumption than suggested in this report. Together with long-term woodfuel supply programs, it is hoped that the negative consequences of woodfuel depletion can be minimized.

7.11 During its first ten years the strategy should result in woodfuel savings of over 3.2 million tons and electricity savings of over 400 Gwh, as well as savings of kerosene, gasoline and diesel fuel. The present value of the household savings which have been quantified amounts to over YR 2.3 billion (US$236 million) in 1988 YR.

7.12 The LPG Crash Program (US$9 million) and the National Agriculture Development Project are essential elements of the household energy strategy. In addition, the purchase of 450,000 LPG cylinders the first year would cost approximately US$9 million and the purchase of about 175,000 bottles per year subsequently would cost 3.5 million. Finally, other activities which were identified earlier in this chapter but which would not be financed under the cylinder purchase, or LPG program amount to US$1,550,000.

Table 7.2: HOUSEHOLD FUEL CONSUMPTION TRENDS, 1991-2000

WITHOUT STRATEGY		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Woodfuels	000 t	5284	5424	5567	5713	5861	6013	6168	6325	6486	6650
Woodfuel cost	YR/t	769	801	835	870	907	946	986	1028	1072	1119
LPG	000 t	114	117	121	125	129	132	137	142	147	151
LPG cost	YR/t	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Electricity	GWh	446	480	517	560	603	643	685	725	765	804
Elec. cost	YR/MWh	3093	3072	3044	3004	2970	2954	2942	2941	2947	2959
Consumer expenditure million YR		6296	6696	7129	7591	8076	8576	9125	9702	10313	10949

WITH STRATEGY		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Woodfuels	000 t	5242	5347	5420	5496	5574	5649	5741	5835	5933	6027
Woodfuel cost	YR/t	769	793	824	859	895	933	973	1014	1058	1103
LPG	000 t	120	128	142	156	170	184	198	212	226	240
LPG cost	YR/t	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
Electricity	GWh	446	473	504	538	570	599	625	655	688	723
Elec. cost	YR/MWh	3093	3072	3044	3004	2970	2954	2942	2941	2947	2959
Consumer expenditure million YR		6128	6461	6854	7270	7703	8146	8612	9119	9660	10228
Annual savings		167	235	275	321	373	431	513	584	652	721
NPV of savings	YR 2,337 million										

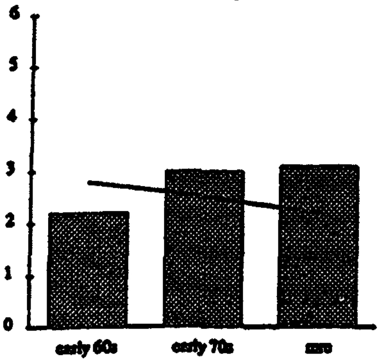
7.13 Because many elements of the household strategy have been incorporated in other projects which have already been initiated, calculating an economic rate of return for the strategy would be a rather academic exercise. Furthermore, calculating economic values for fuels such as firewood, environmental degradation, or household welfare would yield rather arbitrary results. Further economic analysis would not provide additional insights into the value of a household energy strategy in Yemen, or clarify decision making. Rather, in Yemen the adoption of a household energy strategy is perhaps best viewed as a strategy for reducing the cost of energy to households and thereby improving their welfare.

SOCIAL INDICATOR DATA SHEET, 1989

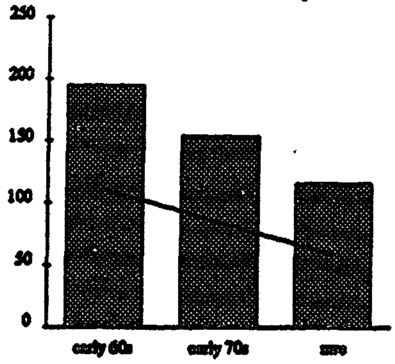
Yemen Arab Republic

	Unit of measure	25-30 years ago	15-20 years ago	Most recent estimate (mre)	Same region / income group: Europe, Middle East, North Africa	Same region / income group: Lower-middle-income	Next higher income group
HUMAN RESOURCES							
Size, growth, structure of population							
Total population (mre ≈ 1988)	thousands	4,659	6,075	8,742	502,676	629,214	424,306
14 and under	% of pop.	42.5	46.4	48.2	38.3	38.3	34.1
15-64	"	54.5	50.4	48.8	56.8	57.4	60.2
Age dependency ratio	unit	0.84	0.98	1.05	0.75	0.74	0.65
Percentage in urban areas	% of pop.	5.1	11.0	22.5	49.7	56.1	68.8
Females per 100 males							
Urban	number	..	..	..	..	..	..
Rural	"	..	..	..	..	..	..
Population growth rate	annual %	2.2	3.0	3.1	2.0	2.2	1.8
Urban	"	9.1	9.6	8.9	3.4	3.5	3.1
Urban/rural growth differential	difference	7.2	7.3	7.3	2.2	2.5	3.8
Projected population: 2000	thousands	..	..	12,633	661,662	805,063	521,035
Stationary population	"	..	..	44,249	..	..	..
Determinants of population growth							
Fertility							
Crude birth rate	per thou. pop.	49.0	49.8	47.9	33.5	31.5	26.4
Total fertility rate	births per woman	6.97	7.10	6.97	4.58	4.08	3.39
Contraceptive prevalence	% of women 15-49	..	..	..	..	..	..
Child (0-4) / woman (15-49) ratios							
Urban	per 100 women	..	..	..	..	..	..
Rural	"	..	..	..	..	..	..
Mortality							
Crude death rate	per thou. pop.	27.2	22.6	15.7	10.6	8.6	8.3
Infant mortality rate	per thou. live births	194.4	153.6	116.0	70.9	59.1	46.9
Under 5 mortality rate		..	..	194.0	100.2	96.5	58.4
Life expectancy at birth: overall	years	39.9	44.9	50.9	62.7	63.8	67.2
female	"	40.7	46.0	52.4	64.5	66.1	69.8
Labor force (15-64)							
Total labor force	thousands	1,322	1,336	1,843	173,176	232,336	156,018
Agriculture	% of labor force	79.0	72.5	..	..	..	..
Industry	"	7.2	8.4	..	..	..	..
Female	"	6.5	10.1	13.4	25.6	31.2	29.5
Females per 100 males							
Urban	number	..	..	..	..	..	..
Rural	"	..	..	..	..	..	..
Participation rate: overall	% of labor force	29.4	25.3	24.6	37.7	39.0	38.2
female	"	3.9	4.9	6.3	19.0	23.5	22.1
Educational attainment of labor force							
School years completed: overall	years	..	..	4.1	..	..	..
male	"	..	..	..	..	..	..
NATURAL RESOURCES							
Area	thou. sq. km	195	195	195	12,216	17,083	20,337
Density	pop. per sq. km	24	31	43	40	36	20
Agricultural land	% of land area	42.5	42.8	42.9	29.7	38.3	31.6
Agricultural density	pop. per sq. km	56	73	101	135	94	65
Forests and woodland	thou. sq. km	16	16	16	926	5,449	7,587
Deforestation rate (net)	annual %	0.0	0.0	0.0	0.2	-0.7	-0.4
Access to safe water	% of pop.	..	..	32.0	62.0	..	79.4
Urban	"	..	..	100.0	88.4	76.7	90.1
Rural	"	..	..	25.0	44.2	46.3	62.7

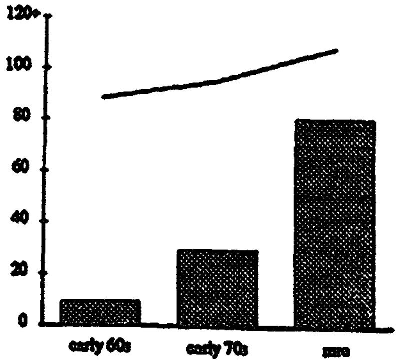
Population growth



Infant mortality



Primary school enrollment



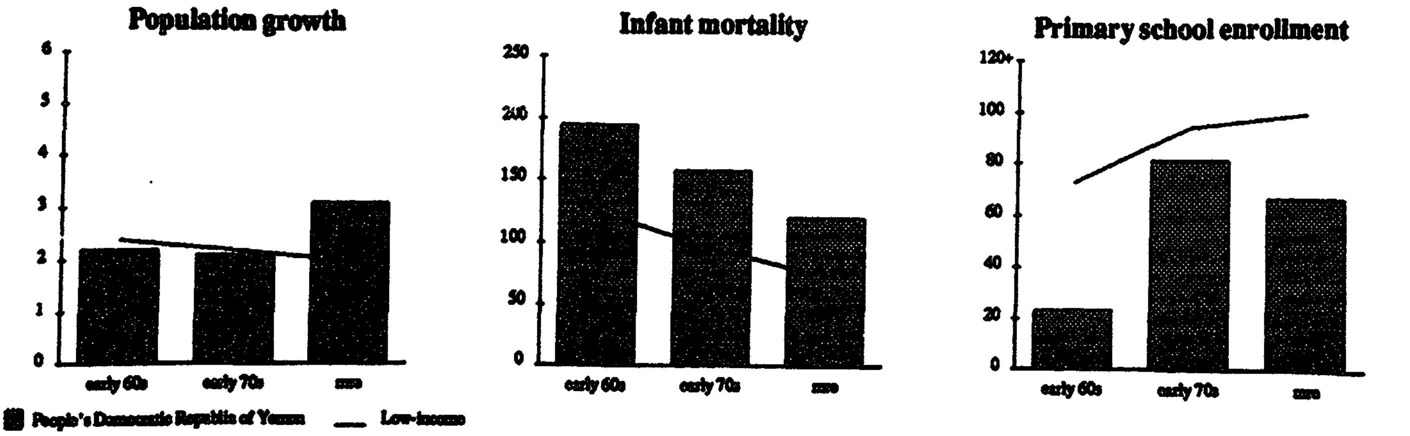
Yemen Arab Republic

	Unit of measure	25-30 years ago	15-20 years ago	Most recent estimate (mre)	Same region / income group: Europe, Middle East, North Africa	Same region / income group: Lower-middle-income	Next higher income group
INCOME AND POVERTY							
Income							
GNP per capita (mre = 1988)	US$	..	140	650	1,660	1,270	2,940
Total household income							
Share to top 10% of households	% of income	..	..	..	..	..	..
Share to top 20% of households	"	..	..	..	..	..	..
Share to bottom 40% of households	"	..	..	..	..	..	..
Share to bottom 20% of households	"	..	..	..	..	..	..
Poverty							
Absolute poverty income: urban	US$ per person	..	..	223	..	..	..
rural	"	..	..	179	..	..	..
Pop. in absolute poverty: urban	% of pop.	..	..	..	..	..	..
rural	"	..	..	..	..	..	..
Prevalence of malnutrition (under 5)	% of age group	..	..	..	..	..	..
EXPENDITURE							
Food	% of GDP	..	..	..	..	..	..
Staples	"	..	..	..	..	..	..
Meat, fish, milk, cheese, eggs	"	..	..	..	..	..	..
Cereal imports	thou. metric tonnes	14	210	835	40,185	36,712	35,596
Food aid in cereals	"	..	29	160	..	7,851	..
Food production per capita	1979-81=100	105.1	108.5	118.3	103.7	97.0	104.3
Share of agriculture in GDP	% of GDP	..	43.9	25.1	15.4	16.0	12.3
Daily calorie supply	calories per person	2,008	2,031	2,318	3,014	2,767	2,980
Daily protein supply	grams per person	65	63	68	83	70	80
Housing	% of GDP	..	..	..	..	..	..
Average household size	persons per household	..	5	..	..	..	..
Urban	"	..	5	..	..	..	..
Fixed investment: housing	% of GDP	..	..	..	..	..	..
Fuel and power	% of GDP	..	..	..	..	..	..
Energy consumption per capita	kg of oil equivalent	7.2	34.8	100.2	1,157.7	886.3	1,427.7
Households with electricity							
Urban	% of households	..	..	..	..	..	..
Rural	"	..	..	..	..	..	..
Transport and communication	% of GDP	..	..	..	..	..	..
Population per passenger car	persons	..	..	..	29	27	14
Fixed investment: transport equipment	% of GDP	..	..	..	..	..	..
Total road length	km	..	..	25,028	..	..	..
Population per telephone	persons	..	..	..	16	16	9
INVESTMENT IN HUMAN CAPITAL							
Medical care	% of GDP	..	..	..	..	..	..
Population per: physician	persons	58,238	37,600	6,268	1,009	1,547	1,021
nurse	"	7,611	..	2,683	798	..	602
hospital bed	"	..	1,300	2,232	446	..	..
Access to health care	% of pop.	..	..	25.0	..	..	..
Immunized (under 12 months): measles	% of age group	..	..	18.0	69.7	62.6	..
DPT	"	..	..	14.0	68.7	64.7	..
Oral Rehydration Therapy use (under 5)	% of cases	..	..	5.8	30.1	28.2	..
Education	% of GDP	..	..	..	..	..	..
Gross enrollment ratios							
Primary: total	% of school-age group	9.0	29.0	79.0	87.4	106.8	103.5
female	"	1.0	7.0	31.0	78.4	101.3	99.4
Secondary: total	"	0.3	4.0	15.0	47.5	52.0	57.8
female	"	..	1.0	3.0	38.7	51.8	56.7
Tertiary: science/engineering	% of tertiary students	..	3.3	..	..	..	..
Pupil-teacher ratio: primary	pupils per teacher	56	38	54	31	28	27
secondary	"	15	22	27	18	18	..
Pupils reaching grade 4	% of cohort	..	35.9	70.4	77.5	81.0	76.8
Repeater rate: primary	% of total enrollment	..	..	20.3	7.4	8.0	18.1
Illiteracy rate: overall	% of pop. (age 15+)	97.5	..	86.3	49.5	26.2	21.8
female	% of females (age 15+)	..	..	96.9	56.8	32.5	25.6
Newspaper circulation	per thou. pop.	..	10.0	..	68.1	79.3	86.5

Source: World Bank International Economics Department, September 1989.

