IRRIGATION MANAGEMENT SERIES

Comparing Irrigation Energy Costs

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Because irrigated agriculture in Kansas is an energy-intensive activity, selecting an irrigation fuel source is a significant decision. This bulletin provides information on how to compare operating costs of various energy sources. It also discusses how to compare alternative-fuel pumping plants in terms of initial investment costs.

Nebraska Pumping Plant Performance

In order to compare fuel or energy costs, pumping conditions must be comparable. The Nebraska Pumping Plant Performance Criteria (NPC) provide such a basis. The criteria were developed in the early 1960s and are recognized throughout the United States as the standard for comparison. Comparison of fuels or energy, however, is only part of the problem. You also should consider equipment and maintenance costs, convenience, ease of automation, and other costs (such as horsepower demand charges by some electricity suppliers). Only some of these factors have easily estimated dollar values.

The NPC values are listed in Table 1. The values indicate pump output in water horsepower-hour (whp-hr) per fuel input (kWh, mcf, or gallon).

Water horsepower is a measure of the *power* input to water and is determined by the total head and flow rate. *Water horsepower-hour* is a measure of the *work or energy* input to the water and is equivalent to developing one water horsepower for one hour.

The NPC values represent the amount of work that a well-designed, properly maintained irrigation pumping plant should be capable of extracting for a given fuel source. Part of the data on engines was developed from a Nebraska tractor test program and the remainder from a variety of sources, including years of irrigation pump testing. NPC is a compromise between the most efficient pumping plant possible and the average pumping plant. Therefore, some pumping plants can exceed the criteria. In fact, tests in Nebraska indicate that approximately 15 percent of systems will exceed the criteria.

While this bulletin uses NPC to compare energy costs of comparable systems, NPC's ability to evaluate pumping-plant performance is briefly discussed. For a more thorough review, refer to K-State bulletin L-885, *Evaluating Pumping Plant Efficiency*.

Comparing Energy Costs

The NPC values from Table 1 were used to develop the equivalent fuel use multipliers in Table 2 to allow comparison of fuel types. These numbers show the energy output value of fuels in the left-hand column of Table 2 as compared to the fuels listed across the top of the table. The energy source in each column has a value of 1 when compared to itself. Thus, 1 mcf of natural gas (925 BTU per cf) produces 69.72 times more whp-hr output as 1 kWh of electricity. Diesel produces 14.12 times more whp-hr output per gallon than 1 kWh does.

The comparable or equivalent energy cost of fuel sources can be determined by using those Table 2 values and the current cost of one energy source. For example, if the electrical rate is $0.08 per kWh , then the comparable energy cost for:

Natural Gas (925 BTU)
=$0.08 × 69.72 = $5.58/mcf
Diesel =$0.08 × 14.12 = $1.13/gal
Propane =$0.08 × 7.79 = $0.62/gal

The interpretation is straightforward. If electricity costs $0.08/kWh, you could afford to pay $5.58/mcf for natural gas, $1.13/gal for diesel fuel or $0.62/gal for propane. These prices vary from place to place, so you will need to use Table 2 and your area's prices. Table 3 provides a quick reference for typical average prices.

Bold italicized values in Table 3 are figures for comparison of typical energy prices at the time of printing. Fuel-price fluctation makes it difficult to determine typical costs.

Estimating Fuel Cost

Values in Table 1 will determine what energy costs should be if equipment is performing at NPC. You need to know the amount of water used and the total "head" on the pump. Head is measured in feet of water or pounds per square inch (psi) and is estimated from the well's water lift and water pressure at the well exit. Lift is the distance from the well's water level while pumping to the centerline of the outlet pipe. The discharge head is the gauge pressure at the outlet multiplied by a conversion factor of 2.31 feet per psi. Together these are called Total Dynamic Head (TDH)—or simply head.

