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Energy Efficiency Ratios of Surface Mining Systems for a Small Iowa Coal Mine[1]

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The normal criterion used to determine if a mining venture should be started or continued is its financial profitability. Energy efficiency is another criterion for dealing with public energy decisions. The energy efficiency ratios (output/input) of a large bulldozer, a scraper ripper, a small dragline, and a large dragline system were calculated for the Iowa Coal Project Demonstration Mine #1 (ICPDM #1) located between Oskaloosa and Bussey, Iowa. Even though the large dragline had the lowest cost and highest energy efficiency, it would not be used on this site without having other nearby sites available to allow long-term use.
INDEX DESCRIPTORS: Energy efficiency, surface-mining, scraper-ripper operation, dragline, energy input-output ratios.

INTRODUCTION

This study was undertaken to determine the energy efficiency of the mining method used at the Iowa Coal Project Demonstration Mine #1 and to compare it with several alternatives.

The Iowa Coal Research Project was funded by the State of Iowa in 1974 to revitalize the coal mining industry in Iowa (Energy and Mineral Resources Institute, 1975). Part of the project was to develop the surface mine ICPDM #1. A major goal at the mine was to restore the surface to a configuration designed to allow post-mining crop production equal to or exceeding that preceding the mining operation.

Few publications compare surface-mining systems on the basis of an energy output/input (energy efficiency). Colvin et al. (1975) compared the energy efficiency of two different mining operations in western Pennsylvania. The mines are located within 33 kilometers (km) of each other with one using a scrapper-ripper operation and the other a 30-meter^3 (m^3) dragline to remove overburden. Energy output/input ratios of 48.1:1 for the scrapers and 50.8:1 for the dragline were obtained by ignoring dragline blasting and support energy. The dragline might be an estimated 20 percent less efficient if the blasting and support energy were included.

Clark and Varisco (1975) reported energy output/input ratios ranging from 34:1 to 2.6:1 depending on energy-flow-boundary definitions for shale-oil production in Colorado. Leach (1975) criticized Clark and Varisco for their boundary assumptions and their lumping of energy of different qualities such as coal and electrical energy. Leach believed that the net energy analysis provided little new information. Leach's criticism should not apply to the four mining systems presented here because all systems were used to recover a single resource and used similar inputs.

All models in our analysis used machines that could have been manufactured by the same industrial plant and all but the 30-m^3 dragline were powered by diesel engines. The system boundaries, or energy inputs and outputs, shown in Figure 1 were chosen to attempt to give an equivalent basis for comparison of the system. The only major difference was between diesel fuel as an input to mobile machines and the coal as an input to electrical generation for the large dragline. Coal can be converted into a liquid or gaseous fuel for mobile equipment, but that technology is not in common use at this time in the United States.

DESCRIPTION OF THE HYPOTHETICAL MINE SITE

The topographic features of ICPDM #1 were used to develop the calculations used for this analysis. The thickness of overburden varies from four to 24 m. This material is underlain by 122,470 tonne (t) of coal. The total volume over the coal is 1,353,075 m^3. Coal recovery from a single seam was assumed equal for all mining methods. A cross section of the mine is shown in Figure 2.

Heavy media bench scale tests with coarse coals indicate that most Iowa coals can be upgraded to 26,749 kilojoule/kilogram (kJ/kg). During processing ICPDM #1 coal, sulfur content was reduced from 7 percent in raw coal to 5 percent in the clean. Ash was reduced from 15 percent to 10 percent. The clean coal was 80 percent of the weight of raw coal and contained 85 percent of the kJ input value.

The volume of unconsolidated material available before mining was estimated to allow the placement of a uniform 3-m deep layer of unconsolidated material over the site during pit filling. The final topography, after mining, is assumed to be approximately the original contour for all systems, with no unconsolidated material planned for placement below or mixed with consolidated material. The lack of mixing or at least saving sufficient unconsolidated material to provide a reasonable root zone is one of the major advances in reclamation brought about by the mining reclamation laws.

DESCRIPTION OF THE FOUR MINING SYSTEMS STUDIED

The systems chosen for this analysis represent a cross-section of strip-mining methods used in Iowa, western Pennsylvania, and southeastern Ohio on mine properties of similar topography and size. The large dragline that was included was not used on mines as small as ICPDM #1 but was included for comparison purposes.

