JPL PUBLICATION 77-54

Evaluation of Coal Feed Systems Being Developed by the Energy Research and Development Administration

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Prepared for

Energy Research and Development Administration

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December 9, 1977

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JPL PUBLICATION 77-54

Evaluation of Coal Feed Systems Being Developed by the Energy Research and Development Administration

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National Aeronautics and Space Administration

FOREWORD

This report documents an evaluation by the Jet Propulsion Laboratory of the ERDA-sponsored coal feed systems development program. It fulfills contractual obligations under IAA No. EF-77-A-01-2616 for the following deliverables (Subtask 1, Support to ERDA Coal Feeding Development Program):

(1) Development and performance criteria.

(2) Recommendations for selections with supporting data.

This work was administered by R. R. Fleischbein, P.E., Major Facilities Project Management Division.

The evaluation included support from the three coal feeder contractors: Foster-Miller Associates, Ingersoll-Rand Research, Inc., and Lockheed Missiles and Space Company. It also included support from subcontractors in the areas of coal feed system costs (Icarus Corporation), coal feed system reliability (Kaman Sciences Corporation), and the interaction of the feed system with the conversion process (International Research and Technology).

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SECTION I

SUMMARY

Developments in coal conversion are proceeding at many levels in response to a variety of concerns. To obtain increased coal conversion efficiencies, reactor pressures have been increased, creating significant challenges for designers of coal feed systems. ERDA has recognized that the coal feeder is a critical component of a coal conversion plant, affecting capital investment, maintenance cost, plant efficiency, and downtime. In response to the need for improved coal feeders, ERDA has sponsored a program of coal feed system development. Included in the program are feeder developments by three contractors: Foster-Miller Associates (FMA), Ingersoll-Rand Research, Inc. (IR), and Lockheed Missiles and Space Company (LMSC). These contractors identified approximately a dozen feed system concepts which promised improved performance and reduced cost when compared with existing lockhopper and slurry pump coal feeders. Critical components and subsystems of these systems are now being evaluated and tested by the contractors in preparation for a pilot-plant-scale system demonstration effort which will begin about September 1977.

The Jet Propulsion Laboratory has recently begun to provide ERDA with staff support for its coal feed program. An initial task of that support is to evaluate the feeders being developed. The objective of the coal feed system evaluation is to recommend to ERDA those feed systems which should receive continued development support as the program proceeds into the pilot-plant-scale phase and to identify those development actions which should be undertaken for each of the selected feeders.

The coal feed systems considered in the evaluation are listed in Table 1-1. In the table the development contractor is identified, and a brief description of the feeder, its characteristics, and development status is given.

A. EVALUATION APPROACH

The approach taken in the evaluation included the following steps:

(1) Analyze the technical feasibility of each feed system.

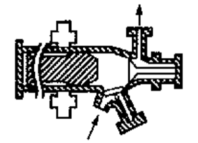
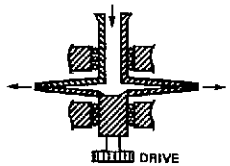
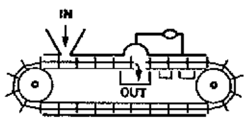
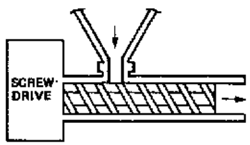
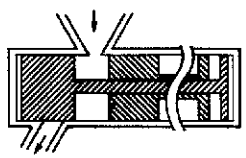
(2) Compare feeder performance capability vs feed system requirements.

(3) Determine feed system applicability to expected coal conversion processes.

(4) Evaluate expected feed system costs relative to baseline lockhopper and slurry pump systems.

(5) Select feed systems for future development which, from the cost analysis, show the best chance of achieving low cost and wide application to future processes, for specified R&D cost limitations.