An acre-foot (ac-ft) of water is 43,560 cubic feet. Each cubic foot weighs 62.4 pounds. Thus, the total energy needed to lift 1 ac-ft to a height of 1 foot would be:

$$43{,}560 \text{ ft}^3 \times 62.40 \text{ lbs/ft}^3 \times 1 \text{ ft} = 2{,}718{,}144 \text{ ft-lbs.}$$

One horsepower is 33,000 ft-lbs/min, so one horsepower-hour (hp-hr) is:

$$33{,}000 \text{ ft-lbs/min} \times 60 \text{ min/hr} = 1{,}980{,}000 \text{ ft-lbs/hr}$$

This is the amount of energy expended when moving the water. The horsepower requirement is often designated as water horsepower to indicate output horsepower used on the water. The energy needed to pump one acre-foot of water at a head of 1 foot is:

Electricity
2,718,144 ft-lbs/ac-ft ÷
1,980,000 ft-lbs/whp-hr
= 1.373 whp-hr/ac-ft per foot of lift

Using the values from Table 1, the amount of each energy source needed to pump one acre-foot of water at a head of 1 foot can be determined as shown below.

$$\frac{1.373 \text{ whp-hr/ac-ft/ft}}{0.885 \frac{\text{whp-hr}}{\text{kWh}}} = 1.55 \text{ kWh/ac-ft/ft}$$

The results of calculations for all fuel sources are shown in Table 4.

Each of these numbers represents the fuel input required (kWh, mcf, or gallon) per foot of head for each acre-foot of water pumped. Multiply these numbers by the total head in feet to get the fuel input per acre-ft of water for a particular lift. You can then multiply this number by the acre-feet of water required to determine fuel required. Fuel cost can then be estimated by multiplying the fuel requirement by the fuel price.

For example, natural gas with an energy content of 925 BTU/cf fuels a center pivot that covers 130 acres with 18 inches (1.5 feet) of water per season. Lift is 150 feet, pressure is 45 psi, and gas cost is $7.50/mcf. The estimated fuel use cost is:

1. Estimating total dynamic head:
   45 psi × 2.31 ft/psi = 104 ft
   \+ lift = 150 ft
   total dynamic head = 254 ft

2. Multiply Table 4 value by head.
   .0223 mcf/ac-ft/ft × 254 ft
   = 5.66 mcf/ac-ft

3. Multiply Step 2 by the amount of water pumped.
   a. 130 acres × 1.5 feet = 195 ac-ft
   b. 5.66 mcf/ac-ft × 195 ac-ft
   = 1,104 mcf

4. Multiply Step 3 by fuel cost.
   1,104 mcf × $7.50/mcf = $8,280

If the cost for fuel exceeded $8,280, the pumping plant was not performing up to the Nebraska Performance Criteria. If the actual cost was $10,475, then:

$$\frac{8{,}280}{10{,}475} \times 100 = 79\%$$

In this example, the pumping plant is operating at 79 percent of NPC and using 27 percent more fuel than necessary. If well lift or the amount of water delivered is not measured, estimates will be less reliable. A badly worn pump can deliver substantially less water than expected. Similarly, the water level should be checked for accuracy. The only sure way is to have the pumping plant checked, but estimates using the above approach can be quite revealing.

The procedure above compares cost or performance on the basis of energy source only.

The most economical energy source, however, is not always the one with the lowest energy-equivalent cost. The capital investment in equipment also should be considered. The following example will help illustrate this point.

Example: An irrigator needs to decide whether to use electricity or diesel. He can buy an appropriately sized electric motor for $3,500 and it would cost $25,000 to bring in three-phase power. A diesel engine and gearhead drive are available for $20,000. He decides to use investment costs based on a 5-year return period and 10 percent interest.

Electricity costs $.08 per kW/h. Diesel costs $2.00 per gallon. He estimates use at 1,000 hours per year. Pump discharge is 800 gpm. Pumping lift and pressure requirements are 300 feet of total dynamic head.

Step 1: Estimate WHP Requirements

WHP = GPM × TDH/3,960 =
800 × 300/3,960 = 60.6 WHP

Step 2: Estimate Yearly Energy Bills

(a) Fuel use = (WHP/NPC) × hours of use/year

(b) Fuel use × Energy Cost = Yearly fuel bill

Electricity:

(a) (60.6 WHP / 0.885 WHP - hr per kWh) × 1,000 hr/yr = 68,475 kWh/yr

(b) 68,475 kWh/yr × $0.08/kWh = $5,478/yr

Diesel:

(a) (60.6 WHP / 12.5WHP - hr per gal) × 1,000 hr/yr = 4248 gal/yr

(b) 4248 gal/yr × $2.00/gal = $9,696/yr

Estimated Cost Difference =

$ 9,696	Diesel
– 5,478	Electricity
$4,218/yr	Advantage to electricity

Step 3: Investment Costs Estimation

(Find investment cost of the most expensive system minus the least expensive):

Electricity 25,000 + 3,500 =	$28,500
Diesel	20,000
Difference	$ 8,500
	Advantage to diesel

Use Table 5 to find a capital recovery factor (CRF) for the return period and interest rate.