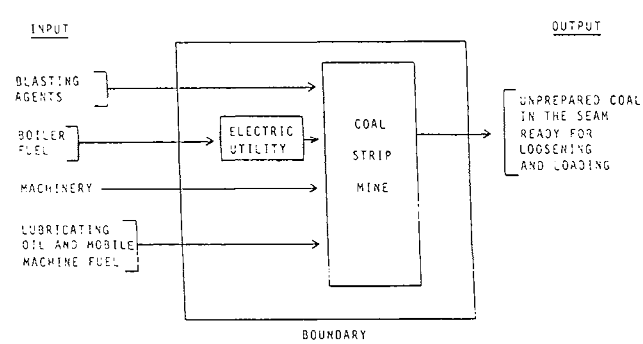

Fig. 1. Boundary definitions used in the net energy analysis of four mining systems

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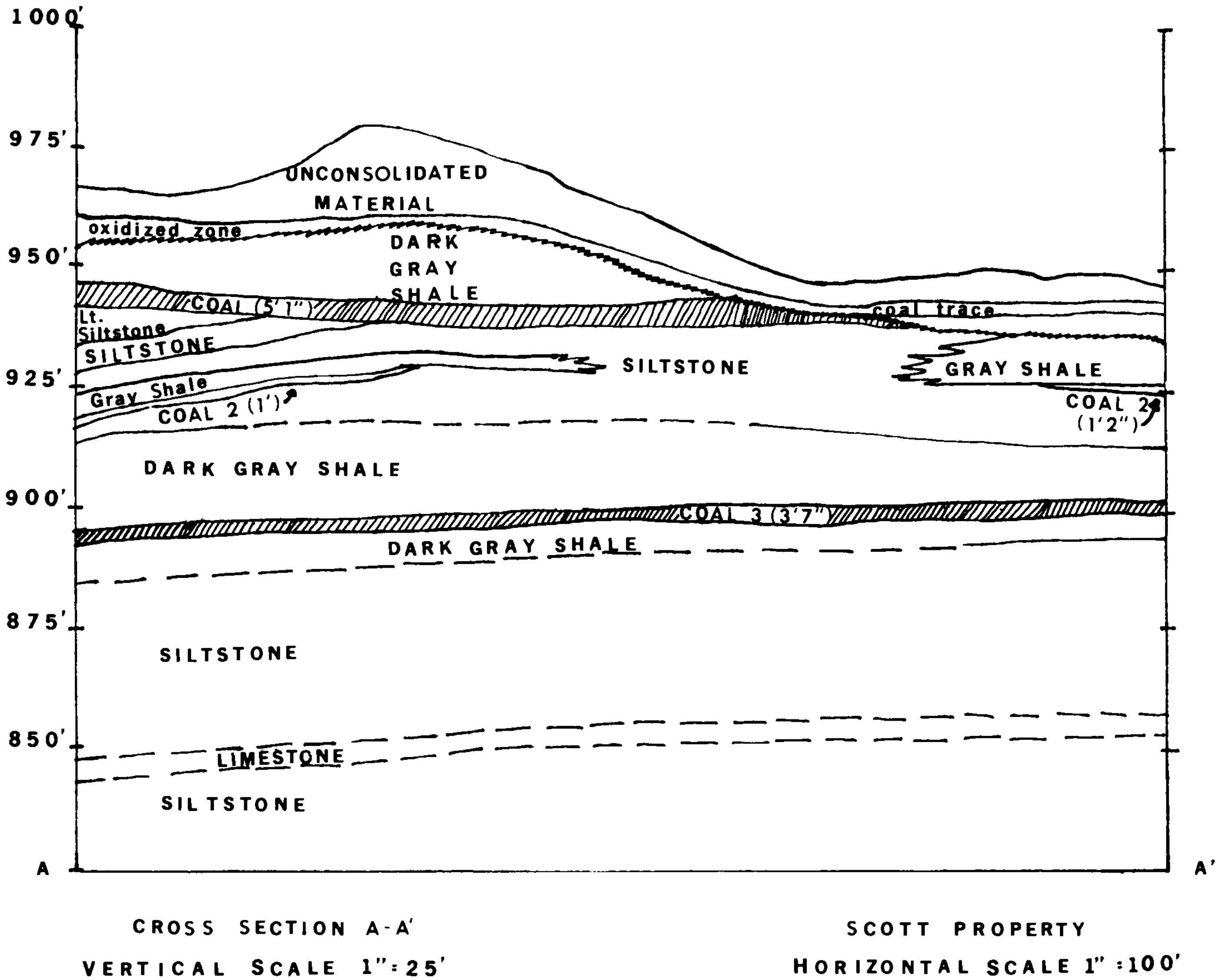

Fig. 2. Cross section of ICPDM #1

System Number 1 (Scraper-Ripper)

The scraper system is based on the fleet of machines used at ICPDM #1. This included one 10.7-m^3 twin-engine diesel scraper, two 13.8-m^3 twin engine diesel scrapers and three 224-kilowatt (kW) diesel crawlers equipped with dozers and rippers. The scrapers moved most of the material with the dozer ripping the consolidated material and handling material that could not be loaded in the scrapers. The scrapers were normally push-loaded by the dozers. Production rates and costs were based on measurements taken at ICPDM #1 with equipment working one shift per day. The unconsolidated material was handled separately from the consolidated material and it was not necessary to stockpile all of it as is done with other systems.

