# PRODUCER GAS FUELED IRRIGATION: EVALUATING THE POTENTIAL OF A TECHNOLOGY

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## Abstract

Development and commercialization of technologies that utilize on-farm energy sources are beset by uncertainty. Producer gas, a technology that allows wood to be converted to a gaseous fuel which can power internal combustion engines, is evaluated for irrigation systems using simulation modeling and stochastic efficiency analysis. For many market conditions, producer gas stochastically dominates diesel fuel for powering a center pivot irrigation system in terms of lower cost. Commercial potential exists, but experience with pilot installations is required to further reduce uncertainty.


*Key words:* farm energy, wood, costs, simulation.

The generation of a new technology involves decisionmaking under uncertainty for the manufacturer, distributor, and ultimate user of the technology. The manufacturer must take knowledge of a technical process accumulated through research and development, and invest the capital, labor, and managerial skills to develop a marketable product while facing uncertainty as to the demand for the product (Nelson, 1046-1048). The distributor, once the technology package is available, must make the decision to handle it and undertake the sales effort necessary to market it while also facing an uncertain demand for the technology. Finally, the user faces uncertainty as to the profitability of the new technology given the current situation. The production system must be appraised considering both the current and new technology and a decision made relative to the potential contribution of the new technology.

The generation of agricultural technologies, likewise, occurs under conditions of uncertainty. The farmer, the ultimate adopter of the technology, faces uncertainty resulting from unpredictable natural events, substantial variation in yields, and highly volatile prices. The uncertainty impacts, the derived demand for a new technology, and thus the profitability of decisions made by the distributor and manufacturer, must be considered.

On-farm energy production technology generation has faced such uncertainty. The interest in on-farm energy production is induced by the farmers' inherent derived demand for fuels and by the uncertainty in the fuel market. Oil supply disruptions and unprecedented price increases have caused farmers to wonder if they could use some of their resources for fuel production to reduce fuel costs and insulate themselves from future market uncertainties. But, to date, few on-farm fuel technology packages are being used or even manufactured and distributed.

Since many of the potential manufacturers of on-farm energy systems are small firms that specialize in agricultural equipment, it was thought that economists, especially extension economists, could provide information which would be useful in the intermediate steps of technology development and adoption. With microcomputers, readily available data and straightforward methods of analysis, economic information can be generated which reduces the uncertainty associated with developing technology. At this stage of development, research cannot conclusively indicate economic potential, but it can provide an intermediate appraisal. The intent of this analysis is to facilitate transition from the research and development stage to the pilot operation stage of technology evolution.

An evaluation of producer gas (PG) from wood,[1] a potential on-farm energy system, is presented to demonstrate the type of analyses being suggested. While large scale units are manufactured for the forestry industry, only a few manufacturers have tentatively initiated

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[1]Producer gas from wood is a technology which has at times been extensively used. In World War II, European countries powered over one million vehicles with gasified wood (National Research Council, p. 2). The Appendix gives a brief overview of the technology.

production of farm scale equipment. The economic potential for on-farm use is not clear. This article presents an evaluation of producer gas-powered irrigation using a microcomputer, methods of analysis well known to agricultural economists, and information obtained from readily available sources. The first section gives information on the application of PG to irrigation and presents the conceptual information built into the microcomputer model. The second section presents the results in probabilistic terms useful in appraising the potential of the technology. The last section draws conclusions about the use of such an approach to reducing uncertainty in technology development.

## ANALYSIS

The basic question both farmers and manufacturers have is: Will an investment in a PG system to fuel an irrigation system likely reduce cost of operation enough to give a reasonable return on the investment? If so, the farmer will have an interest in the technology and there is a potential market for the manufacturer's system. If not, the manufacturer can drop efforts to promote the system for this use. The major decision variables associated with the question concern: (a) the total cost of having a PG system in place and operating and (b) the value of the conventional fuel (diesel in this case) displaced by use of PG. If it can be clearly demonstrated that the net present value of the costs (NPVC) of the new fuel system and its operation is less than NPVC of the conventional fuel system, there is economic incentive for the manufacturer and farmers to evaluate the alternative fuel system in greater detail.

Corn was selected as the irrigated crop to be studied and the system used a diesel powered, medium-pressure center pivot unit covering 138 acres. Irrigation in the study area, North Florida, is supplemental. Water application needs vary from year-to-year due to the wide variability in rainfall.[2]

Obtaining energy from PG to power the pump involves utilizing the diesel fuel system and engine as it is initially used, and adding a thermal gasifier for converting the wood to PG. The fuel system becomes what is described as a "dual-fuel" system where a high proportion of the energy comes from PG and a small amount of diesel fuel is used to control predetonation.