Table 1-1. Coal Feed Systems

System	Developer	Schematic Drawing	Description	Pressure Limitations	Coal Type, Size and Preparation Requirements	Development Status	Development Uncertainties
• Positive Displacement	Foster-Miller		Cycled cavity piston fluidized coal feeder	1500 psi	• Any type • Size - fine/medium	Prototype in test	• Purging gas requirements may become large in large feeders • Valve sequencing and sizing • Materials selection for seals and valve seats
• Centrifugal Feeder	Foster-Miller		Rotating centrifugal fluidized coal pump	1500 psi	• Any type • Size - fine	Prototype in test	• Pressure sealing dependent on coal properties • Sprue design uncertain • Feed throttling for control or throughput • Rotating seals
• Linear Pocket Feeder	Foster-Miller		Tubular conveyor with coal conveyed to high pressure by a chain or interconnected pistons	500 psi	• Any type • Size - medium/coarse	Prototype being assembled	• Incomplete filling generates back leakage and may limit pressure capability • Gas/liquid interface in water section • Wear and survival of rings and chain
• Screw Feeder	Ingersoll-Rand		Type of auger which conveys coal axially down its length as the screw is rotated	1500 psi	• Bituminous-agglomerating (for heated screw) • Size - up to 1" • Drying to 3-4% moisture	Prototype/pilot slave in test	• Possibly large power requirements • High pressure crusher to reduce extrudate to required size • Scale up of feeder with respect to heat input to coal • Screw/barrel wear • Operating parameters to provide throughput with minimum power
• Single Acting Piston Feeder	Ingersoll-Rand		Two coaxial delivery pistons operate in a common cylinder housing	1500 psi	• Any type • Size - fine to coarse	Concept only	• Sealing and material wear • Purging coal from cavity • Coal jamming or piston/sleeve interface during loading and unloading

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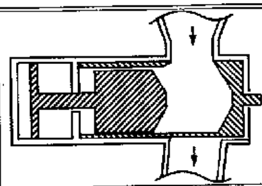
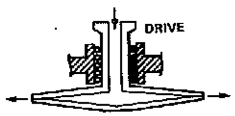
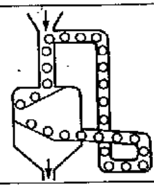
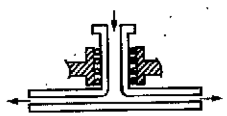
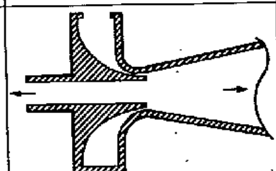
FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 1-1. Coal Feed Systems (Continuation 1)

System	Developer	Schematic Drawing	Description	Pressure Limitations	Coal Type, Size and Preparation Requirements	Development Status	Development Uncertainties
• Rotary Valve Piston Feeder	Ingersoll-Rand		Coal is transferred to high pressure by a piston sleeve rotation	1500 psi	• Any type • Size - fine to coarse	Concept only	• Same as single acting piston feeder
• Kinetic Extruder Feeder	Lockheed		Rotating centrifugal coal pump	1000 psi (single stage) 1500 psi (two stages)	• Any type • Size - fine	Prototype in test	• Same as centrifugal feeder
• Standpipe-Ball Conveyor Feeder	Lockheed		Standpipe filled with metal balls which conveys coal in the spaces between the balls	300 psi	• Any type • Size - fine to coarse	Bench tests	• Control of ball spacing and feeding mechanism • Purging gas out of H_2O feed line
• Fluid Dynamic Lock Feeder	Lockheed		Rotating bladeless turbine	2:1 pressure ratio per stage	• Any type • Size - find	Prototype tests	• Parasitic skin drag on disk requires high power • Rotating face and bearing seals • Coal flow through machine • Wear on bearings, seals, disks
• Gas-Solids Injector Feeder	Lockheed		Gas-solids injector pump	2:1 pressure ratio per stage	• Any type • Size - fine/medium	Prototype tests	• Wear in nozzle throat • Compressor seals and bearings for recirculating gas systems

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(6) Consider expanding the cost-effective feeder set as a means of increasing the probability of feed system commercialization.