People's Democratic Republic of Yemen

	Unit of measure	25-30 years ago	15-20 years ago	Most recent estimate (mre)	Same region / income group: Europe, Middle East, North Africa	Same region / income group: Low-income	Next higher income group
HUMAN RESOURCES							
Size, growth, structure of population							
Total population (mre = 1988)	millions	1.35	1.65	2.34	503	2,881	629
14 and under	% of pop.	44.8	47.5	45.0	38.3	35.4	38.3
15-64	"	52.5	49.8	52.6	56.8	60.2	57.4
Age dependency ratio	unit	0.91	1.01	0.91	0.75	0.66	0.74
Percentage in urban areas	% of pop.	30.1	34.3	41.6	49.7	34.2	56.1
Females per 100 males							
Urban	number	..	89	..	..	..	..
Rural	"	..	111	..	..	..	..
Population growth rate	annual %	2.2	2.1	3.1	2.0	2.0	2.2
Urban	"	3.6	3.4	5.1	3.4	3.7	3.5
Urban/rural growth differential	difference	2.0	1.9	3.5	2.2	2.2	2.5
Projected population: 2000	millions	..	..	3.34	662	3,625	805
Stationary population	"	..	..	10.62	..	..	..
Determinants of population growth							
Fertility							
Crude birth rate	per thou. pop.	49.5	47.8	47.9	33.5	30.4	31.5
Total fertility rate	births per woman	6.97	6.97	6.66	4.58	3.89	4.08
Contraceptive prevalence	% of women 15-49	..	..	..	..	57.4	..
Child (0-4) / woman (15-49) ratios							
Urban	per 100 women	..	..	..	..	..	..
Rural	"	..	..	..	..	..	..
Mortality							
Crude death rate	per thou. pop.	26.3	21.8	15.5	10.6	10.0	8.6
Infant mortality rate	per thou. live births	194.4	157.2	120.0	70.9	72.6	59.1
Under 5 mortality rate	"	..	..	176.0	100.2	174.8	96.5
Life expectancy at birth: overall	years	39.9	44.9	50.9	62.7	61.4	63.8
female	"	40.7	46.0	52.4	64.5	62.3	66.1
Labor force (15-64)							
Total labor force	millions	0.38	0.43	0.61	173	1,343	232
Agriculture	% of labor force	54.4	46.0	..	..	..	..
Industry	"	12.2	15.3	..	..	..	..
Female	"	8.3	10.0	11.9	25.6	36.0	31.2
Females per 100 males							
Urban	number	..	91	..	..	..	..
Rural	"	..	135	..	..	..	..
Participation rate: overall	% of labor force	28.3	25.8	26.1	37.7	49.2	39.0
female	"	4.7	5.1	6.1	19.0	34.9	23.5
Educational attainment of labor force							
School years completed: overall	years	..	..	..	..	..	..
male	"	..	..	..	..	..	..
NATURAL RESOURCES							
Area	thou. sq. km	333	333	333	12,216	36,997	17,083
Density	pop. per sq. km	4	5	7	40	76	36
Agricultural land	% of land area	27.5	27.6	27.6	29.7	36.1	38.3
Agricultural density	pop. per sq. km	15	18	25	135	211	94
Forests and woodland	thou. sq. km	18	17	16	926	9,154	5,449
Deforestation rate (net)	annual %	-0.6	-0.6	-0.6	0.2	-0.3	-0.7
Access to safe water	% of pop.	..	..	..	62.0	..	..
Urban	"	..	..	..	88.4	73.4	76.7
Rural	"	..	..	..	44.2	..	46.3



People's Democratic Republic of Yemen

	Unit of measure	25-30 years ago	15-20 years ago	Most recent estimate (mre)	Same region / income group: Europe, Middle East, North Africa	Same region / income group: Low-income	Next higher income group
INCOME AND POVERTY							
Income							
GNP per capita (mre = 1988)	US$	..	..	430	1,660	310	1,270
Total household income							
Share to top 10% of households	% of income	..	..	..	..	..	..
Share to top 20% of households	"	..	..	..	..	..	..
Share to bottom 40% of households	"	..	..	..	..	..	..
Share to bottom 20% of households	"	..	..	..	..	..	..
Poverty							
Absolute poverty income: urban	US$ per person	..	..	..	..	..	..
rural	"	..	..	..	..	..	..
Pop. in absolute poverty: urban	% of pop.	..	..	..	..	..	..
rural	"	..	..	..	..	..	..
Prevalence of malnutrition (under 5)	% of age group	..	..	40.0	..	..	..
EXPENDITURE							
Food	% of GDP	..	..	..	..	..	..
Staples	"	..	..	..	..	..	..
Meat, fish, milk, cheese, eggs	"	..	..	..	..	..	..
Cereal imports	thou. metric tonnes	146	86	212	40,185	27,738	36,712
Food aid in cereals	"	..	9	31	..	7,122	7,851
Food production per capita	1979-81=100	93.7	108.6	83.4	103.7	116.4	97.0
Share of agriculture in GDP	% of GDP	..	19.8	15.6	15.4	33.0	16.0
Daily calorie supply	calories per person	1,982	1,873	2,298	3,014	2,392	2,767
Daily protein supply	grams per person	50	50	72	83	57	70
Housing	% of GDP	..	..	..	..	..	..
Average household size	persons per household	..	..	..	..	..	..
Urban	"	..	..	..	..	..	..
Fixed investment: housing	% of GDP	..	..	..	..	..	..
Fuel and power	% of GDP	..	..	..	..	..	..
Energy consumption per capita	kg of oil equivalent	..	499.3	707.9	1,157.7	323.7	886.3
Households with electricity							
Urban	% of households	..	..	..	..	..	..
Rural	"	..	..	..	..	..	..
Transport and communication	% of GDP	..	..	..	..	..	..
Population per passenger car	persons	105	143	83	29	..	27
Fixed investment: transport equipment	% of GDP	..	..	..	..	..	..
Total road length	km	..	..	7,100	..	..	..
Population per telephone	persons	..	..	..	16	..	16
INVESTMENT IN HUMAN CAPITAL							
Medical care	% of GDP	..	..	..	..	..	..
Population per: physician	persons	12,867	..	4,344	1,009	1,462	1,547
nurse	"	1,851	..	1,057	798	1,746	..
hospital bed	"	..	1,201	..	446	756	..
Access to health care	% of pop.	..	..	75.0	..	..	..
Immunized (under 12 months): measles	% of age group	..	..	35.0	69.7	43.4	62.6
DPT	"	..	..	25.0	68.7	41.3	64.7
Oral Rehydration Therapy use (under 5)	% of cases	..	..	10.1	30.1	21.6	28.2
Education	% of GDP	..	..	..	..	..	..
Gross enrollment ratios							
Primary: total	% of school-age group	23.0	81.0	66.0	87.4	99.3	106.8
female	"	10.0	51.0	35.0	78.4	87.8	101.3
Secondary: total	"	11.0	23.0	19.0	47.5	33.4	52.0
female	"	5.0	10.0	11.0	38.7	26.1	51.8
Tertiary: science/engineering	% of tertiary students	..	6.0	12.2	..	..	..
Pupil-teacher ratio: primary	pupils per teacher	..	34	26	31	10	28
secondary	"	21	22	20	18	19	18
Pupils reaching grade 4	% of cohort	..	74.0	65.9	77.5	..	81.0
Repeater rate: primary	% of total enrollment	..	..	..	7.4	..	8.0
Illiteracy rate: overall	% of pop. (age 15+)	..	72.9	58.6	49.5	43.3	26.2
female	% of females (age 15+)	..	..	74.8	56.8	56.5	32.5
Newspaper circulation	per thou. pop.	..	1.3	5.9	68.1	20.4	79.3

Source: World Bank International Economics Department, September 1989.

HOUSEHOLD FUEL MARKETING SURVEY METHODOLOGIES

Introduction

1. Three household surveys were performed in 1987/1988 in the YAR: two household energy surveys carried out by the University of Sana'a (HES 1 and 2), and a household energy module for the CPO Family Budget Survey (FBS). These three surveys were designed to be complementary. The abundance of surveys created problems, e.g., which survey is more reliable in cases where there are different answers for duplicated questions, but also yielded a rich database on household energy consumption. The nature and limitations of each survey are described below.

2. The CPO effort was an extensive family budget survey (FBS) to which 3 additional pages were attached regarding energy consumption and appliance ownership. It concentrated on expenditures incurred by households to acquire such fuels. Theoretically, this survey should provide higher reliability because of the large sample (over 1600 households) plus the fact that households were visited several times during the three-month period of each round and were requested to record their expenditure in booklets provided by the CPO. However, this method was not appropriate for collected traditional fuels such as firewood, crop residues and dung, or self-produced charcoal. The enumerators estimated the quantities consumed and costed them according to the market prices. There was no physical weighing of quantities in this survey.

3. The first University survey was a comprehensive household energy survey (HES) designed to gather basic information on all types of fuels used by households in the YAR, including sources of supply. HES 1 presented some limitations compared to the FBS; (i) the sample size was smaller (759 completed questionnaires), and (ii) each selected household was visited once and the information collected is based mainly on the memory of the respondent. On the other hand, HES 1 used systematic fuel weighing to determine the daily consumption of firewood, crop residues, dung and charcoal.

4. The second University survey (HES 2) was launched in 1988 to collect more information on household electricity consumption as neither the FBS nor HES 1 concentrated on this energy source. Electricity usage in YAR is particularly interesting because of the extensive use of generators owned by the private sector. The scope of work of this survey also focused on tree planting and management, and household fuel preferences.

5. Given these characteristics, the following procedures were developed:

(a) Frequencies

Since the samples of the FBS and the first HES are actually subsamples of a single sample it is possible to pool both samples which will increase the statistical significance of information common to both. It appears from the comparison of the two data bases that when the number of households possessing a certain attribute (e.g., the use of LPG) is large enough, the difference between the two data bases is relatively small;

(b) Quantities

(i) Priority should be given to information based on weighing which means that data on firewood, crop residues, dung and charcoal should be taken from the first HES. When compared to other countries and given the Yemeni traditions, the average consumption of firewood is more reasonable in HES 1 (10 kg per day per user-household) compared to the FBS (5.2 kg per day),

(ii)Conventional fuels which are primarily purchased in standard units should be taken from the FBS. The information computed from the FBS database matches better with the available information when checked. For example, LPG consumption of households was about 71 million tonnes according to the FBS estimates, compared to almost 89 million tonnes according to the HES 1 database, whereas the total sales of the country for the same year and for all sectors was about 80 million tonnes, and

(iii)The quantity of electricity consumed by households should be estimated from HES 2 for the reasons mentioned above; and

(c) Disaggregation

The samples were distributed over all 11 Governorates (i.e. the northern governorates of ROY). Rural and urban households from each governorate were selected for enumeration. The FBS included semi-urban households as well. This sampling procedure was designed to have all three categories (urban, semi-urban and rural) represented in the final sample. However, governorate results require cautious analysis because of very small number of observations in certain cases. The number of observation was checked every time disaggregated information was needed. To obtain a more reliable geographic grouping, governorates were classified by regional variation of rainfall, soil conditions, vegetation and topographic structure. The following zonation was developed:

Sana'a: Sana'a governorate, including the capital situated in the central highlands, where about 20% of the population live,

The Coast: Hodeida governorate, representing coastal lowlands of the Tihama,

The Southern Highlands: Taiz and Ibb governorates, situated in the mid-highlands,

The Central Highlands: Dhamar and Al-Beidha, also located in the mid-highlands but differentiated from the Southern Highlands by different difference biomass coverage and firewood availability,

The Northwest Escarpment: Hajja and Mahweet governorates, situated on the Western Slopes, and

The North-Northeast: Saada, Mareb and Al-Jawf governorates, representing the Eastern Slopes.

6. The distribution of households by zone and the sample size for each area (rural and urban) are summarized in the following table:

Table 1: DISTRIBUTION OF HOUSEHOLDS BY ZONE
(CPO sample and University sample)

	URBAN Households	%	RURAL Households	%	TOTAL Households	%
SANAA	71,474 (381)[a]	50.5	209,02[illegible] (196)	17.1	280,496 (577)	20.5
COAST Hodeida	26,153 (145)	18.5	176,499 (199)	14.5	205,652 (344)	15.1
NORTH-WEST ESCARPMENT Hajja-Mahweet	3,203 (49)	2.3	163,490 (169)	13.4	166,693 (218)	12.2
SOUTHERN HIGHLANDS Taiz-Ibb	29,382 (218)	20.7	440,635 (412)	36.1	470,017 (630)	34.4
CENTRAL HIGHLANDS Dhamar-Beidha	9,109 (101)	6.4	160,859 (195)	13.2	169,968 (296)	12.5
NORTH, NORTH-EAST Saada-Mareb-Jawef	2,215 (60)	1.6	70,009 (185)	5.7	72,224 (245)	5.3
Y A R	141,536 (954)	100.0	1,220,594 (1356)	100.0	1,362,130 (2310)	100.0

a/ pooled sample size.

Sampling

7. All samples were drawn by the CPO from the household frame of the February 1986 national census. The size of FBS was 1638 households representing 1.2 per thousand of the whole population while the size of the University sample was 761 households, or 0.6 per thousand. The sample is distributed over the 11 Governorates of the country, with households randomly chosen from 3 strata: urban, semi-urban, and rural areas. Only 2 strata (urban and rural area) were retained in the University sample. 58 villages from 40 districts selected from total of about 24,000 villages scattered in 197 districts were visited by the CPO team. Of these 58 villages, 29 from 29 districts were visited by the University enumerators (See Table 3).