Since irrigation with both fuel systems uses the same irrigation unit, engine and diesel fuel system, the NPVC for the two systems can be expressed as:

$$NPVCD_s = \sum_{t=1}^{n} [1+R]^{-t} [(DFOS_t)(DP_t)]$$

and

$$NPVCW_s = CEC + \sum_{t+1}^{n} [1+R]^{-t} [(WFOS_t)(WP_t) + (LCF)(WFOS_t)(PL) + (PD)(DFOS_t)(DP_t) + FRC]$$

where:

$NPVCD_s$ = net present value of cost of diesel fuel over a n=10-year period, in dollars;
$NPVCW_s$ = net present value of cost of PG fuel system over a n=10-year period, in dollars;
$DFOS_t$ = diesel fuel requirement in year t, in gallons;
R = discount rate;
$DP_t$ = price per gallon of diesel fuel in year t, in dollars;
CEC = PG system equipment costs, in dollars;
$WFOS_t$ = wood fuel requirements, in tons of wood chips in year t;
$WP_t$ = price per ton of wood in year t, in dollars;
LCF = conversion factor for determining labor requirements, in hours of labor per ton of wood;
PL = price per hour of labor, in dollars;
PD = proportion of diesel fuel used in dual fuel; and
FRC = filter replacement cost, in dollars per year.

The equations imply that for the presently used fuel system the only cost is for the diesel fuel; whereas, for the PG system there is the cost of equipment, maintenance, labor, wood, and the small quantity of diesel fuel. Other costs associated with maintenance and operation of the irrigation system are the same for both fuel systems.

Correct capital budgeting at the firm level requires tax aspects to be considered. However, including tax aspects in a preliminary assessment of a technology reduces the generality of the results, given that items specific to an individual user (i.e., debt-equity ratio, marginal tax rate, tax-related depreciation, interest paid

[2]Since center pivot irrigation systems are used for corn in North Florida, it is assumed that: (a) irrigation as a cultivation practice is economical, (b) system costs well, center pivot sprinkler unit, pump and diesel power unit costs are sunk and (c) continued use of the system will depend upon relative fuel and product prices (Boggess and Amerling).

on the asset purchase loan, investment tax credits, and the general rate of inflation; see Robertson et al., p. 38) must be specified. Since tax considerations generally favor investment in new equipment, and since the intent of the study was to show qualitatively the preliminary potential of the developing technology, the simpler NPVC formulation was used.[3]

In the equations the energy requirement, prices of wood and diesel fuels, cost of labor, opportunity cost of funds, and ultimate cost of the PG system are uncertain. Therefore, the NPVC's associated with the two systems are also uncertain (Anderson et al., p. 252). The factors are all economic except for the energy required for irrigation. Reflecting the future values of these economic factors is a problem since little reliable information is available for projecting them. Petroleum prices serve as an example: a *Wall Street Journal* article had the title, "More or Less, Oil Will Go Up, or Down, or Maybe It Won't" (Getschow). Given the 10-year period of analysis, the same statement could probably be made for the other economic factors being considered. The irrigation energy requirement, on the other hand, can be specified probabilistically based on rainfall frequency data.

Simulation methodology was used to determine the NPVC's because of the case with which the uncertain factors can be handled. Monte Carlo simulation was used for the irrigation requirement since rainfall distribution data are available[4] while diesel fuel, wood, and labor prices are handled in a discrete manner because no acceptable distributions are available for these. The results of the simulation are a series of cumulative probability curves for NPVC for the two fuels given the specified prices. Since the curves represent the cumulative probability of the net present value of costs, rather than the customary net present value of the investment (in this study all aspects of corn production are held the same except for the fuel systems), the curve that lies to the left represents the dominant technology. The difference between the curves represents a probabilistic difference between the net present value of the costs of the two fuel systems.