System Number 2 (Large Dragline)

The 30.6-m^3 electric dragline system uses scrapers to move all the unconsolidated material and to fill the last pit with consolidated material. The scrapers must be large enough that the fleet can meet the production requirement at the estimated price per m^3. The pit is assumed to average 18 m deep by 30 m across. Dozers would rough-grade the dragline spoil piles before the scrapers replace the unconsolidated material, all of which is assumed to be stockpiled. The dragline would be scheduled for 20 hours per day, seven days a week.

System Number 3 (Small Dragline)

The 3.8-m^3 diesel dragline system operates the same as the 30.6-m^3 dragline system except that the pit would be 12 m wide and the dragline would not be scheduled for more than 8 hours per day.

System Number 4 (Large Dozer)

The large diesel bulldozer system has scrapers to remove the unconsolidated material. The single large bulldozer then rips and dozes the consolidated material to uncover the coal. The dozer pushes the material back to approximate original contours before the unconsolidated material from the stockpile is replaced by the scrapers.

Manufacturers' estimating guides that were used to develop the production rates and fuel consumption figures included Allis Chalmers (ca. 1972), Caterpillar Tractor Company (1974), Fiat-Allis (1974), International Harvester (ca. 1970), and information from dragline producers that was obtained in confidence. Information in

Habeck (1975) and Cummins and Given (1973) aided the estimating process for the two dragline systems. Information compiled during the operation of ICPDM #1 was used in developing the estimates of energy used and costs for the scraper-ripper operation.

The operating assumptions (i.e., hours per day, pit configuration, etc.) for all systems were based on the authors' observations of similar systems primarily in Iowa and Pennsylvania in 1975 and 1976. The firms visited were all non-union, and appeared to be competitive and well established. Energy equivalents were taken from standard tables where available, from analysis of coal samples from ICPDM #1, and from Davis and Blouin (1976).

The amount of material rehandled is strongly influenced by the chosen pit layout and sequence of mining, particularly the scraper-ripper system, because with proper planning the majority of pits could be refilled in lifts as additional pits were being opened. The two dragline systems and the large dozer system were designed to have all of the material that would be placed above regraded-consolidated material stockpiled and rehandled because of the limited size of the site and observations of field operations at similar sites.

The dragline pit sizes shown in the sketches of final pit cross sections in Figure 3 were designed to fit the boom lengths as described in Habeck (1975), Cummins and Givens (1973), and others. The pit size for the scraper-ripper system was based on observations at ICPDM #1. The pit dimensions for the large dozer were based on observations of a similar operation in Pennsylvania.

The machines assumed in the calculations are listed in Table 1. The consolidated and unconsolidated volumes were calculated at the original volumes at ICPDM #1. The amount of material rehandled was calculated based on the operation of each system described earlier. The production rate for the scraper-ripper system was taken from records of the operation at ICPDM #1. The rates for the other system were estimated using the approaches and assumptions previously discussed. The scraper production rate was used to move the unconsolidated material for all systems. The production rate for the drills was based on discussions with the driller contacted about drilling overburden at ICPDM #1 although no drilling was actually done. The dozing for the two dragline systems was based on short distance rough-grading of dragline spoil.

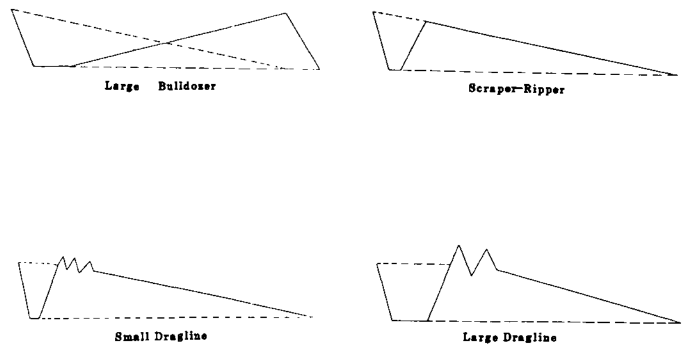

Fig. 3. Final pit configuration

The energy consumption rate in L/hr for the scraper-ripper system was taken from records at ICPDM #1. Diesel fuel consumption was based on an estimate from the Caterpillar Handbook. The manufacturers' information perviously discussed was used to develop the energy consumption rates for the other systems listed in Table 1.