8. For each of the 29 villages selected in this group, every "n"th household was selected, where n is the appropriate sampling interval for that village. The selected households were allocated in an alternating manner to each of the two surveys. For example, the "n"th household was selected for the CPO survey, the 2 "n"th for the University survey, the 3 "n"th for the CPO survey, the 4 "n"th for the University survey and so forth. The number of households selected from these 29 villages was approximately equal to twice the number of households selected from the 29 villages where only the CPO survey was carried out. Consequently, the CPO sample size is twice as large as the University sample. The distribution of the samples by urban and the rural location within each Governorate does not reflect the real distribution of the population for two main reasons:

(a) Dispersion of population in the country, particularly in the isolated rural areas, where there are 24,000 villages with an average size smaller than 50 households per village. This makes it expensive to increase the rural sample size; and

(b) Rural households are more homogenous than urban, so that the urban households are over-sampled relative to their representation in the population to ensure higher statistical significance.

9. From a statistical point of view, the larger CPO sample is more statistically significant than the University demand survey. If we consider p as the proportion of the households having a given characteristic, the CPO survey results reach a 95% confidence level for all $p >= 0.05$ to be estimated within 20% error difference. To have an equivalent p, the level of confidence of the University survey results must come down to 85%. The contrast becomes more important if we intend to have results concerning the urban and rural area separately. To reach 95% of confidence level we have $p >= 0.11$ in the urban area and $p >= 0.10$ in the rural area of the CPO sample; and $p >= 0.27$ in the urban area and $p >= 0.16$ in the rural area of the University sample.

CPO Survey

10. Interviewer training and the pilot testing were held during the last week of January 1987 and the first visit of the first round began on February 8, 1987. Due to a shortage of manpower, preliminary results of the first round were made available only by the end of December 1988. The Family Budget Survey Questionnaire included 4 sections on energy, with questions on:

(a) geographic location of the household and socio-economic criteria and the summary totals for expenditure groups;

(b) different fuels consumed; quantity, cost and degree of availability;

(c) sources of supply of energy, method of transportation and time needed for fuel transportation, and the reasons for not using LPG stoves in cooking; and

(d) the appliances used for each end-use and the proportion of fuel consumed for each end-use.

University Surveys

11. Training and pilot testing took place from February 18-21, 1987. Twenty-four demand questionnaires were pre-tested in and around Sana'a, covering urban and rural households. These were then discussed with supervisors and interviewers. It was determined that households were usually unable to tell the quantity of traditional fuel acquired in standard units and were unable to give reasonable estimates for the period during which the fuel was consumed (especially for long periods). Therefore each team had to periodically weigh the traditional fuels consumed.

12. The field work began on February 22, and finished on March 15, 1987. Five teams of 2 to 4 enumerators and 1 supervisor each were involved in data collection stage (18 individuals in total). The Sana'a team was made up of 2 women to facilitate the interviewing process without offending

local customs and traditions. A supply questionnaire was filled in by the supervisors in the same areas where the demand survey was being carried out. The supply system investigation included primary producers, wholesalers, truckers and retailers (about 60 questionnaires). The information collected from suppliers was used to cross-check answers given by households with regard to prices of different units of different types of fuels.

13. The HES 1 questionnaire was divided into 5 sections, with questions on:

(a) geographic location of the households and socio-economic criteria including an attempt to determine the income;

(b) consumption of traditional fuels such as charcoal, wood, dung, and crop residues;

(c) consumption of non-traditional fuels such as electricity, LPG, and Kerosene. The previous two sections provide the following information:

(i) the quantity of fuel consumed during the period of November-December-January, with daily consumption of traditional fuels weighed by interviewers;

(ii) the cost of fuel consumed during the same period;

(iii) estimation in percentage of the distribution of fuels consumed by end-uses; and

(iv) Sources of supply;

(d) cooking practices, especially the different kinds of utensils and stoves used; and how often such practices are used, together with fuel used, together with the cost of appliances, their age and their expected life; and

(e) energy consumption trends and preferences. Households were asked if their consumption has changed since 1984; and if so to indicate the main reasons and their reaction to such change. Information was also collected on the reliability of the supply and the reasons for not using particular fuels.

14. The Supply questionnaire included six sections:

(a) general information on the primary business activity and type of fuel supplied;

(b) wood production and distribution;

(c) charcoal production and distribution. Sections (b) and (c) provided information on the average monthly sales according to each type of wood and each major outlet supplied and the corresponding prices. Information was also collected on seasonal variations in sales and location of markets and their importance;

(d) species of wood collected for direct sales and for charcoal production; and the main source of supply;

(e) transportation, capital and operating costs of fuelwood and charcoal suppliers; and

(f) issues and problems facing the business of wood and charcoal.

Problems and Solutions

15. The main problems encountered were basically technical and can be summarized as follows:

(a) The University sample is not a sub-sample of the larger FBS because it was judged to be difficult to interview the same households twice during the same period. However, both samples were drawn from the same master sample so that they could be pooled or compared on a general basis (according to the areas, the regions and the occupation of head of household) rather than case by case;

(b) The enumerators had never used pre-coded questionnaires before so intensive training and careful checking of the completed questionnaires were necessary; and

(c) The first version of the questionnaires was written in English and then translated to Arabic, and special care had to be observed not to invert variables' order in the coding space. However, the SPSS package uses a Roman alphabet so files and variables names had to be entered in English. Thus, data from the Arabic questionnaire were entered on SPSS English spreadsheets. Special care was required to record the right value for the right variable.

16. To avoid these problems, the following actions were undertaken:

(a) Data had to be entered from right to left according to the Arabic version of the questionnaire;

(b) A very important set of editing rules was established to ensure automatic control of entered data;

(c) For the CPO questionnaire the serial number of the question (or table) and the number of the line within each question (or table) is integrated into the name of the variable to facilitate data entry and processing to non-fluent English operators (see Annex 5). Because the questionnaire design was not appropriate for data entry, the last 3 pages of the questionnaire (Energy sections and summary group expenditures and Head of Household criteria) had to be copied during the revision and coding period in designed formats. The use of these formats presented the following advantages:

(i) It shortened data entry time from 30 minutes to 10-15 minutes per questionnaire;

(ii) It reduced the number of variables from 320 to 295 by eliminating the impossible cases such as baking bread using battery-electricity;

(iii) It reduced the risk of error as all the answers were pre-coded and the missing items were taken into account;

(iv) The formats were written in both languages, Arabic and English, which could help controlling data entry by non-fluent English operators;

(v) The formats included the coding instructions for qualitative variables; and

(vi) The formats included also SPSS instructions to get files and save data entered.

Table 2: DISTRIBUTION OF THE POPULATION IN URBAN, SEMI-URBAN AND RURAL AREAS
YAR - FEBRUARY 1986

Governorate	Urban	Semi-Urban	Rural	In Household Total
Sana'a	71,474	43,022	166,000	280,496
Taiz	21,808	2,368	229,000	253,176
Hodeidah	26,153	12,499	164,000	202,652
Ibb	7,574	4,267	205,000	216,841
Dhamar	7,144	179	117,000	124,323
Haajja	2,081	1,998	114,000	118,079
Beidha	1,965	3,680	40,000	45,645
Sa'ada	1,837	2,089	47,000	50,926
Mahweet	1,122	492	47,000	48,614
Mareb	185	0	14,000	14,185
Jawf	193	0	7,000	7,193
Total	141,536	30,594	1,190,000	1,362,130

Source: CPO - 1986 Census.

Table 3: NUMBER OF GOVERNORATES, DISTRICTS AND VILLAGES IN YAR
AND THE NUMBER COVERED BY THE CPO SURVEY AND
SANA'A UNIVERSITY SURVEY

	Governorate	District (Nahya)	Village	Households
YEMEN (Feb 1986)	11	197	24,000	1,362,130
CPO Survey	11	40	58	1,638
University Survey	11	29	29	761

Table 4: PROPORTION OF URBAN, SEMI-URBAN, AND RURAL HOUSEHOLDS
IN EACH GOVERNORATE

Governorate	Urban	Semi-Urban	Rural	Total
Sana'a	25.48	1.08	73.44	100
Taiz	8.61	0.94	90.45	100
Hodeidah	12.90	6.17	80.93	100
Ibb	3.49	1.97	94.54	100
Dhamar	5.75	0.14	94.11	100
Hajja	1.76	1.69	96.55	100
Beidha	4.31	8.06	87.63	100
Sa'ada	3.61	4.10	92.29	100
Mahweet	2.31	1.01	96.68	100
Mareb	1.30	0	98.70	100
Jawf	2.68	0	87.36	100
YEMEN	10.39	2.25	87.36	100

Table 5: PROPORTION OF URBAN AND RURAL HOUSEHOLDS IN EACH GOVERNORATE

In %

Governorate	Urban	Rural	Total (including S. urban)
Sana'a	25.48	74.52	100
Taiz	8.61	91.39	100
Hodeidah	12.90	87.10	100
Ibb	3.49	96.51	100
Dhamar	5.75	94.25	100
Hajja	1.76	98.24	100
Beidha	4.31	95.69	100
Sa'ada	3.61	96.39	100
Mahweet	2.31	97.69	100
Mareb	1.30	98.70	100
Jawf	2.68	97.32	100
YEMEN	10.39	89.61	100

Table 6: DISTRIBUTION OF THE CPO SAMPLE (for each round* by area within each Governorate)

In households

( ) Completed questionnaires

Governorate	Urban	Semi-Urban	Rural	Total
Sana'a	300 (281)	21 (122)	102 (403)	423
Taiz	120 (112)	21 (130)	123 (242)	264
Hodeidah	120 (98)	33 (133)	87 (231)	240
Ibb	48 (48)	24 (126)	102 (174)	174
Dhamar	48 (48)	9 (68)	60 (116)	117
Hajja	24 (23)	21 (72)	60 (95)	105
Beidha	24 (24)	18 (56)	39 (80)	81
Sa'ada	24 (21)	21 (59)	39 (80)	84
Mahweet	18 (12)	9 (48)	39 (60)	66
Mareb	12 (12)	0 (28)	30 (40)	42
Jawf	12 (12)	0 (18)	30 (40)	42
Total	750 (691)	177 (860)	711 (1,551)	1,638

*There are four rounds covering the whole survey year, although the household work was based on only one.

Table 7: DISTRIBUTION OF SANA'A UNIVERSITY SAMPLE BY AREA WITHIN EACH GOVERNORATE

( ) Completed questionnaires Governorate	In households Urban	Rural	Total
Sana'a	101 (100)	74 (74)	175 (174)
Taiz	42 (42)	85 (85)	127 (127)
Hodeidah	42 (47)	62 (66)	104 (113)
Ibb	15 (16)	71 (71)	86 (87)
Dhamar	16 (20)	44 (37)	60 (57)
Hajja	8 (8)	29 (22)	37 (30)
Beidha	8 (9)	32 (34)	40 (43)
Sa'ada	8 (8)	29 (28)	37 (36)
Mahweet	6 (6)	27 (27)	33 (33)
Mareb	4 (3)	31 (30)	35 (33)
Jawf	4 (4)	23 (22)	27 (26)
Total	254 (263)	507 (496)	761 (759)

1988, PHYSICAL QUANTITIES (thousand metric tons, except for electricity in GWh and natural gas in mmscf)

	Firewood	Charcoal	Dung & Res	Electricity	LPG	Gasoline	Kerosene	Jet Fuel	Diesel	Fuel Oil
Industry				207					64	79
Commerce		62		107	4					
Transport						554		62	281	
Households	4896	41	822	356	83		64			
Other				96	9				56	
Total	4896	103	822	766	96	554	64	62	40	179

2000, PHYSICAL QUANTITIES

	Firewood	Charcoal	Dung & Res	Electricity	LPG	Gasoline	Kerosene	Jet Fuel	Diesel	Fuel Oil	Natural Gas
Industry				1019					82	18	7420
Commerce		78		285	10						
Transport						1225		140	550		
Households	6027	57	822	804	240		55				
Other				165	19				136		
Total	6027	135	822	2273	269	1225	55	140	768	18	7420

1988, TOE EQUIVALENT

	Firewood	Charcoal	Dung & Res	Electricity	LPG	Gasoline	Kerosene	Jet Fuel	Diesel	Fuel Oil	Total
Industry	0	0	0	18	0	0	0	0	64	79	161
Commerce	0	43	0	9	4	0	0	0	0	0	57
Transport	0	0	0	0	0	571	0	63	281	0	914
Households	1860	29	260	31	88	0	65	0	0	0	2332
Other	0	0	0	8	10	0	0	0	56	0	74
Total	1860	72	260	66	102	571	65	63	401	79	3538

2000, TOE EQUIVALENT

	Firewood	Charcoal	Dung & Res	Electricity	LPG	Gasoline	Kerosene	Jet Fuel	Diesel	Fuel Oil	Natural Gas	Total
Industry	0	0	0	88	0	0	0	0	82	18	183	371
Commerce	0	55	0	25	11	0	0	0	0	0	0	90
Transport	0	0	0	0	0	1262	0	141	550	0	0	1953
Households	2290	40	260	69	254	0	56	0	0	0	0	2969
Other	0	0	0	14	20	0	0	0	136	0	0	170
Total	2290	95	260	195	285	1262	56	141	786	18	183	5553

WOODY BIOMASS ASSESSMENT

1. A survey of woody biomass growing stocks was undertaken in the northern governorates between July 30 and August 13, 1988, as part of the ESMAP Household Energy Strategy Study. The objectives of the study were to:

(a) make a preliminary assessment of the woody biomass growing stocks and their productivity in the northern governorates;

(b) identify fuelwood deficit and surplus areas to enable fuelwood 'crisis' areas to be defined;

(c) assess the sustainability of the woody biomass resources;

(d) discuss fuelwood exploitation in terms of the main environmental problems in the northern governorates; and

(e) identify appropriate follow-up activities.