The basic logic underlying the simulation is illustrated in Figure 1. Daily rainfall recorded at Gainesville, Florida (Portier) over a 23-year period is used to determine the volume of irrigation to be applied during the corresponding crop season using a strategy by Rhoads. Ten crop-season irrigation volumes are randomly drawn and the corresponding energy requirements in terms of diesel fuel and dual-fuel (wood and diesel fuel) are calculated. Similarly, the labor requirements associated with the wood gasifier are determined. The process is continued until 100 sets of 10-year crop-season requirements of diesel fuel, dual-fuel, and labor are obtained. Next, annual prices for diesel fuel, wood and labor, along with filter costs are used to generate 100 sets of 10-year sequences of crop-season costs associated with the two fuel systems. The cost sequences along with the

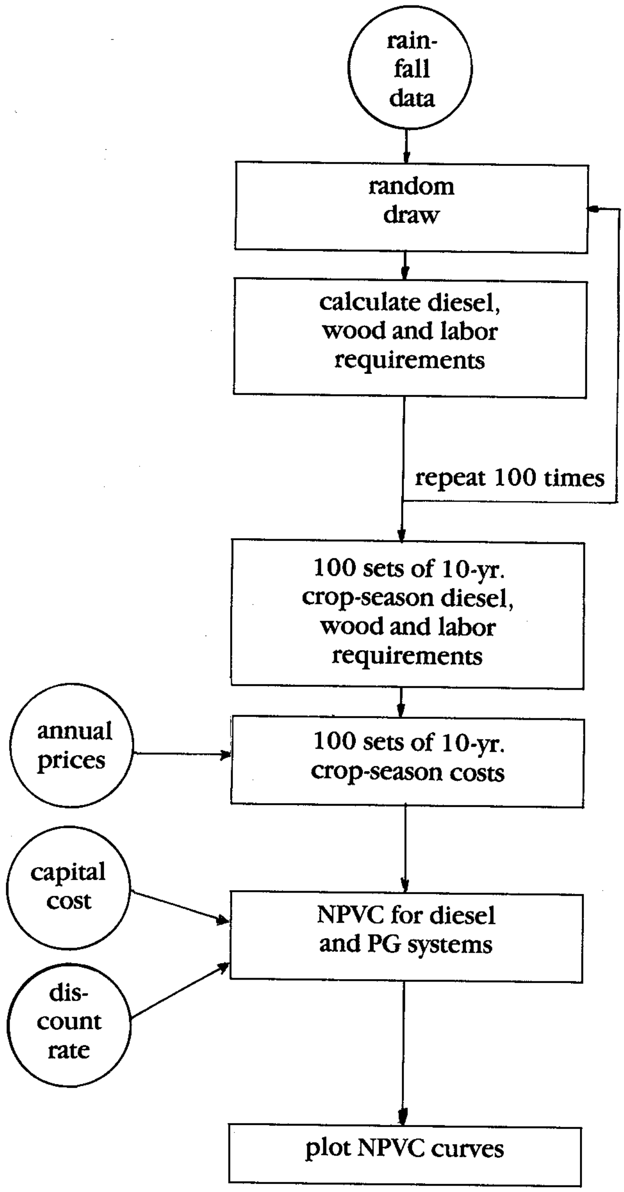


**FIGURE 1. Flow diagram of simulation model.**

[3]A check on the effects of tax aspects for a specific case is made in the results section, however.

[4]Monte Carlo simulation was used for the irrigation fuel requirements rather than simple budgeting or E-V analysis because rainfall amounts over short intervals corresponding to irrigation periods are distributed as an incomplete gamma distribution (Imhoff and Davis). The use of simple budgeting or E-V analysis would not be appropriate unless rainfall was approximately normally distributed.

capital cost of the PG system are used to determine the NPVC for the two systems for a given discount rate. Finally, the 100 NPVC's for each fuel system are plotted as cumulative probability curves.

The PG system utilized in this study is based on information obtained from Shaw et al.'s work on fueling a diesel powered irrigation system with wood. The wood gasifier is a down draft type with a maximum output capacity of approximately 1.0 X $10^6$ BTU per hour but is choked down to 0.75 X $10^6$ BTU per hour to match the diesel engine. The diesel engine is of a type suitable for dual-fuel use. Under operation the engine obtains approximately 10 percent (PD = 0.1) of its energy from diesel fuel and the remainder is from PG[5]. Although using dual-fuel reduces the engines rated power from approximately 80 HP to 62 HP, it is still sufficient to drive the irrigation system (Shaw et al.).

The quantity of diesel fuel for a season's irrigation was obtained by using a fuel conversion factor, the total time of pumping and the continuous power required by the irrigation system (62 continuous brake horsepower). The quantities of wood and diesel for the dual-fuel system were similarly determined. Assuming a 35 percent engine efficiency, the conversion factor for diesel fuel to power output is 0.056 gallons per horsepower hour. Using the same engine efficiency and a 70 percent efficiency for the conversion of wood to producer gas, the comparable conversion factor for the wood system is 2.3 pounds of clean wood per horsepower hour (Johansson).