(7) Examine specific applications as a reason for continuing the development of a concept which otherwise would not be selected.

(8) Review the feed systems selected on the basis of the cost analysis and modify this set based on the technical assessment.

B. FEED SYSTEM REQUIREMENTS

As a foundation for the coal feed systems development program, performance goals were established for the feed systems based upon the requirements of future coal conversion processes. The feed system requirements are as follows:

(1) Pressure - 150 to 1500 psi.

(2) Coal size - fines to coarse* (2 inches). The feeder should not affect coal size consist or properties, but should deliver coal as required to the process.

(3) Continuous flow should be provided.

(4) Coal metering capabilities are required.

(5) Lifetime - 20 years.

The above requirements were developed by analysis of the conversion processes which, it is anticipated, will achieve future commercialization. Further reviews of these processes enabled classification of them into generic types based on their operating pressure and feed size consist. The coal size and delivery pressure capabilities of the feed systems were then matched against the generic requirements of the processes to establish the compatibility of the candidate feeders and the various conversion processes.

C. EVALUATION RESULTS

Cost analyses formed the foundation for the initial selection of feed systems. Costs were provided by the three contractors and independently by Icarus Corporation. The installed costs provided by the contractors and Icarus were in good agreement, typically within 35% of each other for each feeder. The evaluation reported here was based on the costs provided by the contractors. Sensitivity analyses have established that the same feeder selection is obtained if the costs provided by Icarus are used.

Capital, operations, and maintenance costs were used to calculate life cycle costs for each feeder. The life cycle costs and development

*Lockheed was contracted to develop feeders for 1/8 x 0 coal.

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costs estimated by JPL were used to derive the following three parameters for each feeder and for various combinations or sets of feeders:

- $\Sigma\Delta C$ - The life cycle cost difference between the baseline (lockhopper) feeder and the candidate feeder summed over the process applications. A maximum value of this parameter represents the objective of the plant developer who seeks to minimize costs.
- L - Cost leverage = $\Sigma\Delta C$/development costs. A maximum value of this parameter represents the goal of ERDA, which seeks the maximum return for its development funding.*
- R - Realizability. The probability of successful commercialization.

Figure 1-1 shows how these three parameters change with increased development funding, and with different selections of feeder sets. All combinations of feeder sets which could meet all process conditions were examined. Figure 1-1 shows the most promising combinations. The sets shown provide the best choice, i.e., they optimize one or all of the three decision parameters for the range in development costs. The figure illustrates the following points:

(1) The feeder set which maximizes L is the centrifugal (or kinetic extruder) and linear pocket feeder. This set also provides a high value for $\Sigma\Delta C$. However, there would be a high risk that these feeders would not realize commercialization (low R).

(2) The rotary valve piston feeder is predicted to have a higher probability of commercialization than the combination of the centrifugal and linear pocket feeder, but its predicted high life cycle and development costs result in lower $\Sigma\Delta C$ and L values. Actually, considering cost inaccuracies, the rotary piston and centrifugal/linear pocket feeders probably have comparable values for $\Sigma\Delta C$ and L.

(3) Because of the low values for R which would result if only one feeder or feeder set were developed, it is recommended that parallel developments be undertaken to increase the probability of feed system commercialization. Parallel development of feed systems will reduce the parameter L, as is shown in the figure, because development costs are increasing faster than corresponding increases in $\Sigma\Delta C$. By

*Note that the values of L show relative differences between systems. The actual value of L may be 10-50 times the number shown depending on how many plants derive economic benefit from use of the new feeders/gasifier systems.