The methodology used to accomplish these objectives is briefly described below.

2. Measurements of trees and shrubs were made in all of the land-use zones identified in the USAID-sponsored Land-use Inventory (1983), except urban areas. 51 sample plots were selected in the Tihama, Western Highlands, Central Highlands and Eastern Plateau. The following information was collected for each plot: (a) general site description, including aspect and dominant slope; (b) height, crown point, trunk/stem diameter at breast height (dbh), crown diameter, and evidence of coppicing and pollarding for all trees; (c) height, crown diameter and evidence of cutting of shrubs, dwarf shrubs and succulents which are known to be used as fuel; and (d) site photographs when light and weather conditions permitted.

3. The data collected were converted into estimates of woody biomass growing stocks (both as total above-ground volume and wet weight) using equations developed in areas of northeast Africa with similar ecological conditions. Wood productivity was estimated using Clement's equation and local precipitation data. The use of roots as a woody biomass fuel was evaluated in the context of charcoal production, but no quantitative estimates of their growing stock or productivity were made. Dead wood stocks were considered, along with the mechanisms by which these stocks are replenished. Various methods for the estimation of dead wood stocks were used, but the estimates finally used in the study were based on measurements taken in the field sample plots.

4. Interviews were held in seven wood markets around the northern governorates, and with woodfuel consumers. Information gathered during these interviews were combined with the data on woody biomass stocks to identify fuelwood regions (wood-surplus and wood-deficit areas). A map of the wood-surplus areas and the main supply routes between surplus and deficit areas was produced.

5. To assess the long-term sustainability of woody biomass supplies in the northern governorates, gap analysis was used. Data on current woody biomass stocks (both live wood and dead wood), woody biomass productivity, and household consumption (both current and projected, to account for population growth) were combined. The resulting analysis suggests that woody

biomass stocks will be severely depleted by the end of the century, i.e., over the next decade. These projected trends were consistent with the land-use conversion/woody biomass depletion analysis carried out for the Jebel Bura area.

6. These projections of woodfuel resources are based on several considerations and assumptions:

(a) **Woody biomass standing stocks**: The values obtained for both total above-ground tree volumes and woody biomass wet weights are in the same range as previous estimates for the northern governorates and adjacent areas. Nevertheless, problems remain with the projection made here:

(i) the desert area east of 45°30'E has not been included in the estimates, although including this area would not significantly increase standing stocks.

(ii) very high growing stock situations, e.g. windbreaks and coffee shade trees, have been omitted from the calculations;

(iii) trees and shrubs around houses have not been sampled;

(iv) not all of the woody biomass in a tree is available to meet woodfuel demand, e.g. in many agricultural areas pollarding is very common and the tree trunks (which may account for large amounts of wood in some land-use units) are not used;

(v) other end-uses, e.g. construction timber, leaf fodder, browse, and shade, reduce the amount of wood available.

Whereas factors (i) through (iii) would increase the current stock estimate, (iv) and (v) would reduce it. In addition, the limited number of samples in the inventory may not provide a representative estimate. In any case, once the national stock falls to 25 to 30 million t, the depletion of wood supply accelerates.

(b) **Dead wood stocks**: Estimates of dead wood stocks are less reliable than those of live wood. First, there are very few studies with which to compare the estimates used here for the northern governorates. Secondly, the estimate is based on relatively few sample plots. Thirdly, more needs to be known about the trade in dead wood, in particular the decline in dead wood stocks and rates of replenishment.

(c) **Wood productivity**: Wood productivity estimates have been extrapolated from sources outside Yemen. Although these estimates are comparable to those suggested by several foresters, there are two factors which need to be accounted for in more detail:

(i) increased productivity due to occult precipitation; and

(ii) decreased productivity due to frost.

In this analysis, these factors were taken into account using a simplified methodology.

(d) **Wood consumption**: Total consumption projections made here are based on a 6% annual growth in urban consumption and 2% growth in rural consumption, reflecting population growth in these two areas. No fuel switching is assumed. Rural consumption per household is assumed to be greater than urban consumption, which reflects the findings that urbanization in the northern governorates results in lower fuelwood consumption per household. Nonetheless, even taking into account the trend of urbanization (i.e. lower woodfuel consumption per household but more households), fuelwood resources are threatened. Naturally, as the wood resource is depleted, wood prices will rise, providing stronger incentives for tree planting and fuel switching. It is unlikely that the resource will ever become truly depleted; in addition to behavioral changes related to fuelwood supply and demand, certain trees will remain for shade, fruit, and fodder. A more relevant question than when the resource will be depleted is what changes will take place in consumer and producer behavior as a result of rising prices and increased scarcity.

7. The relationships between woody biomass exploitation (both current and projected) and the Yemeni environment were considered. In particular, the impact on soil erosion and terrace degradation, groundwater recharge, wind erosion and sand encroachment, microclimate degradation, and agricultural productivity were evaluated. Follow-up activities were identified in five areas: (a) land-use conversion analysis; (b) woody biomass supply mechanisms; (c) additional woody biomass inventory investigations; (d) charcoal production; and (e) agroforestry. Detailed results of this survey are available in the following report: Millington, Andrew "YAR: Woody Biomass Resource Assessment," consultant paper prepared for ESMAP, July 1989.

DUNG AND CROP RESIDUE RESOURCES

1. Resource Base and Supply System. Animal dung and agricultural residues constitute the remainder of biomass fuel resources in Yemen, after woody biomass. Although the northern governorates has a livestock population of 4.8 million, only the cattle herd of roughly 950,000 is taken into consideration for assessing the dung resource base. Cattle are mainly, if not completely, handfed and more or less permanently kept near the house. The other livestock such as sheep, goats, donkeys and camels roam around the rangeland. Taking annual dung production of 1 ton per head of cattle, the total "useful" dung production is about 950,000 tons per year. However, due to the extensive use of dung as a fertilizer (by as much as 76% of all agricultural holdings), dung burned for cooking fuel represents only a small fraction of this figure.

2. To determine the crop residue resource base for fuel purposes, one must estimate not only residue production but also its use as fodder. There is a high demand for fodder in YAR and crop residues find willing buyers. Many cereals such as sorghum, millet and maize are selected not only for their grain yield, but also for their complementary use as fodder. In case of crop failure, the yield can still be harvested for use as livestock feed. If crop prospects look favorable, the leaves of the growing maize and sorghum plants are stripped (except the top ones) and fed to the livestock, either green or dried. After the harvest the entire upper stalk is cut to be used as forage. The residue of threshed pulses are also used as feed, as are potatoes, the tops of many vegetable crops and residues of oil seed, sugar cane and sesame. Apart from residues, forage crops such as alfalfa, Sudan grass and silage-type maize and sorghum varieties are especially cultivated to be used as fodder.

3. It is difficult to estimate the level of production of crop residues because dry matter per ha. can vary considerably, from 1 to over 6 tons, depending on local conditions and management. However, an attempt is made to quantify annual residue supply in Table 1. Assuming 25% losses, available residues amount to about 1,495,000 tons per year.

Table 1: PRODUCTION OF CROP RESIDUES

Crop	Production (tons)	Residue to grain ratio	Residue Production (tons)
Wheat	70,000	1.75:1	122,500
Maize	53,000	2.50:1	132,500
Sorghum/millet	635,000	2.50:1	1,587,500
Barley	54,000	1.75:1	94,500
Sesame	5,000		8,750
			1,945,750

4. One must now compare crop residue supply with the estimated fodder needs of the livestock population. Production from rangelands of the northern governorates is estimated at 508,500 tons of dry matter per year, mainly composed of leaves, loppings and pods. It is assumed that 50% of

this yield is available as feed. From Table 2, it is evident that this is not sufficient to feed the existing livestock population. If one takes half of the rangelands yield and adds it to the quantity of available crop residue plus the yield of forage crops such as alfalfa (45,000 tons produced, equivalent to a dry weight of 9000 tons), the total available animal fodder is 1,758,250 tons annually. Assuming that Yemeni livestock are slightly underfed, this balances with total fodder needs from Table 2. Therefore, it can be concluded that, currently, crop residues are not widely available as a fuel due to competing demands for use of residues as fodder.

Table 2: ESTIMATED FODDER NEEDS OF LIVESTOCK

Livestock	Number	Average Live Wt. (kg)	Total Weight (kg)	Equivalent Livestock Units a/	Estimated Fodder Requirement (tons)
Camels	90,200	200	18,000,000	36,000	120,000
Sheep	3,000,000	15	45,000,000	90,000	300,000
Goats	1,985,000	15	30,000,000	60,000	198,000
Cattle	976,000	130	126,000,000	253,500	845,000
Donkeys	455,000	110	50,000,000	100,000	333,000
Total	6,506,200	470	269,000,000	539,000	1,796,000

a/ One livestock unit equals 500 kg of livestock.

5. Demand and Price Structure. The household energy surveys did not turn up statistically significant evidence of energy purchases of dung or crop residues. If these are bought, they are used for fertilizer or animal feed. Therefore, no data on prices for non-woody biomass fuels are available. The quantities of dung and residues consumed by rural and urban households in the governorates where these energy sources are used can be found in Table 3. Residues are a relatively important fuel (constituting 10% or more of final household fuel demand) in the rural areas of Ibb, Dhamar and Beida, and in the urban part of Ibb. Dung is similarly important in the rural areas of Dhamar and Beida, but does not play a role in urban household energy demand.

Table 3: DEMAND FOR OTHER BIOMASS

Region	Rural Residue	Rural Dung	Urban Residue	Urban Dung
	KGOE (% of total annual fuel consumption)			
Sana'a	73 (3)	120 (5)	3 (<1)	6 (1)
Coastal	109 (7)	56 (4)	0 (0)	0 (0)
Northwest	121 (6)	40 (2)	47 (3)	0 (0)
Souther	115 (9)	38 (3)	58 (8)	2 (<1)
Central	296 (13)	278 (12)	3 (<1)	61 (5)
Northeast	10 (1)	1 (<1)	0 (0)	0 (0)

6. End-uses. To the extent that they are consumed by Yemeni households, crop residues and dung are burnt primarily as a cooking fuel. Residues and dung are most important in the rural parts of Beida governorate where they supply 10% of useful cooking energy. In all other governorates, other biomass provides less than one-tenth of energy used for cooking purposes. Additionally, some residues and animal manure may be burned for water and space heating.

7. Trends and Issues. Without more information about Yemeni household attitudes towards the use of fuels which are inferior to woody biomass as well as data on the relative prices of residues and dung for use as a fuel versus, respectively, use as fodder and fertilizer, it is difficult to make predictions about projected demand for this biomass. However, some preliminary predictions may be drawn from neighboring countries, e.g., Ethiopia. There, as woody biomass became increasingly scarce, some households moved up the energy ladder to use kerosene and LPG but many more moved down the ladder towards increased consumption of dung and crop residues. In the northern governorates, incomes are higher than in Ethiopia but there still may be a significant number of poorer households who cannot afford to move upwards to substitute petroleum fuels. Thus, as fuelwood resources dwindle and become prohibitively expensive, these consumers may turn to these other biomass resources and their use as a fuel will increase, with potentially negative consequences for livestock and soil fertility.

TANNUR AND STOVE TESTING PROGRAM 1/

Introduction

1. In the framework of the World Bank's ESMAP "Household Fuel Marketing Study, Phase 2", a field visit of five weeks was made by P. Visser (Biomass Technology Group), to the Yemen capital of Sana'a. Counterparts for this mission were the Central Planning Organization of the Yemen Arab Republic, and the Faculty of Science of the University of Sana'a. Basic goal for the mission was to evaluate and improve existing Yemeni tannurs (the local bread oven) and cookstoves.

2. A survey was done to evaluate the energy consumption of professional tannur bakeries. The tannurs and cookstoves were tested and improved at the laboratory of Sana'a University. Finally, negotiations were started with a local manufacturer of metal tannurs for the manufacture of gas burners to retrofit the traditional wood-burning clay tannurs.

3. The report opens with a brief description of relevant Yemeni cooking habits and cooking equipment (chapter 2). Then, in chapter 3, a survey of known literature on tannurs is presented, which focuses on the available data on energy consumption. Chapter 4 describes the testing and improvement of the tannurs, and is the main chapter of this report. Next, chapter 5 discusses the production facilities for the burner used to retrofit the traditional clay tannur with LPG. The survey on the professional tannur bakeries is presented in chapter 6 and finally, the testing of cookstoves is described in chapter 7.

Cooking Habits and Cooking Equipment

4. The cooking habits in Yemen differ widely from region to region (Steverlynck, 1988, Zabara, 1988, and Young, 1986). However, the following generalizations can be derived:

(a) The basis for every Yemeni meal is bread of which many types are made (Bornstein, 1972). The type called chobazas is the most common, followed by malloog, tameez and rashooz. Basic ingredients are flour, yeast and water. The breads differ in size (the diameter of malloog being much bigger than that of the other breads) and in the additives used (for rashooz oil is added, for malloog the outside of the bread is covered with a thin layer of helbah, a vegetable sauce).

(b) All breads are flat and baked on the wall of the so-called tannur, a vertical, conical, clay oven, see figure 4.1.

1/ *Excerpted from Visser, P., "Household Energy Options in the Yemen Arab Republic: Test Results on Tannurs and Cookstoves", ESMAP, December, 1988. References in this section refer to annexes in the original report.*

(c) The side dishes of the meals are comprised of rice, vegetable stews and meat, chicken, or fish. Traditionally these dishes are cooked on the wood-fired tannur. They are kept warm in a maugad which uses the remaining charcoal. The maugad is also used to reheat cold food.