The dual-fueled PG system requires the same labor as the diesel fuel system plus additional labor for servicing the gasifier. Although Shaw et al.'s unit used an automatic wood feed, hand loading was selected in the present study because of simplicity, and labor requirements are consequently higher. Every 3 hours the hopper on the gasifier is checked and approximately 500 pounds (12 cubic feet) of wood chips are loaded into the hopper. In addition to loading wood chips, labor is needed to change filters.[6] The labor requirement (LCF) translates into 2.6 hours per ton of wood.

## RESULTS

The irrigation strategy resulted in 7 to 13 irrigation applications during the growing season depending upon the rainfall conditions. The associated irrigation energy requirements ranged from 4.3 X $10^8$ to 8.2 X $10^8$ BTU, and this translates into 3,200 to 6,000 gallons of diesel (DFOS) for the all diesel case and 60 (2,700) to 110 tons (4,900 cubic feet)[7] of wood (WFOS) combined with 320 to 600 gallons of diesel for the dual-fuel case.

The simulation model allowed ready calculation of the NPVC for the two fuel systems for a number of combinations of the uncertain economic factors. Fuel prices were set such that $DP_t = DER(DP_1)$ and $WP_t = WER(WP_1)$ where DER and WER are annual price escalation rates for diesel fuel and wood, respectively. Initial conditions (t=1 for 1982) were as follows. The cost per gallon of diesel ($DP_1$ was set at \$1.10, a common price level for bulk delivery in 1982. The cost of clean wood chips ($WP_1$) was set at \$30 per ton.[8] The labor wage rate (PL) was \$3.50 per hour and a 6 percent real discount rate (R) was selected. The PG equipment and installation (CEC) was \$3,500.[9] Filter costs (FRC) were \$360 per crop-season. All prices are real and expressed in 1982 dollars.

A simulation, termed the "base scenario," was run with the initial conditions and with diesel fuel prices escalated at 2 percent per year so that the price was \$1.31 at the end of the 10-year period. All price escalations are the proportion above any general inflation that might occur during the period. The wood cost was held constant at the initial \$30 per ton.[10] Six other simulation runs were performed in which the real cost per gallon of diesel fuel was varied

[5]Although spark ignition engines will operate on 100 percent PG, to control predetonation in compression ignition engines, a small amount of diesel fuel is needed. Johansson reports that 10 to 15 percent diesel is required. Shaw et al., however, in early trials had difficulties with the particular injection pump on their engine and had to use 25 percent. Based on Johansson's greater experience with engines of a type and capacity similar to the one used in this study, 10 percent was used.

[6]As it comes from the down draft gasifier, the PG is relatively clean, but to remove any remaining particulates a cyclone cleaner and glass fiber filters are used (Shaw et al.).

[7]The volume of wood chips requires approximately 500 square feet of storage area and is covered by plastic in a way that allows continued air drying. It is anticipated that a volume less than the volume needed for the entire irrigation season will be stored at any given time.

[8]Presently, clean hardwood chips with 35 percent moisture can be delivered FOB in North Florida for between \$15 and \$18 per ton (Timber Mart South, Inc.). The \$18 per ton value translates into \$25.50 per ton for the 15 percent moisture wood used in the calculations.

[9]Gulf Wood Energy, Inc. sells a wood gasifier sufficient to provide PG for the diesel motor for \$3,000 and has estimated that installation can be made for \$500.

[10]It is unlikely that wood prices will increase substantially above the general inflation rate during the 10-year period of analysis. Hardwood supplies in the North Florida region are plentiful and no dramatic increase in demand is projected (Karchesy and Koch, Society of American Foresters).