RESULTS AND CONCLUSIONS

The 30 m^3 dragline had the lowest cost, the shortest time, and the best energy ratio (Table 2). This ratio was 60:1 without capital energy (emergy required to make machines) and 58 with capital energy. The

Table 1: System parameters for the calculations for cost and energy efficiency from Colvin (1977)

	Scraper-ripper	Large dragline	Small dragline	Large dozer
Machines	1 — 10.7-m^3 scraper 2 — 13.8-m^3 scraper 3 — 224-kW crawlers	Marion 7820 — 17[a] 30.6-m^3 bucket 68.6-m boom	Marion 111 M-D[a] 3.8-m^3 bucket 24.4-m boom	Fiat-Allis[a] HD 41B w/full u-blade and ripper
Volumes (10^6 m^3)	0.76 cons. 0.23 uncons. 0.34 rehandle	0.76 cons. 0.23 uncons. 0.56 rehandle	0.76 cons. 0.23 uncons. 0.40 rehandle	0.76 cons. 0.23 uncons. 0.60 rehandle
Production rates	— — 115 m^3/hr (scraper-dozer team)	115 m^3/hr scraper 15 m/hr drills 800 m^3/hr dragline 300 m^3/hr dozer	115 m^3/hr scraper 15 m/hr drills 92 m^3/hr dragline 300 m^3/hr dozer	115 m^3/hr scraper 920 m^3/hr ripping 710 m^3/hr dozing —
Energy consumption rates	114 L/hr (dozer- scraper team) — —	90 L/hr scrapers 19 L/hr drill .95 kWh/m^3 dragline 45 L/hr dozers	90 L/hr scrapers 19 L/hr drill 49 L/hr dragline 45 L/hr dozers	90 L/hr scrapers 95 L/hr dozer — —

[a]Reference to a company or product name is for specific information only and does not imply approval or recommendation to the exclusion of others that may be suitable.

Table 2. Results of the calculations of cost and energy efficiency from Colvin (1977)

	Scrapper-ripper	Large Dragline	Small dragline	Larger dozer
Total cost (1977 $)	$ 1,027,000	$ 896,000	$ 1,289,000	$ 1,000,000
Cost per BCM	1.03	0.91	1.29	1.01
Cost per tonne of coal	8.38	7.32	10.52	8.13
Time	2 years	2 months	4.4 years	4 years
Rehandle	34%	57%	40%	60
Energy ratio out/in	45:1	58:1	51:1	51:1

scraper-ripper system had the least overburden rehandle (rehandling the same material more than once).

The energy efficiency comparisons (Table 2) showed that for a large site (more than 10-year life of mine site with medium- to large-sized equipment) an appropriately sized dragline would be the most energy efficient and would uncover coal for the least cost.

The dragline, however, would not be used on this site because of the fixed costs of moving such a large machine to the site. The cost shown in Table 2, per bank cubic meter (BCM), might be reduced by half and rehandle should approach that of the scrapers if this site were included in a large mine.

For the small mine site based on ICPDM #1, either the large bulldozer or scraper-ripper system of overburden handling would have been 26 cents per BCM, cheaper than the small 4-m^3 dragline. The energy efficiency of the mobile equipment would be the same or (Table 2) 13 percent less than the energy efficiency of the small dragline system.

The use of the scraper-ripper system at ICPDM #1 was dictated by several factors. In 1975, at the time the mine was started, there would have been a long delay (more than 1 year) in obtaining draglines. The large dozer was proposed but was not chosen because of the lack of experience with large dozers in Iowa. From an efficiency standpoint, however, the large bulldozer, with a calculated output/input ratio of 51:1 would have saved 190,000 gal (719,000 L) of diesel fuel when compared to the scraper-ripper system with an output/input ratio of 45:1. From a cost standpoint, the use of the scraper-ripper system at ICPDM #1 was reasonable and provided local miners with an alternative to the small dragline that was the standard prior to 1974 when the Iowa Coal Project was funded.

The results of this study indicate that mobile equipment (scraper and dozer) competes favorably with the small dragline. Observations in Pennsylvania indicated that large draglines could be used on small sites if they could be scheduled on a series of local sites for the life of the machine.

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