(d) In recent years, the urban cooking habits have changed. An all-metal, gas-fired tannur has appeared on the market. Moreover, gas burners have become available to retrofit the wood-burning clay tannur (no data is available on the actual penetration of this gas equipment in the households). On top of this an increasing number of people buy their bread. Moreover, kerosene and/or gas burners are used for the preparation of the side dishes.

(e) Many different types of pans are found on the market. They differ in shape, size, and material. The most common pans are cylindrical, have a diameter ranging from 200 to 600 mm and are made from aluminum. They are sold with lid. Ceramic pots are used for special preparations. Pressure cookers are becoming more and more popular, especially for the preparation of meat. Unfortunately no numerical data is available on the use of these pans.

Review of Literature on Tannurs

5. Publications dealing with the general technical aspects of tannurs (or the similar Pakistan and Indian tandoors) are small in number. The publications known to the author are shown in the list of references. Even more scarce are the numerical data on the performance of tannurs. Table 3.1 gives data gathered from the available publications. Most of this data is obtained by interviewing the users of the tannurs and not by measurement.

6. The Family Oven is an improved tandoor, developed by Usinger. It is a dome shaped oven, very much like the Italian Pizza oven. The Bread Oven is a big traditional brick oven, originally fired with wood, but now retrofitted to burn diesel oil.

7. As a final reference the energy consumption of some modern bread ovens are mentioned:

(a) Shirey and Selker (1985), electrical oven, SEC = 1.96 MJ per kg of flour; and

(b) Schmitt and Siemers (1985), automatic gas-fired tunnel oven, SEC = 1.1 MJ per kg of flour.

The SEC values in table 3.1 range widely and are quite high compared with the energy consumption of modern ovens given above. The data suggests a correlation between the SEC and the amount of flour: the larger the latter, the smaller the SEC. However, the table also shows some contradictory values. From the table it is difficult to decide on the SEC which could be used as a reference for improved models. Therefore it was felt necessary to perform a series of tests on the traditional clay tannur using wood as well as on the traditional tannur using LPG and on the gas fired metal tannur.

Table 3.1: TANNUR PERFORMANCES

Reference	Fuel	Total flour (kg)	SFC.a/ kg.fuel kg.flour	SEC.b/ MJ kg.flour	Stove type
Young 1968	gas c/	25.0	0.14	6.4	Tannur
Al Motawakel	gas	1.3	0.64	29.4	Tannur
Usinger 1985	wood d/	4.4	0.91	15.4	Tannur
"	"	5.0	0.98	16.4	Tannur
"	"	4.9	1.20	20.4	Tannur
"	"	3.7	1.39	23.3	Tannur
"	"	7.0	1.01	16.9	Tannur
"	"	27.0	1.45	24.4	Tannur
"	"	4.4	0.50	8.4	Fam. Oven
"	"	5.5	0.51	8.6	Fam. Oven
"	"	5.1	0.59	10.0	Fam. Oven
"	"	3.5	1.14	19.2	Fam. Oven
"	"	8.9	0.74	12.5	Fam. Oven
"	"	28.0	0.30	5.1	Fam. Oven
Al Motawakel	wood e/	1.6	0.96	18.1	Tannur
Schmitt 1985	"	-	-	27.0	Tannur
"	"	-	-	17.6	Tannur
Estimated performances:					
Young 1986	gas	100	0.12	5.5	Tannur
"	"	150	0.12	5.5	Tannur
"	"	150	0.16	7.3	Tannur
"	"	50	0.24	11.0	Tannur
"	oil f/	500	0.16	7.0	Bread Oven

a/ Specific Fuel Consumption (see section 4.3)
b/ Specific Energy Consumption (see section 4.3)
c/ Combustion value - gas: 45.7 (MJ/kg)
d/ Combustion value - wood: 16.8 (MJ/kg)
e/ Combustion value - wood: 18.7 (MJ/kg)
f/ Combustion value - oil: 43.5 (MJ/kg)
g/ Intermittent baking

Testing and Improving Tannurs

Introduction

8. Two tannur types were tested:

(a) the traditional Clay Tannur; and

(b) the Metal Tannur.

9. The main goal of the tests was to get reliable data on the Specific Energy Consumption (SEC) which is the ratio between the energy needed to bake the bread and the quantity of flour used.

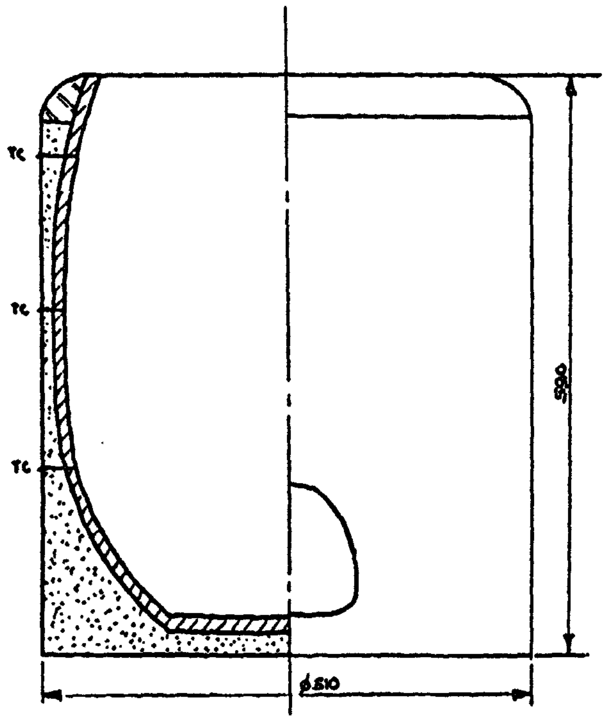
10. Two series of tests were performed. The first series on tannurs without modifications, the second on the traditional Clay Tannur retrofitted with a gas burner. Moreover some possible improvements were tried out on both the Clay Tannur and the Metal Tannur.

11. The chapter begins with a description of the tannurs and burners used in the tests whereafter the test procedure is explained and the test equipment is described. The chapter ends with a presentation of the results and the conclusions.

Description of Tannurs and Burners

12. The Clay Tannur. The traditional wood-burning Clay Tannur is shown in figure 4.1. It consists of a ceramic insert, encased in a metal cylinder of galvanized steel sheet.

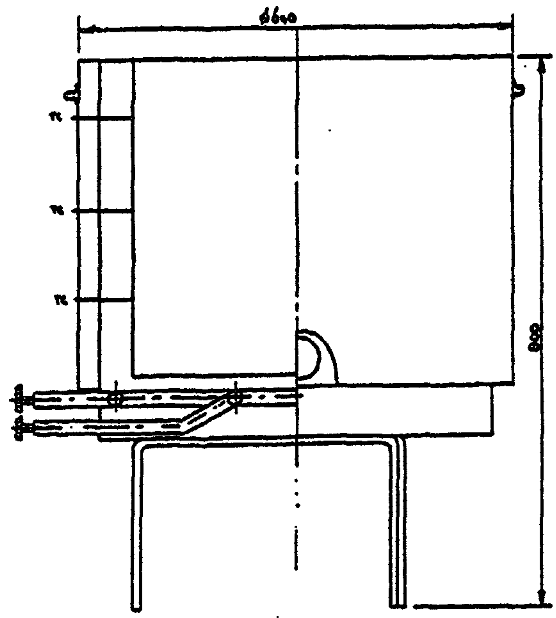
Figure 4.1: THE TRADITIONAL CLAY TANNUR



13. The annular gap between the tannur and the cylinder is filled with a mixture of sand and salt. This layer is said to have insulating qualities but is more heat storing than insulating. At the top this layer is sealed with a mixture of cement and gypsum. At the bottom of the tannur an opening is available to add wood and which allows combustion air to enter. This opening cannot be closed and therefore the airflow cannot be controlled. The traditional wood-burning Clay Tannur is locally made by artisans and costs about 350 YR.

14. The Metal Tannur. The Metal Tannur, figure 4.2, is a relatively new device on the market. It is completely made out of 1 mm metal sheet and has a built-in gas burner. The Metal Tannur is locally made by a company called "Ready made windows and modern gas furnaces" in Hadda street, and costs about 1700 YR.

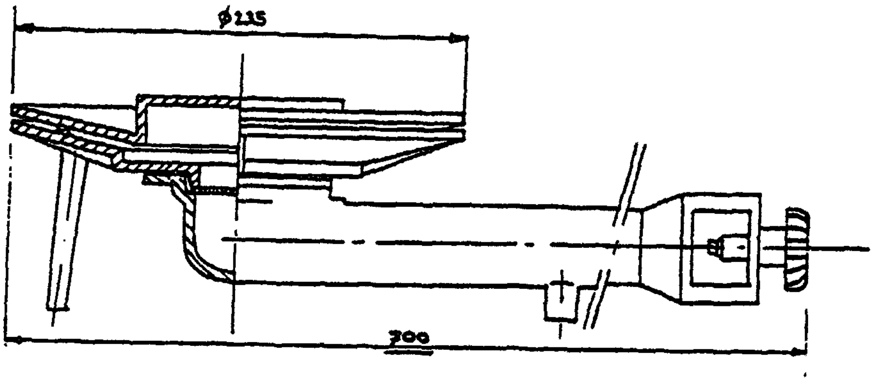
Figure 4.2: THE METAL TANNUR



15. The Metal Tannur consists of three metal cylinders. The innermost cylinder forms the actual oven in which the bread is baked. Between this cylinder and the second one, two concentric gas burners are mounted which are made from steel tubes of ¢ 22 mm. The annular gap is closed at the bottom, a number of holes allow some gas flow. The outer cylinder serves as a protection against the hot cylinders.

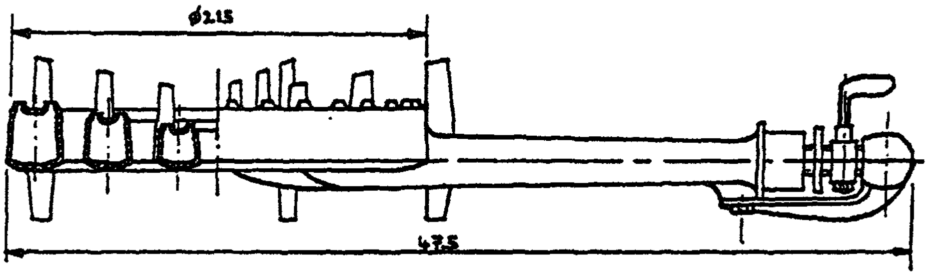
16. The Disk Burner. The Disk Burner (figure 4.3) is a Taiwan copy of an Italian gas burner. It is sold to retrofit the traditional wood-burning Clay Tannurs. The Disk Burner is made of cast iron, and consists of two slightly conical disks which are about 4 mm apart. The gas burns at the rim of the disks. The gas flow is controlled by a valve, but is more easily adapted by the pressure control valve on the gas bottle. It is sold for about 450 YR.

Figure 4.3: THE DISK BURNER



17. The Ring Burner. The Ring Burner (figure 4.4) is also made in Taiwan. It is made of cast iron and consists of three rings with small holes in their top surfaces. Each ring is separately fed and hence they can be used independently. Pan supports ar incorporated in the design. The burner is sold for 340 YR.

Figure 4.4: THE RING BURNER



Test Procedure

18. In testing bread ovens, the results are expressed as the ratio of the fuel used to bake the bread and the quantity of flour used in the dough. (Schmitt and Siemers, 1985). The ratio is normally determined for a whole baking session, that is the baking of several charges, one after another, with reheating of the oven in between. The quantity of fuel used can be expressed in kilograms as well as in Mega Joules. This gives lead to two different definitions:

$$\text{Specific Fuel Consumption, SFC} = \frac{\text{fuel used (kg)}}{\text{initial flour (kg)}}$$

and

$$\text{Specific Energy Consumption, SEC} = \frac{\text{fuel used (MJ)}}{\text{initial flour (kg)}}$$

The Specific Energy Consumption is used when comparing the performance of bread ovens using different types of fuel.

19. To get a better feeling for the heat involved in the baking process a number of temperatures were recorded. Three thermocouples were fixed to the walls of the tannurs. Their position is indicated in the figures 4.1 and 4.2. Gas and bread temperatures were measured too.

20. The procedure of the actual testing was as follows:

(a) The ingredients to bake 15 chobaz were weighed, the dough prepared, and the final quantity of dough was weighed;

(b) The reference temperature for the thermocouples as well as the ambient temperature was measured with a mercury thermometer;

(c) The initial amount of fuel was weighed, and the fire started (wood was lit with a little kerosene). Time was recorded and the temperature recorders were started;

(d) After the heating-up period, the time of the actual baking was recorded;

(e) Of some of the chobaz the gas temperature in the vicinity of the bread as well as the crust temperature were recorded;

(f) When using wood, the necessary extra batches were weighed and charged to the fire;

(g) At the end of the baking, the time was recorded, the recorders were stopped and the weight of the baked chobaz was determined;

(h) Finally the remaining fuel was weighed, as well as for wood, the remaining charcoal.

21. The tests were executed by two experienced women bakers who prepared the dough and did the actual baking. The university gave the required technical assistance.

22. Each test was repeated three times and the data collected was used to calculate the following quantities:

(a) average power of the fire;

(b) specific fuel consumption (SFC);

(c) specific energy consumption (SEC); and

(d) energy cost expressed in YR per kg of flour baked.

The above quantities were used to make a simple heat balance of the different tannurs. (See annex 5 for calculation procedures.)

Equipment

23. Weighing was done with a Sartorius industrial electronic balance, type IP31 with a capacity of 31 kg and an accuracy of 1 g.