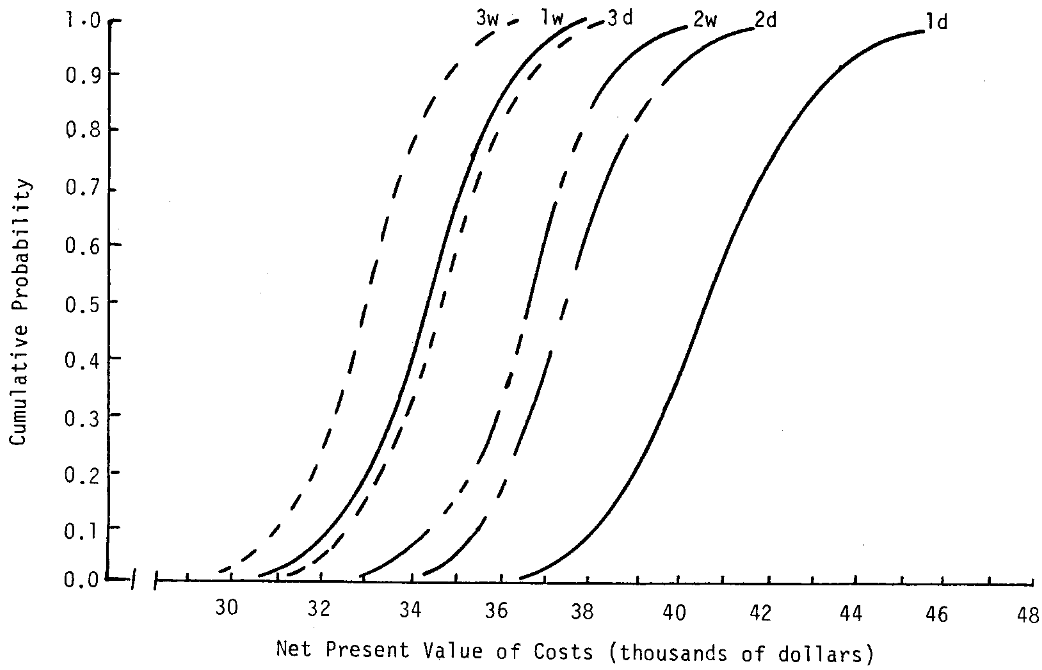


**Figure 2. Stochastic dominance resulting from various wood and diesel fuel prices.**

from $0.92 to $1.31 and the real cost per ton of wood chips varied from $25 to $40 for the 10 years of evaluation. The real cost per hour of labor was set at $3.50 and $4 per hour, and the real discount rate was set at 4, 6, and 8 percent.

A clear, simple means of presenting the results to the manufacturers and farmers, one which allowed a ready means of determining which system was superior, was desirable. Stochastic efficiency analysis (Anderson et al., p. 282), although somewhat complex in concept, was selected because of its ease of graphic presentation. The effect of the variable rainfall is seen in the shape of the cumulative probability curves and the effect of the discrete levels of the economic factors is seen in the relative position of the curves.

The results of the simulations are presented as curves in figures 2-4, and the specific values used in the calculations are presented in Table 1. In the base scenario, Figure 2 (curves 1d and 1w) where diesel fuel escalates to a $1.31 in 10 years, the PG system is clearly dominant.[11] This dominance continues for cases where diesel fuel prices, and wood costs are both increased 2 percent per year (curves 1d and 2w), are both decreased 2 percent per year (curves 3d and 3w), and both held constant at the 1982 levels (curves 2d and 1w). The dominance also continues for increases in labor costs to $4 per hour (curves 1d and 5w in Figure 3). Also,

Table 1. Specific Values Used to Calculate NPVC Curves

| Curve[a] | Diesel price escalation rate | Diesel price in T=1 | Wood price escalation rate | Wood price in T=1 | Labor rate | Discount rate |
|---|---|---|---|---|---|---|
| 1d | 0.02 | 1.10 | — | — | — | 0.06 |
| 1w | — | — | 0.00 | 30 | 3.50 | 0.06 |
| 2w | — | — | 0.02 | 30 | 3.50 | 0.06 |
| 2d | 0.00 | 1.10 | — | — | — | 0.06 |
| 3d | −0.02 | 1.10 | — | — | — | 0.06 |
| 3w | — | — | −0.02 | 30 | 3.50 | 0.06 |
| 4w | — | — | 0.00 | 40 | 3.50 | 0.06 |
| 5w | — | — | 0.00 | 30 | 4.00 | 0.06 |
| 6d | 0.02 | 1.10 | — | — | — | 0.08 |
| 6w | — | — | 0.00 | 30 | 3.50 | 0.08 |
| 7d | 0.02 | 1.10 | — | — | — | 0.04 |
| 7w | — | — | 0.00 | 30 | 3.50 | 0.04 |

[a]See Figures 2, 3, and 4.

[11]A system is first degree stochastically dominant if the area under curve is greater than or equal to the area under the curve for the alternative system for all possible values of costs (Anderson et al., p. 282).