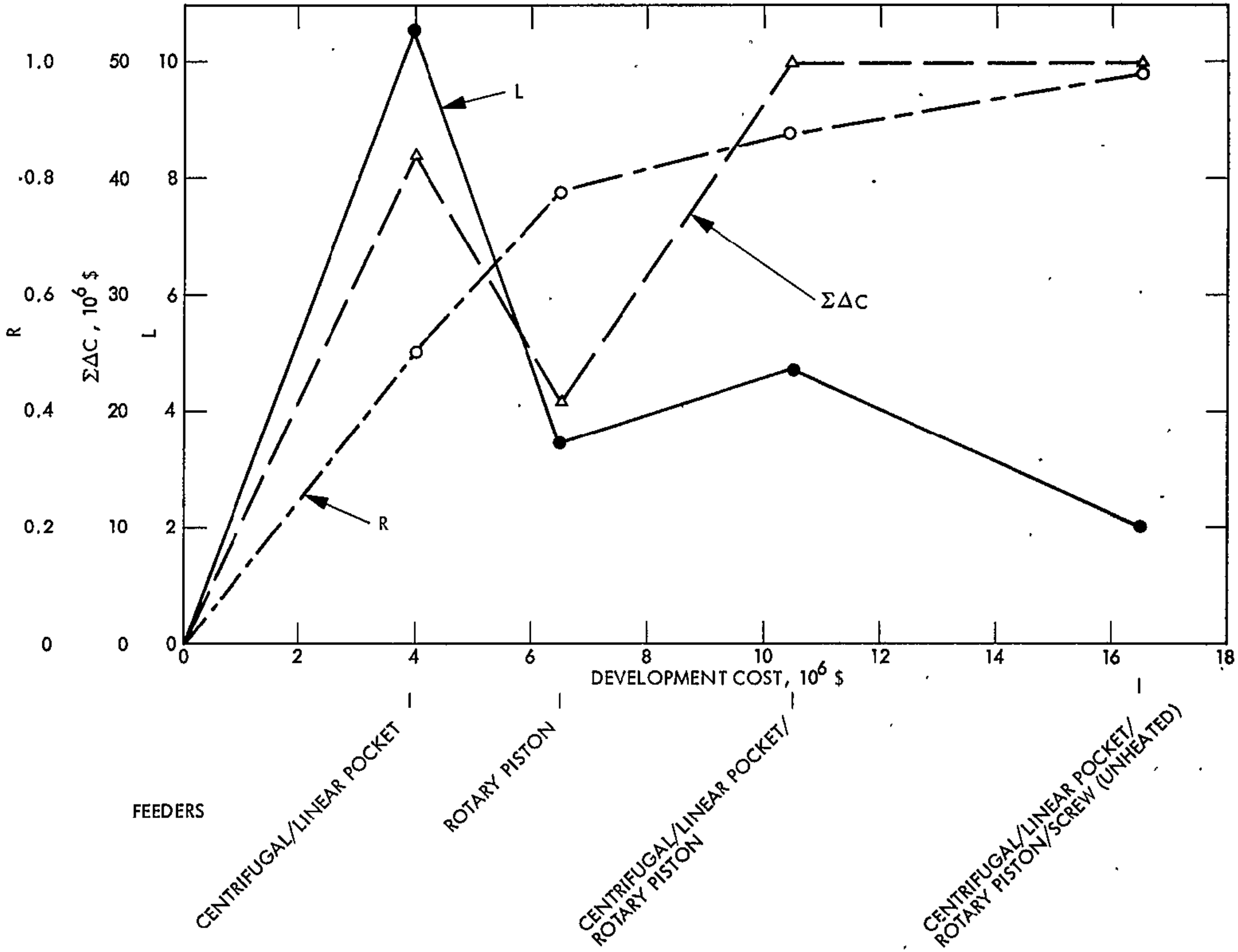

Figure 1-1. Feed System Selection Parameters

combining the centrifugal/linear pocket and rotary piston feeders, increased realizability is achieved; however, it is not until a third parallel development, the unheated screw, is added that an acceptably high value for R is achieved.