24. Temperatures were measured with cromel-alumel and colpper-constantan thermocouples. The thermocouples were connected to two Philips chart recorders. Range of 20 mV with an accuracy of 0.2 mV.

25. Conversion of the mV readings to degrees C was done using polynomial equations from Hewlett-Packard. Accuracy of the conversion was 1°C.

26. The gas consumption was determined in two ways; first, by monitoring the weight of the gas bottle and second by means of a Schlumberger accumulating gas meter, Q = 0.016 to 2.5 m^3/h.

Results: Qualitative Evaluation

27. Traditional Clay Tannur. According to the standards of the bakers, the traditional wood-fired Clay Tannur produced perfect chobaz and malloog bread. However, the disadvantages of the traditional Clay Tannur are clear: a lot of heat is transferred to the surroundings and there is a serious smoke problem.

28. Clay Tannur with Disk Burner. The traditional Clay Tannur with the Disk Burner did not produce bread of an acceptable quality. The flames touched the lower side of the bread, where it burned, while the upper part wasn't yet done. Moreover, the wall temperature appeared to be too low, causing the bread to stick to the wall. To improve the burner, a deflector plate was mounted on top of it. Although the flames were reduced and directed to the wall of the tannur, they still burned the bread.

29. Clay Tannur with Ring Burner. The traditional Clay Tannur with the Ring Burner did not perform well either. The wall temperature remained too low, especially in the lower part of the tannur. A deflector plate improved the heat transfer to the wall, but also produced large flames which burned the bread.

30. Clay Tannur with Ring Burner and Radiator. Inspired by the wood fire, we looked for a way to change the convective heat transfer of the gas fire and make it more radiant. A spherical cover, made of fine (5*5 mm) wire mesh was placed over the burner. This configuration gave promising results. The wall was heated evenly and hardly any flames came out of the radiator. The bread was of a good quality and the baking of malloog did not cause problems. Another advantage of the radiant heat source is that the use of a lid is less essential. With the radiant heat source, the temperature drop was much less important when taking off the lid.

31. Metal Tannur. The gas burning Metal Tannur performed well, although it takes some time to get used to it. The Metal Tannur produced a good quality chobaz and malloog. To improve the oven, insulation of the tannur was attempted with pebbles between the two outer cylinders. The pebbles had no positive influence on the SEC, they only provided better stability of the tannur. No insulating materials, like glass-wool, are available in Yemen and therefore this line of improving this oven was not pursued.

Results: Quantitative Evaluation

32. Table 4.1 summarizes the results of the tests. For a full exposure of tests results see Visser, Annex 1. The calculation procedures are given in Visser, Annex 5.

Table 4.1: TEST RESULTS CHOBAZ BAKING

		Power kW	SFC kg/kg	SEC MJ/kg	Cost YR/kg
Clay Tannur	Wood	29	2.7	35	5.2
Clay Tannur + Disk Burner	Gas	9	0.4	19	1.5
Clay Tannur + Ring Burner	Gas	12	0.5	22	1.8
Clay Tannur + Radiator	Gas	13	0.4	18	1.4
Metal Tannur	Gas	12	0.2	10	0.8
Metal Tannur, pebbles	Gas	11	0.3	14	1.2

Energy prices used: (Ferguson, 1988) - wood 148YR/GJ, gas 82 YR/GJ.

33. The table shows, first, the striking difference between the power of the wood fire and the gas burners. The latter all have about the same value and are roughly 40% of the power of the wood fire. Second, a gas fire of 12 kW is sufficient for baking a good bread. Thus, big fires are not required for the baking process (bad habit). Third, the energy costs when using wood at half the measured power output are still higher than with gas. Fourth, all gas retrofitted Clay Tannurs give similar results in terms of energy use and financial costs. However, only the Ring Burner with radiator produces a good bread. Fifth, the Metal Tannur is almost twice as energy efficient as the gas fired Clay Tannur. This is due to the low mass and direct heat input to the bread. The differences between the models with and without pebbles are more due to fire management (different bakers) than to the hardware.

34. To get a better insight into the heat quantities involved in the baking process, two efficiencies were defined:

$\Gamma 1$ = heat absorbed by the tannur/heat input from the fuel
$\Gamma 2$ = heat to bake the bread/heat input from the fuel

$\Gamma 1$ and $\Gamma 2$ are defined for the whole baking cycle.

35. Table 4.2 summarizes the results. A full exposure of the calculations is given in annex 2 of Visser, while the calculation procedures are given in annex 5 of Visser.

Table 4.2: EFFICIENCY RESULTS THERMAL ANALYSIS

		Γ1 (tannur) (%)	Γ2 (bread) (%)
Clay Tannur	Wood	10	4
Clay Tannur, Disk Burner	gas	19	10
Clay Tannur, Ring Burner	gas	13	7
Clay Tannur, Radiator	gas	15	9
Metal Tannur	gas	28	13
Metal Tannur, pebbles	gas	22	16

36. The table shows, once again, that the Metal Tannur is much more efficient. The traditional clay tannur with ring burner and radiator, the only one producing a decent bread, is an improvement over the wood fired tannur, but does not achieve the performance of the metal tannur.

Conclusions

37. The Ring Burner with Radiator is an acceptable burner with which the traditional wood-burning Clay Tannurs can be retrofitted. A careful selection of the radiator material must be made to ensure a reasonable lifetime. Looking at the energy cost it is clear that the Metal Tannur is much better than the Clay Tannur. Moreover, it is expected that the Metal Tannur can be further improved by filling the annular space between the two outer walls with a lightweight insulating material like glass-wool or rockwool (experiments are required). However, it should be borne in mind that the price for the Metal Tannur is more than twice that of a Clay Tannur with a Ring Burner.

38. The SEC of the Metal Tannur lies in the same range as the SEC's given by Usinger for the Family Oven. Thus a dome shaped oven like the Family Oven does not offer a good alternative, also because it requires the introduction of a completely new way of baking.

Production Facilities

39. If the traditional Clay Tannur is to be retrofitted with the Ring Burner plus radiator, then this equipment preferably should be locally produced. To get an impression of the possibilities of local production, a visit was paid to the factory producing the Metal Tannur: the "Ready made windows and modern gas furnaces" factory in Hadda street. The factory is well equipped with sheet cutting and bending machines, presses, drilling machines, spot-welding equipment and a number of self developed special production machines. Further the factory has a workshop with lathes etc. in which tools for the factory are made. The factory is well organized, has a maximum production capacity 200 Tannurs per day and realizes a production of 130 Tannurs per day. The Metal Tannur is sold to retailers all over Yemen. There even is some export to Yemeni abroad.

40. Prof. Motawakel of Sana'a University and the author met with the technical manager, Mr. Muslak Guddam and with the owner Mr. Muhammed Al-A-Wdi. According to Mr. Guddam they would not have problems in making the burner as specified. However, he would not give a detailed cost estimate and referred to the owner Mr. Al-A-Wdi. The latter was afraid that a new product would be brought on the market which would compete with the Metal Tannur. Therefore he was quite reluctant to collaborate. After showing us around he left and no cost estimate for a Yemen made burner was obtained. However, it is the author's strong feeling that this factory is able to produce a good burner for a reasonable price and it therefore is recommended to pursue this contact.

Tannur Bakeries

Introduction

41. Tannur bakeries in Sana'a were surveyed to gather additional data on the energy consumption of tannurs (see also Table 3.1). The survey was done in cooperation with the Central Planning Organization. The survey was constrained by the fact that many tannur bakeries are run by women and hence are not accessible to men. Therefore we focussed on bakeries which had close working relationships with restaurants, which are freely accessible. Eight bakeries were willing to participate.

Questionnaire

42. The Questionnaire was comprised of 4 questions:

(a) What is your basic fuel?;

(b) Which type of bread do you usually make?;

(c) How much flour do you use per day?; and

(d) How much fuel do you use per day?

If the answer to questions three and four was "2 sacks" or "1 can", then additional questions were asked to specify the quantities in terms of kilograms or liters.

43. During the visit, the tannur and burner were examined, to get an idea of the equipment used in professional bakeries. Moreover the bakers were asked whether they would be willing to participate in an experiment to determine the SEC experimentally.

Results

44. The results of the questionnaire are summarized in Table 6.1.

Table 6.1: BAKERY SURVEY

Bread		Fuel kg/day	Flour kg/day	SEC kg/GJ
tameez	gas	12.5	25	23
rashooz	gas	25.0	75	15
chobaz	gas	4.2	25	8
malloog	wood	64.0	50	24
rashooz	gas	25.0	50	23
rashooz	gas	12.5	38	15
rashooz	gas	25.0	75	15
roti	oil	166.4	300	24

45. The roti bakery used and oil-fired rectangular dome oven, built of bricks. It was about 3 * 2.5 meters, with a maximum height of 1 meter. The bread, called roti, produced by this bakery differs from the others. Rotis are small loaves baked in a bread tin.

46. Two different types of Tannur burners could be distinguished. Type 1 is a cylindrical box, diameter 350 mm, height 80 mm, with twenty holes of 3 mm diameter in the outside wall of this cylinder. Once installed in the tannur, the burner is covered with a round metal or ceramic plate which leaves about 80 mm between the edge of this plate and the wall of the tannur. Tannurs equipped with this burner are rather big. They have their largest diameter at the bottom (about 1200 mm), a height of about 1200 mm and a top opening with a diameter less than 500 mm. Bakeries nr. 1 and 3 were using this type of tannur and burner. The second type Tannur burner consists of a gas-jet which impinges on a metal or stone object in the center of the tannur bottom. This object becomes red hot and radiates heat (the gas flames, which are bright yellow, radiate too). This burner type is used in Tannurs which are considerably smaller (dimensions 700, 1000, and 400 mm respectively).

Conclusions

47. The table shows that Tannurs fired with gas have an SEC between 24 and 15 MJ per kg of flour (the Chobaz baker, no. 3, gave unreliable data). These figures agree with the numbers found by Al Motawakel and Usinger (see Table 3.1). The SEC numbers differ however considerably from those found by Young (1986) for large bakeries. The difference cannot be explained by the quantity of flour used. Only measurements can clear this discrepancy.

48. The performance of the roti-oven is poor, certainly against the number given by Young for a similar oil-fired oven. Again, only measurements can reveal the actual SEC.

Testing of Cookstoves

Introduction

49. In the framework of this mission, a representative sample of existing cookstoves was tested and improvements proposed. Zabara (1988) provided the basis on which stoves were selected (see also Annex 4). The Primus pressurized kerosene stove, although often found in households (Zabara, 1988), was not included in the series. Extensive test-data on these stoves can be found in Prasad et al. (1985).

Stoves Description

50. The Maugad. The Maugad is the traditional charcoal stove which keeps the food warm after it has been cooked on the tannur. The Maugad is not really a stove, it "is more appropriately described as a receptacle for holding hot ashes and charcoal on top of which is placed a pot". (Young, 1986). It consists of a metal bowl on a cylindrical stand. The stove has pan supports but no grate or any other feature to control the combustion air. It costs about 150 YR.

51. The Ring Burner. In the tests discussed here, the Ring Burner, used in the Clay Tannur, (see Figure 4.4) was used to represent the burners without frame (see Annex 4). Only the two inner rings of the burner were used. The burner allows control of the quantity of entrained combustion air. This burner is sold at 340 YR.

52. The Casful Stove. The third stove, called Casful, is made in Taiwan, and consists of a burner which resembles the ring burner, mounted in a cast iron frame. The burner is composed out of two rings. The quantity of entrained combustion air can be controlled. The stove costs 200YR.

53. The Rinnai Stove. The Rinnai Stove is a luxurious stove model. It is made in Japan from enamelled steel sheet with a stainless steel top surface. The two burner heads are very well made of special alloys and the stove is equipped with a piezo-electrical ignition. It costs 700 YR.

Test Procedure

54. The stove characteristics to be determined in the tests are:

a) the maximum power output, Pmax;

b) the efficiency at high power, Γmax;

c) the ability to produce a low fire for simmering operations, Pmin;

d) the efficiency at low power, Γmin; and

e) the turn down ratio, Pmax/Pmin/.

The test methodology which was used is basically the one proposed by CILSS. A pan filled to 2/3 of its capacity with water is brought to the boil whereafter the water is kept simmering for half an hour. The pan has a diameter of 25 cm, which corresponds to the pan most commonly used (Zabarah, 1988).

55. The procedure of the actual testing is as follows:

a) The pan was filled with 5 kg of water and the water temperature is measured;

b) The fuel is weighed and the stove lighted;

c) The pan with water is placed on the stove, and the time recorded. The stove is operated at maximum power;

d) As soon as the water reaches boiling temperature (≈93°C at this altitude), the fuel as well as the pan with the water is weighed and the time recorded;

e) The pan is placed back on the stove for a simmering period of 30 minutes. The stove is operated to keep the water temperature at or just under 93°C, in any case not to drop under 90°C;

f) At the end of this simmering period, both fuel and pan with water are weighed again;

g) From this data Pmax, Γmax, Pmin, and Γmin are calculated (see annex 6 for details). Each test is repeated three times and the results averaged.

Results

56. The results of the water boiling tests are summarized in Table 7.1. (Full exposure of the test results in appendix 3).

Table 7.1: RESULTS OF COOKSTOVE TESTS

		Pmax (kW)	Γmax (%)	Pmin (kW)	Γmin (%)	Turndown ratio
Maugad	charcoal	4.1	8.8	1.5	6.1	2.7
Ring Burner	gas	3.4	45.8	1.4	36.5	2.4
Casful	gas	4.3	43.0	1.4	34.4	3.1
Rinnai	gas	2.6	57.1	0.6	35.7	4.5

57. The efficiency of the Maugad at high and low power is extremely poor. The stove is not suited for cooking. The stove also performs poorly for the job it was designed for, namely keeping the food warm. It explains why, traditionally, the Maugad with pans and pots are covered with a heavy cloth.