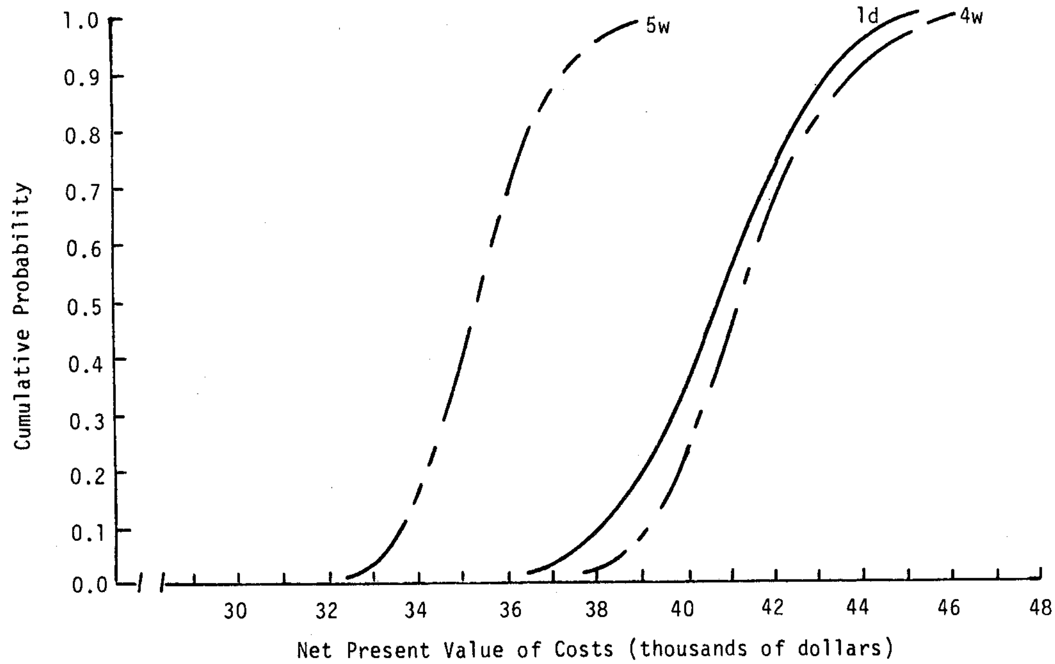


**Figure 3. Stochastic dominance resulting from $40 per ton wood price and $4 per hour labor rate.**

dominance continued for an 8 percent real discount rate (curves 6d and 6w in Figure 4) and, of course, showed stronger dominance when the real discount rate was 4 percent (curves 7d and 7w). Only when wood prices were set at $40 per ton and diesel was escalated at 2 percent per year did the diesel fuel dominate the PG system (curves 1d and 4w in Figure 3).

The graphs can be interpreted numerically as follows. For the base scenario (curves 1d and 1w), considering only the central part of the probability distribution from 10 to 90 percent,

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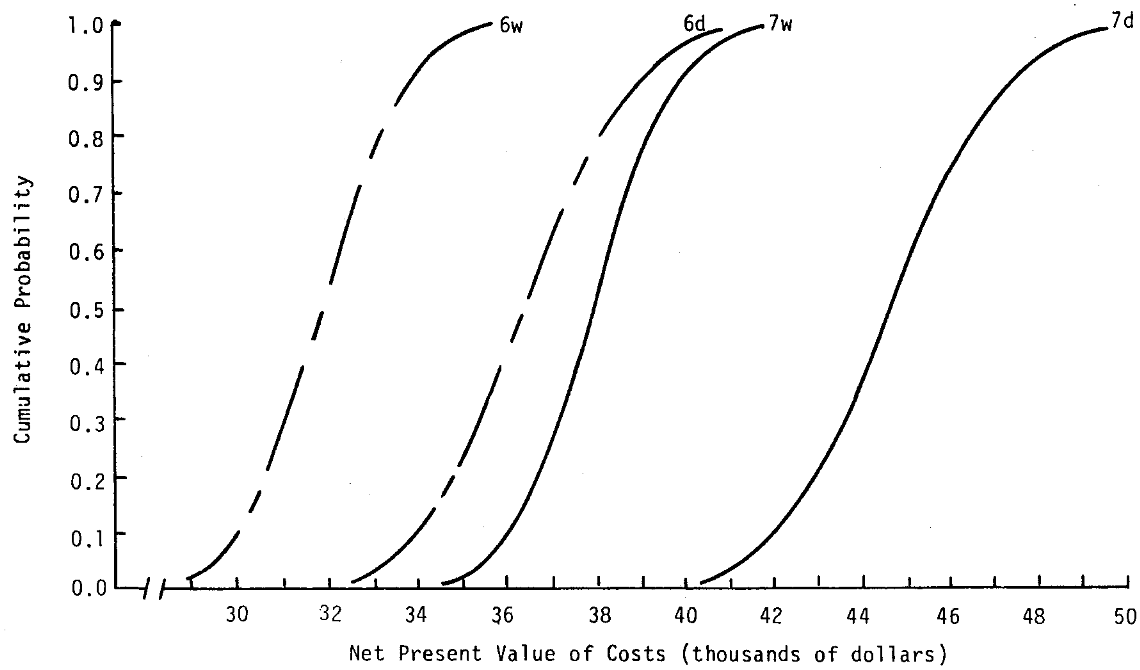