CRF for 5 years @10 percent = .2638
Annual Cost for Extra Investment
8,500 (0.2638) = $2,242

Step 4: Annualized Cost Comparison

Combine the annualized energy use and investment cost into one term. Be certain to add or subtract as appropriate.

Energy Comparison plus annualized Cost Comparison

In this example, the Energy Cost Advantage for electricity minus the annualized capital cost of electricity as compared to diesel is:

$4,218 + (–$2,242) = $1,976

This is a $1,976 advantage to electricity as compared to diesel.

Conclusion: Although the annualized investment cost of electricity is greater than that of diesel, for this example, the annual operating cost of electricity is much less, making the 5-year outlook favor electricity. Two other factors favoring electricity are convenience of operation and oil and tune-up costs of the diesel engine. Remote operation also is more feasible with electricity.

Energy cost comparisons, estimates of pumping plant efficiency, and comparison of invenstment costs can also be compared using a software tool called FuelCost. It is available on the web at *http://www.oznet.ksu.edu/mil*.

Because irrigated agriculture is energy-intensive, it requires large capital investments for energy and related equipment. The above example illustrates a simple procedure for comparing energy sources. It does not include all factors. Some factors can be examined on an economic basis. Others require your judgment or personal preference. Factors you should consider include:

1. The initial purchase price of the power unit and associated items such as drive mechanism, fuel storage tanks, pipelines, and bringing in electrical service.
2. The expected useful life of the items in number 1.
3. Repair and maintenance costs.
4. Labor requirements to operate and maintain the system.
5. Dealer service reliability and availability.
6. Repair parts availability.
7. Future availability of the energy source.
8. Convenience of operation and automation.

Table 1: Nebraska Performance Criteria for Pumping Plants

Fuel	**Pump Output**
Electricity	0.885 whp-hr/kWh
Natural Gas (925 BTU/cf)	61.7 whp-hr/MCF
Diesel	12.50 whp-hr/gal
Propane	6.89 whp-hr/gal

Table 2: Cost Equivalent Fuel Multiplier Table

	Electricity	Natural Gas	Diesel	Propane
Electricity	1	0.0143	0.071	0.128
Natural Gas (925 BTU/cf)	69.72	1	4.94	8.96
Diesel	14.12	0.203	1	1.81
Propane	7.79	0.112	0.551	1

Table 3:Typical Cost Comparison

Electricity	***0.08***	0.11	0.14	0.20
Natural Gas (925 BTU)	5.58	***7.50***	9.88	14.34
Diesel	1.13	1.52	***2.00***	2.90
Propane	0.62	0.84	1.10	***1.60***

Table 4: Pumping Fuel Units Required for Lifting 1 acre-foot of water 1 foot in height

Fuel Type	Fuel Unit	Fuel Units /ac-ft/ft
Electricity	kwh	1.551
Natural Gas (925 BTU/cf)	mcf	0.0223
Diesel	gal	0.1098
Propane	gal	0.1993

Table 5. Selected Capital Recovery Factors

Length of Loan or Length of Useful Life	Annual Interest Rate (%)				
Years	5	7	10	12	15
2	0.5378	0.5531	0.5712	0.5917	0.6151
5	0.231	0.2439	0.2638	0.2774	0.2983
7	0.1728	0.1856	0.2054	0.2191	0.2404
10	0.1295	0.1924	0.1627	0.177	0.1993
15	0.0963	0.1098	0.1315	0.1468	0.171

Related Extension Bulletins and software tools:

L-885 *Evaluation Pumping Plant Efficiency Using On-Farm Fuel Bills*

L-886 *Reading Pump and Engine Performance Curves*

FuelCost (software to estimate pumping plant efficiency) available at *http://www.oznet.ksu.edu/mil*

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