58. The gas stoves perform well, the Rinnai clearly being the best of the three. It gives not only the highest efficiency, but also the highest turn down ratio. Both characteristics make the Rinnai the most energy and time efficient stove for normal cooking practices. The other gas stoves perform on an acceptable level, and are reasonable stoves. Their turndown ratio is somewhat lower mainly because of a less sophisticated design of the gas valve.

Conclusions

59. There is a sufficient number of good gas fuelled cooking stoves on the market. Quality and performance vary with the price of the stoves, but even the cheapest performs on an acceptable level. Controllability is, in combination with the reducing valve on the gas bottle, good for stoves of the Rinnai type and reasonable for the cheaper stoves. The equipment now on the market is also suited for dissemination in the future, even when the gas composition changes (all gas bottles are, and will be, provided with pressure reduction valves and the stoves themselves are equipped with combustion air control features).

ECONOMIC ASSESSMENT OF RURAL POWER OPTIONS

1. As discussed in Section 6, the majority of rural households in the northern governorates consume small amounts of electricity. Few of these households are connected to the grid; most instead rely on small private generation. Despite the high costs of rural power supply in the northern governorates, whether by grid extension or private diesel generation, there is a high willingness and ability to pay for electricity. Given the willingness and ability to pay, the high cost of conventional options, the low level of power consumption, and the relatively good insolation found in the northern governorates, decentralized photovoltaic (PV) systems appear to be a promising power option for rural households.

2. The following assessment economically compares grid extension, diesel generation, and individual household PV systems to establish the conditions under which each option is least-cost. This assessment considers decentralized rather than centralized PV systems. Many earlier PV system designs for household power supply were centralized, meaning that small settlements would be supplied by a central PV system, possibly including a large inverter, and a mini-grid for power distribution. Recent studies 1/ have indicated that for household loads and settlement sizes where PV is most likely to be competitive with other electricity supply options, the decentralized approach has the following advantages over centralized systems:

(a) lower capital costs per consumer;

(b) lower real levelized energy costs;

(c) no right of way needs for the mini-grid or centralized facility;

(d) power outages affect only individual loads;

(e) technically less complex and hence easier to maintain and more reliable;

(f) modular, more flexible system responsive to changes in load requirements of individual users; and

(g) responsibility for payment, care, and maintenance of system easily defined (all lie with the individual system owner).

3. A typical decentralized PV system was depicted in Figure 6.2. It consists of PV modules, batteries to store energy for nighttime use or during periods of poor insolation, and a controller for preventing the over-charging or excessive discharging of batteries. The system would provide 12 VDC power, but unlike most remote generators, power would be available on a continuous basis. Batteries are sized to provide enough energy to power the load for a given number of days. Two days of storage are assumed in this assessment, since the loads are not critical. Modules are sized to provide enough energy to supply all loads during the day when the ratio of monthly average daily insolation to total daily load is least. It is assumed here that daily household loads are constant throughout the year, so that modules are sized to provide enough energy daily to meet daily load during the month with the worst monthly average daily insolation.

1/ *For instance, see "Pakistan: Assessment of Photovoltaic Programs, Applications, and Markets", World Bank/UNDP/Bilateral Aid Energy Sector Management Assistance Program, Activity Completion Report 103/89, October, 1989.*

4. The three technologies under consideration are assessed with respect to the economic cost of providing households the average level of service currently found among rural electricity users, i.e. low-power lighting and television. The border price of a household PV system, including interior wiring and lights which would meet these needs is approximately US$ 760. This compares favorably to the average cost per consumer of grid extension connection under Power 5, which ranges from US$ 900 to US$ 1300, which does not include interior wiring or lights. It must be noted, however, that grid extension will allow for greater loads per household connection, as well as for other electrical applications, such as irrigation water pumping, for which PV systems are not cost competitive. On the other hand, grid extension will not reach most households in Yemen over the next 20 years simply due to financial constraints.

5. The 12 VDC output of a PV system does not seriously limit the type of end-use devices that may be used. Twelve volt DC televisions and radios are commonly available throughout Yemen, as indicated by the household energy survey results. Twelve volt DC fluorescent tube lights are already sold in Sana'a for small battery lamps and cars, and may be available elsewhere. If the local production of system controllers is not feasible, these components are easily available internationally. If 220 V AC output must be available, small yet efficient electronic inverters (90% +) are available internationally for approximately US$ 1 per peak load watt.

6. Given the widespread use of liquid batteries for household power supply, small photovoltaic systems (a few hundred peak watts) could also be used for battery charging in rural areas. This approach as been used successfully in Thailand, and could be considered for development in Yemen as well. Smaller individual PV systems, perhaps providing only two lighting points are also a lower cost option. The border price of such a system in Yemen would be around $450. These options are not assessed here, but may be a component of the proposed household PV commercialization project.

7. Insolation in the northern governorates has been measured only recently, starting in 1986. Results for that year are given for several sites in the table below. These figures represent the average daily amount of total solar energy received on a horizontal surface during each month of the year for each site, as measured by the YAR Meteorology Department. By tilting photovoltaic arrays, the amount of solar energy received can be increased for certain months, so that the amount of available solar energy may be greater during the worst months than this data suggests. It must be emphasized that this is data for only one year; long term averages, or the insolation in any other given year may be different. Furthermore, there is no guarantee that the recording devices were operating properly, particularly given the incidence of months for which readings are not available. Nonetheless, these results seem to be reasonable given the location and climate of Yemen, and the variations in insolation by region appear to be consistent with what one expects. These results at the very least show the range of insolation quantities and patterns in Yemen.

8. In order to economically compare grid extension, small diesel generation, and decentralized photovoltaic systems, it must be assumed that each system provides the same level of service. Although PV and grid systems would provide virtually continuous power, small diesel generation would only be available during the evening for 5 or 6 hours. Since evening loads such as lighting, television, and radio are the predominant rural household loads (over 90% of total rural household consumption), this difference in system availability does not appear to invalidate the economic comparison.

Monthly Average Daily Insolation for Various Cities in YAR
(1986 only; figures given in kWh/sqm/day)

	Sa'ada	Al-Jawf	Mareb	Mocha	Hodeida	Taiz	Sana'a
Jan	8.2	5.8	4.5	n.a.	n.a.	4.6	3.9
Feb	7.3	6.1	4.6	5.3	4.8	4.2	4.3
Mar	8.4	6.4	5.0	6.1	5.3	5.7	4.6
Apr	7.3	5.5	4.7	6.1	5.8	5.4	4.2
May	8.9	7.3	n.a.	5.8	5.9	6.1	5.0
Jun	8.0	6.5	n.a.	n.a.	5.4	5.4	4.5
Jul	7.0	5.8	5.2	n.a.	5.1	4.8	4.4
Aug	7.6	6.0	5.1	5.1	5.3	5.3	4.5
Sep	8.6	6.5	5.7	5.9	5.2	5.3	5.1
Oct	7.8	6.4	5.6	7.0	n.a.	6.0	4.8
Nov	6.6	5.9	4.9	5.6	5.3	5.4	3.7
Dec	7.0	n.a.	4.3	4.9	4.8	3.8	5.1

Source: YAR Statistical Yearbook, 1988.

9. The average appliance stock for rural electricity-using households is 2.6 fluorescent tube lights, 1.1 incandescent bulbs, and 0.7 televisions. Other appliances have an average incidence of 0.08 per household or less. On average, fluorescent tubes are used about 4.5 hours per day, while incandescent bulbs are used 2.1 hours and the television 3.2 hours. Interestingly, fluorescent lamps are more common and used more than incandescent bulbs; it is not known whether this is due to relative availability or household preference. For this assessment, the base case level of service is considered to be three lights operated 4.5 hours per day and a television operated 3.5 hours per day.

10. The PV systems considered here would meet these service requirements with high efficiency fluorescent lamps and ballasts. These lamps would be sold as part of a complete household PV package. Although they are more expensive than conventional lamps and bulbs, they last longer and consume approximately one-fifth the amount of power that an incandescent bulb requires for the same level of service, and one-half to one-third the consumption of a standard fluorescent lamp. For example, the Philips PL 11 W DC fluorescent lamp draws 14 W and has an estimated life of 6000 hours, but provides the same illuminance of a 75 W incandescent bulb, which has an expected life of only 1000 hours. The high cost of high efficiency fluorescent lamps is offset by the reduction in module and battery requirements and their longer life. Similarly, black and white DC televisions which are commonly found in YAR consume only 15W, less than AC consumption of the same set. Consequently, the three systems cannot be compared on a cost per kilowatt-hour basis since the PV system provides the same service with less energy and therefore a higher cost per kilowatt-hour. The base case PV system consumption is 0.25 kWh/day, and for the conventional systems it is 0.75 kWh/day, which reflects average rural household consumption based on the results of the University Surveys. For sensitivity purposes, a high consumption case of 1.25 kWh/day for the PV systems and 2 kWh/day for the conventional systems is used; this is higher consumption than current rural average YGEC consumption of 1.6 kWh/day.

11. Rather than using a cost per kilowatt-hour, this assessment compares the annualized economic cost of providing the base case level of service with each of the three power options. All costs are given in 1989 US$ border price equivalents. PV system values are based on current international prices and existing technical performance. Given existing manufacturing technology, c.i.f. module prices could fall to US$ 3/Wp with a significant increase in world production. Base case worst month insolation is conservatively estimated at 4 kWh/sqm/day, although of 5 kWh/sqm/day is used for sensitivity analysis, given the insolation data presented in the previous

section. The combination of US$5.50/Wp module cost and 4 kWh/m2/day composes the base case for PV systems, while the combination of US$3/Wp module costs and 5 kWh/m2/day is the "best case" scenario.

12. Grid extension costs are based on Power 5 feasibility study estimates from 1987 escalated by 5% annually for two years to 1989 equivalents. Sensitivity analysis is performed with respect to distance from the existing grid, line costs per kilometer, number of connections, and load per connection. Local components of the Power 5 costs have been multiplied by a border price conversion factor of 0.8. The base case line cost of US$ 6,600/km represents the use of single phase 35 mm2 6.35 kV line over easy terrain, and the high line cost case of US$ 15,500 represents the use of 35 mm2 three phase 11 kV line over difficult terrain. A mid-point cost of US$ 11,000/km is also used, and can represent a mix of the 6.35 kV single phase line with the 11 kV three phase line. Loading capability of the single phase line is assumed to be 600 kVA-km for a spot load, or 1200 kVA-km for a distributed load; for the three phase line, the loading capability for a spot load is 2400 kVA-km, and for a distributed load is 4800 kVA-km.

13. Diesel generation costs are also based on current international prices, consistent with retail prices found in the northern governorates. Sensitivity analysis is carried out with respect to load per connection, number of connections, and real fuel cost escalation. Two fuel cost cases are considered. The base case uses the economic cost of delivered diesel fuel (US$ 0.22/li), while the high case uses a US$ 0.25/li fuel cost and a 3% real annual fuel cost escalation rate. It is assumed that the diesel generator is always properly sized to meet the total load of all connections. This is an assumption favorable to diesel, in that site visits revealed consistent over-sizing (resulting in lower efficiencies), and that in general, households in a settlement that has diesel power will not all be connected to a single large generator, but may be connected to numerous small, less efficient and more costly generators if they are connected at all.

14. Base case assumptions for the different alternatives are given in the table below.

<u>Assumptions for a single decentralized PV system</u>

Real Discount Rate	=	10 %
Worst Month Insolation	=	4 kWh/m2/day
Photovoltaic Module Unit Costs	=	5.50 US$/Wp
Module efficiency (STC)	=	11.5 %
Module lifetime	=	15 years
Battery energy efficiency	=	80 %
Maximum depth of discharge	=	70 %
Battery Lifetime	=	2 years
Battery Unit Cost	=	70 US$/kWh
Controller cost	=	75 US$
Controller lifetime	=	8 years
Cables, etc.	=	30 US$
System Load	=	0.25 kWh/day
Fixed annual O&M cost	=	5 US$
Overall NOC system efficiency	=	8 % (incl. batteries)
Photovoltaic system availability	=	95 %

Derived base case PV system characteristics:

Modules required	=	90 Wp
Battery storage required	=	1 kWh
System capital cost	=	760 US$
Levelized energy cost	=	1.44 US$/kWh
Annualized cost per household	=	152 US$

Grid extension assumptions

Load Distance From Grid (kilometers)	=	7 kilometers
Feeder Costs for Distribution Lines	=	6600 US$/km
15 kVa 6.35/0.4 kV Transformer Costs	=	900 US$
Secondary line costs	=	4000 US$/transformer
Number of Connections to Buildings	=	50
Number of Connections per Transformer	=	25
Average Daily Load per Connection	=	0.75 kWh
Cost per Single Phase Service Connection	=	200 US$
Annual Power Line Maintenance Cost	=	2 % of capital costs
Long Run Marginal Electricity Cost (Generation and Transmission only)	=	0.10 US$/kWh
Lifetime of All Equipment	=	25 years
Grid availability	=	95 %
Real Discount Rate	=	10 %

Derived base case grid extension characteristics:

Connection Cost per Consumer	=	1325 US$
Levelized Energy Cost	=	0.76 US$/kWh
Annualized Cost per Household	=	201 US$

Diesel generation assumptions

Number of Connections	=	50
Power Requirement per Connection	=	0.4 kW/connection
Average Daily Load per Connection	=	0.75 kWh
Diesel Generator Unit Cost	=	450 US$/kilowatt + US$ 200
Diesel Fuel Cost	=	0.22 US$/liter
Average Daily Diesel Operating Hours	=	6 hours/day
Site Civil Costs	=	1000 US$
Site Lifetime	=	15 years
Distribution Line Costs	=	500 US$/10 connections
Service Connection Cost	=	500 US$/connect
Annual Maintenance & Repair	=	10 % of capital costs
Annual Operator Costs (half-time)	=	500 US$
Engine Overhaul Cost Factor	=	30 %
Diesel-Generator Lifetime	=	8 years
Frequency of Diesel Engine Overhaul	=	4 years
Diesel Generator Availability	=	90 %
Real Discount Rate	=	10 %

Derived Base Case Diesel System Characteristics		
Diesel Engine Size	=	20 kilowatts
Total Average Daily Load	=	15 kWh/day
Annual Fuel Consumption	=	7005 li
Capital Cost per Connection	=	309 US$
Levelized Energy Cost	=	0.49 US$/kWh
Annualized Cost per Connection	=	124 US$/kWh

15. In the cases described above, diesel generation is least-cost, followed by PV and grid extension. However, the relative ranking of these systems changes considerably as conditions such as insolation, number of households, average load per household, etc. vary. The following figures present the results of sensitivity analysis, and are used to identify the conditions under which each alternative provides least-cost electricity supply.