**Figure 4. Stochastic dominance resulting from 4 and 8 percent discount rates.**

a person can be said to be 80 percent certain that the PG system's NPVC will fall between $32,000 and $36,000, while the diesel fuel system's NPVC will fall between $38,000 and $43,000 for the 10 years. In the case where both diesel fuel prices and wood costs decline at 2 percent per year (curves 3d and 3w), the differential between the curves is not as great, and the effect of the initial capital cost for the PG system is seen. Now a person can be 80 percent sure that the PG system's NPVC will fall between $31,000 and $34,500 while the diesel fuel's NPVC will fall between $32,500 and $37,000. And finally for the scenario where wood costs are initially quite high (curves 1d and 4w), one sees the case where investment in a PG system would likely lead to higher fuel costs than for diesel fuel.[12]

## CONCLUSIONS

PG fueled irrigation appears to have some potential. The information presented indicates the PG technology could be cost saving over a range of market conditions. Information of this type, the evaluation of the economic potential, is useful to those who must act to bring the technology into use, but it is not sufficient. Potential manufacturers, distributors and farmers need additional information before making specific investment decisions. Substantial uncertainty still remains for each of these groups. Since no specific experience exists in actual operation of PG fueled irrigation systems, the next reasonable step would be for manufacturers and farmers to cooperate and install several pilot units. Use of the PG system for a crop season would provide answers to many questions about operations and costs. In addition, the use would demonstrate to other farmers the potential of the system. Whether the results of such a test are positive or negative, the added information would help decisionmakers in the next step of evaluating this new technology.

The PG fuel system is but one of a number of on-farm energy production systems with unclear potential. The actors in the generation of these new technologies face similar uncertainties. They face uncertainty stemming from the lack of fundamental information about the on-farm use of the new technology. More importantly, they face substantial market uncertainty. Since the value of the output of any new energy system is a shadow value depending upon the price of the fuel it replaces, the fluctuations in the energy markets will greatly affect the feasibility of the new technologies. If conventional fuel prices once again resume their increase, the potential for these new technologies will increase. But if conventional fuel prices continue to decline or level off, investment in development of the new technologies will be less profitable and could lead to losses. The process of planning is therefore quite difficult. A statement by Oxford economist Robert Mabro in the *Wall Street Journal* (quoted by Ibrahim) sums up the situation: *"We may be seeing a new chapter where oil prices ... are going up and down like a yo-yo ... We can't tell what the consequences are because we have no experience. We just don't know how to plan for something like this."* Extension economists working with the actors in the technology generation and using improved methods of analysis can assist in improving the uncertain planning process.

## APPENDIX

### Producer Gas Technology

Pyrolysis of solid fuels such as wood, charcoal, coal, peat, and agricultural wastes under controlled conditions provides gaseous fuels which can be used in a number of ways. Producer gas systems directly combust a small proportion of the solid fuel under controlled conditions thereby heating the remaining solid material and causing a pyrolytic reaction. The result is a gaseous fuel consisting of combustible gases carbon monoxide (CO), hydrogen ($H_2$) and a small amount of methane ($CH_4$), along with non-combustible carbon dioxide, nitrogen and water vapor. Bungay (pp. 126-133), Kohan and Shadizadeh give details of the chemical reactions involved. The National Research Council and the Solar Energy Research Institute have reported extensively on the technical aspects of using PG as a fuel for internal combustion engines. Johansson, Goss and Coppock, Ogunlowo et al. and Parke and Clark have reported on using PG systems in agricultural settings. Although not all agricultural materials

[12]A check of the influence of tax aspects was made by recalculating the NPVC's for the base scenario (curves 1d and 1w) and the no increase fuel price case (curves 2d and 1w) at the median values. It was assumed that capital costs were not financed, the marginal tax rate was 20 percent, depreciation was calculated using the 5-year schedule and the investment tax credit was 20 percent (10 percent regular and 10 percent energy investment credits). For the base scenario, the NPVC's were approximately $32,500 and $27,000 for diesel fuel and PG, respectively. For the no increase in wood or diesel fuel case, the NPVC's were approximately $30,000 and $27,000 for diesel fuel and PG, respectively. In both cases the PG system continued to dominate the diesel system, and the differential is approximately the same as for the median value shown on the curves, where taxes were not included. Setting the marginal tax rate at 10 percent made little difference in the outcome, while setting it at 30 percent changed the differential by approximately 20 percent in both cases.

have proven to be suitable fuels, wood has proven to be a reliable fuel source for producer gas systems (Johansson, Solar Energy Research Institutional, Shaw et al.)