16. The following conclusions emerge from this analysis:

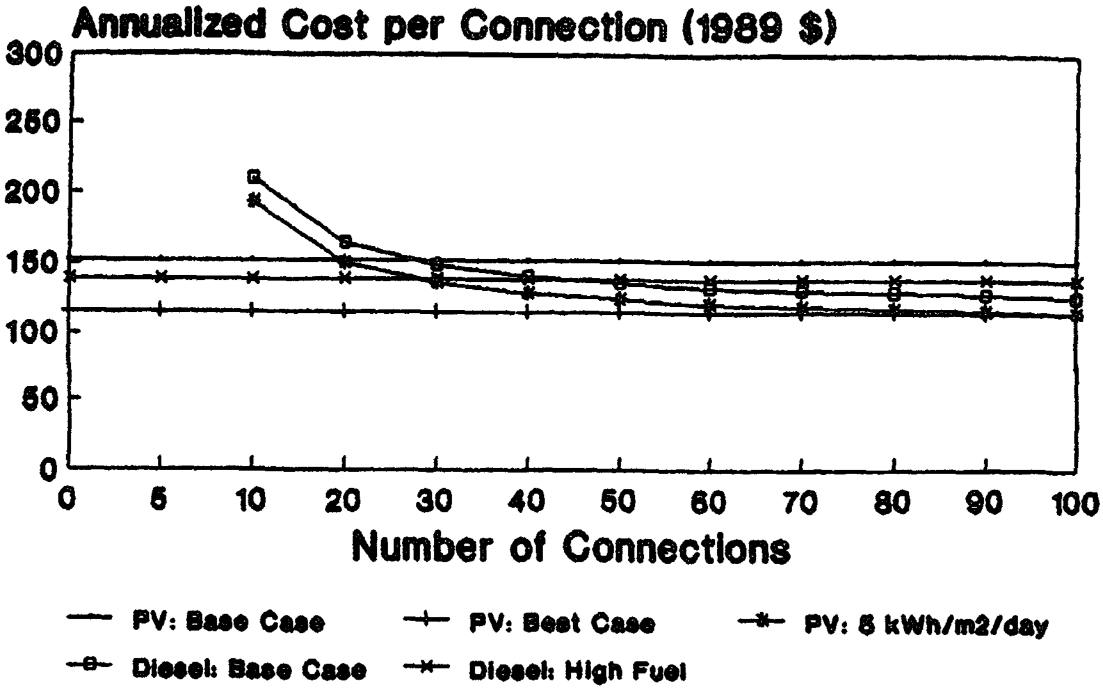
(a) Assuming base case energy consumption, decentralized PV systems could provide the least-cost household electricity supply option throughout the northern governorates for settlements of less than 20 to 45 electrified households (depending on fuel price trends and insolation) in areas where there are fewer than 12 to 16 household or other lower power connections per kilometer of 11kV line (depending on insolation and assuming easy grid access. More difficult grid access would increase this number, e.g. for grid extension costing $15,500/km, PV would be cheaper in areas with less than 35 connections per km of 11 kV line).

(b) At reduced module costs expected in the next few years, PV would be the least-cost power option for settlements of less than 100 to 160 households (depending on fuel price trends) located in areas with fewer than 25 connections per kilometer of 11kV line (assuming easy grid access and single phase line; more difficult access would increase this number.) Even if average grid-connected loads would increase to 2kwh/day, PV would still be least-cost in areas with less than 4 electrified households per kilometer of 11kV line.

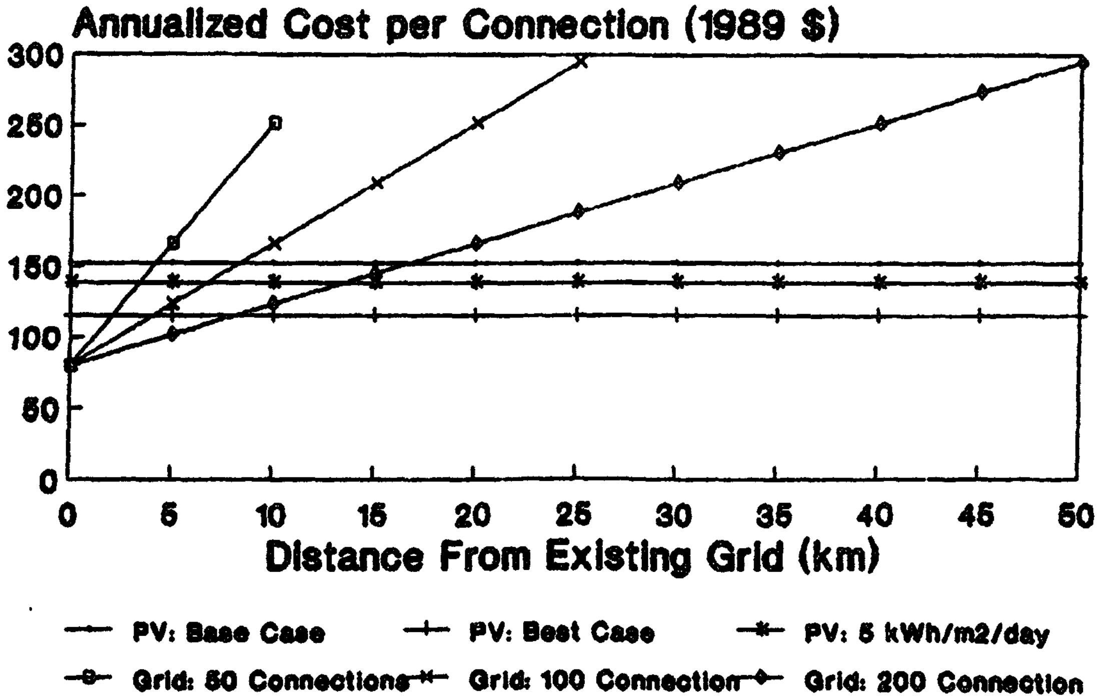
17. In general, the larger the total load (number of connections multiplied by the average daily load per connection) and the closer it is to existing 11 kV supply, the more likely it is that grid extension will provide the least-cost means for household power supply. However, given that a considerable portion of the rural population (which is characterized by relatively low power consumption per electrified household) is dispersed throughout areas away from planned or existing grid supply, grid extension is not an economically least-cost option for many of these households. Moreover, even if it was economically justified to connect these households to the grid, it is improbable that the financial resources to do so can be mobilized within the next 20 years whereas at least some households would be able to finance a PV system on their own.

18. In areas where grid extension is not economically or financially feasible, diesel generation or decentralized photovoltaic systems are the only feasible means of meeting household power needs. Diesel generation is better where loads are more concentrated, but the above results suggest that PV systems are economically less costly for settlements or villages of less than 20 to 45 electrified households. Settlements of this size would have populations in the range of 120 to 275 inhabitants or more if not all households are electrified. Certainly there are many such settlements scattered through the rural areas of the northern governorates. With further reductions in module costs, PV systems could be appropriate for settlements of as many as 1,000 inhabitants.

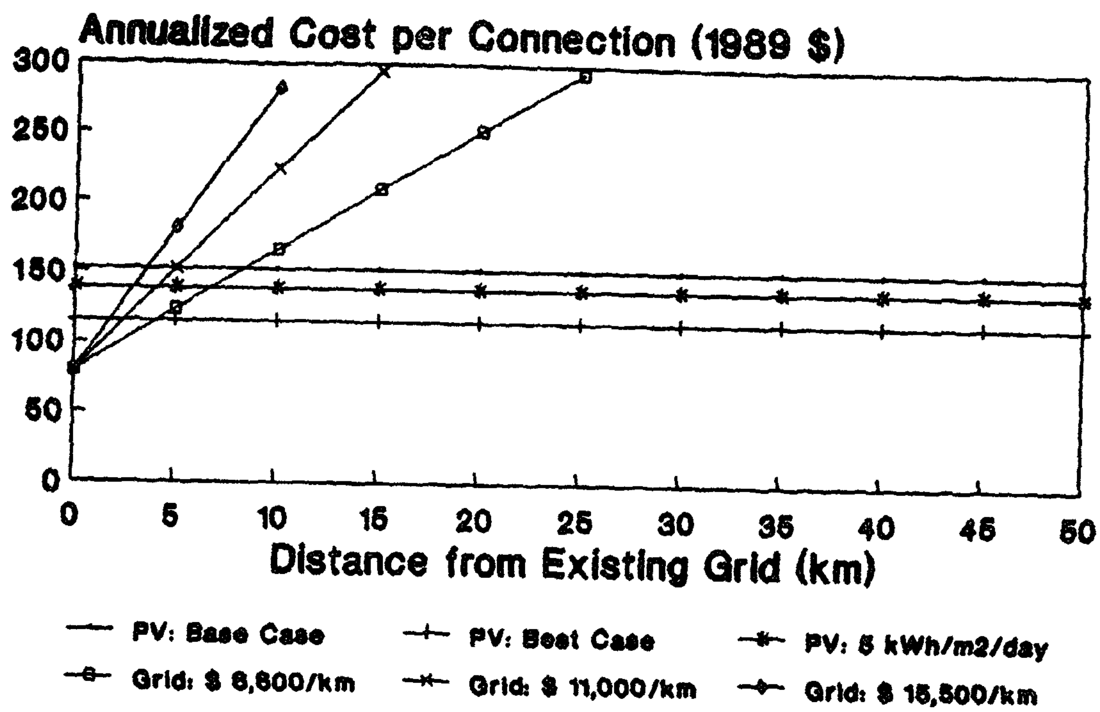
PV VS. DIESEL GENERATION
BASE CASE ELECTRICITY CONSUMPTION



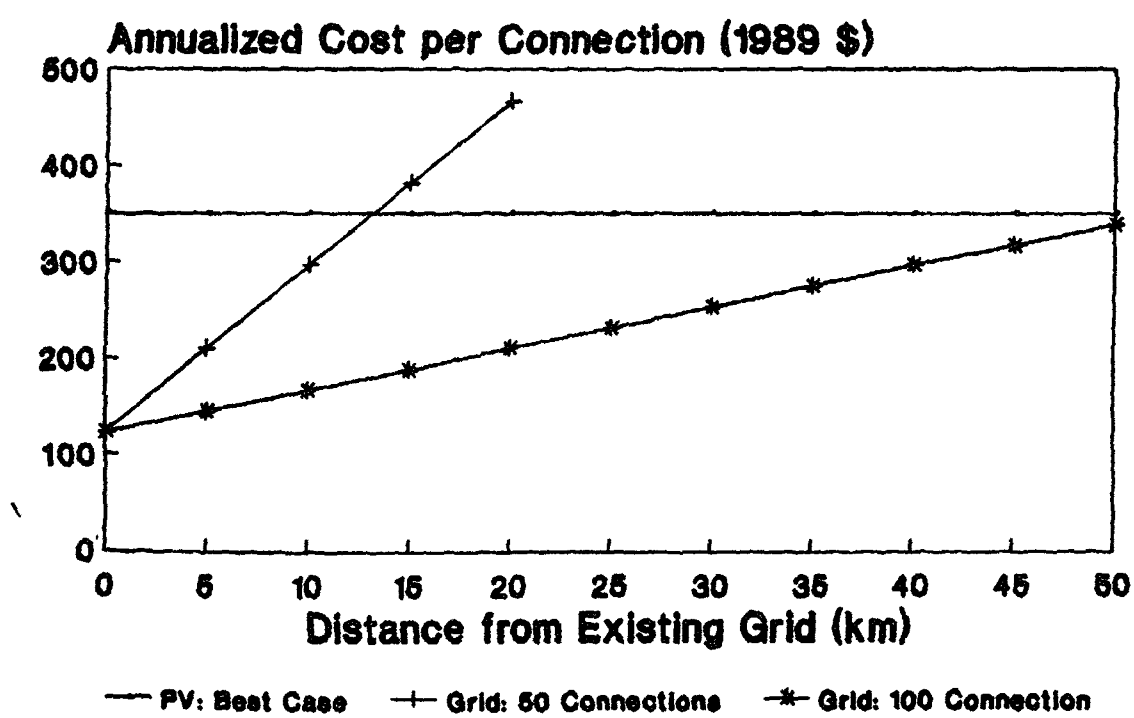
PV VS. GRID EXTENSION
BASE CASE ELECTRICITY CONSUMPTION



PV VS. GRID EXTENSION
LINE COST SENSITIVITY



PV VS. GRID EXTENSION
DAILY LOAD SENSITIVITY



1.25 kWh/d PV load and 2 kWh/d grid load