## REFERENCES


Anderson, Jock R., John L. Dillon, and Brian Hardaker. *Agricultural Decision Analysis,* Ames, Iowa: Iowa State University Press, 1977.

Boggess, W. G. and C. B. Amerling. "A Bioeconomic Simulation Analysis of Irrigation Investments." *So. J. Agr. Econ.,* 15(1983):85-91.

Bungay, Henry R. *Energy, The Biomass Option,* New York: John Wiley and Sons, 1981.

Getschow, George. "More or Less Oil Will Go Up, or Down, or Maybe it Won't." *Wall Street Journal,* (May 5, 1982):1.

Goss, J. R. and R. H. Coppock. "Producing Gas from Crop Residues." *California Agriculture,* Berkely, California, May, 1980.

Ibrahim, Youssef M. "Sinking Feeling: Latest Oil Uncertainty Concerns Drop in Price Rather than Big Rise." *Wall Street Journal,* (March 8, 1982):1.

Imhoff, M. W. and J. M. Davis. "Precipitation Probabilities Based on the Gamma Distribution at 76 North Carolina Locations." Rept. No. 195, Water Resources Research Inst., University of North Carolina, 1983.

Johansson, Eric. "Swedish Tests of Otto and Diesel Engines Operating on Producer Gas." Uppsola, Swedin: National Machinery Testing Institute, 1981.

Karchesy, Joseph, and Peter Koch. "Energy Production from Hardwoods Growing on Southern Pine Sites." General Technical Report 50-24. Pineville, Louisiana: Southern Forest Experiment Station, Forest Service, USDA, 1979.

Kohan, Stephan M. "Basic Principles of Thermochemical Conversion." Chapter 8, pp. 145-172, in *Biomass Conversion Processes for Energy and Fuels,* Somir S. Sofer and Oskar R. Zaborsky, ed. New York: Plenum Press, 1981.

National Research Council. *Producer Gas: Another Fuel for Motor Transportation,* Washington, D.C.: National Academy Press, 1983.

Nelson, Richard R. "Research on Productivity Growth and Productivity Differences: Dead Ends and New Departures." *J. of Econ. Lit.,* XIX(1981):1029-1064.

Ogunlowo, A. S., W. J. Chancellor, and J. R. Goss. "Dual-Fueling a Small Diesel Engine with Producer Gas." *Trans. of ASAE,* 24(1981):48-51.

Parke, P. P. and S. J. Clark. "Biomass Producer Gas Fueling of Internal Combustion Engines Naturally Aspirated and Supercharged Mixtures."ASAE Paper No. 81-5393, St. Joseph, Michigan: ASAE, 1981.

Portier, Kenneth M. "Hydrologic Information Storage and Retrieval System." Dept. of Statistics, University of Florida, 1982.

Rhoads, F. M. "Water and Nutrient Management for Maximum Corn Yield in North Florida." Agr. Research and Education Center, Quincy Research Report 78-1, University of Florida, 1978.

Robertson, J. D., W. N. Musser, and B. V. Tew. "Lease Versus Purchase of a Center-Pivot Irrigation System: A Georgia Example." *So. J. Agr. Econ.,* 14(1982):37-42.

Shafizadeh, Fred. "Fuels from Wood Waste." Chapter IX, p. 141-159, in *Fuels from Waste,* L. L. Anderson and D. A. Tillman, ed. New York: Academic Press, 1977.

Shaw, L. N., D. M. Post, J. D. Whitney, S. L. Hedden and D. B. Churchill."Energizing an Irrigation Pump Engine with Citrus Wood." ASAE Paper No. 83-3076, St. Joseph, Michigan: ASAE, 1983.

Society of American Foresters. "Energy in Forestry—Production and Use." School of Forest Resources and Conservation Report 5, University of Florida, 1978.

Solar Energy Research Institute. *Generator Gas: The Swedish Experience from 1939-45.* SERI/SP-33-140. Golden, Colorado., 1979.

Timber Mart South, Inc. *Timber Product Prices,* 7 (July, 1982) Highland, North Carolina.