(4) The positive displacement feeder, if added to the above set, would only slightly increase the commercialization realizability, but would increase the development cost by about 30%. The additional cost for little gain, coupled with the feeder's projected low reliability, leads to the recommendation that development of the positive displacement feeder be discontinued, or limited to testing of the present system and concentration on improving the system's reliability.

(5) None of the other feeder systems offer any additional cost or realizability advantages over the four selected in (3) above. In addition, none of the other feeders was determined to have advantages for specific applications or redeeming technical features which would recommend their selection.

D. RECOMMENDED SYSTEMS

As a result of the above analysis the following feed systems are recommended for further development:

(1) Foster-Miller centrifugal feeder or LMSC kinetic extruder.

(2) Foster-Miller linear pocket feeder.

(3) Ingersoll-Rand rotary valve piston feeder.

(4) Ingersoll-Rand unheated screw feeder.

The recommended actions for each feeder and the bases for the recommendations are summarized in Table 1-2. The recommended development actions are described in more detail in JPL Document No. 5030-94, Coal Feed System Development Plan. For all selected feeders the development uncertainty is high. Continued evaluation of the selected concepts is required and is reflected in the development plan.

The reliability assessment performed by Kaman Sciences pinpointed the ancillary equipments as the critical elements in feed system reliability. Therefore, system aspects should receive greater attention in the continuing program.

The process impact study conducted in conjunction with International Research and Technology Corporation revealed the potential sensitivity of the processes to feeder characteristics. These results emphasize the need to view the feeder as but one equipment of an integrated coal conversion plant.

Table 1-2. Recommended Coal Feed System Development Actions

Feed System	Recommended Action	Basis for Recommendation
Positive Displacement Feeder	Discontinue major development effort. Limited testing of available equipment and design analysis to verify cost and reliability assessment	• No cost advantage relative to selected systems • Serious reliability problems
Centrifugal/Kinetic Extruder Feeder	Continue component testing to verify concept functional capability, and pressure ratio potential(1)	• Potential low cost system for high pressure processes using fine coal. • System simplicity
Linear pocket feeder	Conduct pilot-scale development. Assess sealing, leakage and pressure capability. Verify coal metering to the pockets and water lock design(2)	• Potential low cost system for low pressure systems (to 500 psi) using fine to coarse coal
Screw Feeder	Conduct pilot scale development. Emphasize the unheated screw(3)	• Provides parallel development alternative to other recommended developments to increase probability of commercial feed system development. • One of only two feeders capable of meeting all process requirements (piston feeders are only in conceptual stage of development).
Single Acting Piston Feeder	Discontinue development efforts in favor of rotary piston feeder development	• Cost savings potential is not as great as rotary piston. Development problems may be easier, however.
Rotary Valve Piston Feeder	Conduct component development, emphasizing piston sealing and wear, solids loading and unloading to prevent jamming and system design to minimize power requirements	• Potential cost savings compared to baseline. • Potential application to all process requirements.
Standpipe Ball Conveyor Feeder	Discontinue development	• Complex. • Applicable only to low pressures (below 150 psi).
Fluid Dynamic Lock Feeder	Discontinue development	• Complex staging required to reach even 150 psi. • High cost compared to baseline systems.
Gas-Solids Injector Feeder	Discontinue development(4)	• Complex staging required to reach even 150 psi. • High cost compared to baseline systems.

(1) Because of development uncertainties parallel development efforts should be considered.
(2) Recommendation contingent on results of prototype testing.
(3) This system has questionable cost advantages. Requires application analysis during Phase III to determine best applications.
(4) This system should be analyzed for application to low pressure systems and topping stages.

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SECTION II

EVALUATION METHODOLOGY

The candidate coal feed systems have been evaluated in terms of the following criteria:

(1) Technical feasibility.

(2) Projected performance and applicability to future coal conversion plants.

(3) Projected commercial-scale capital, operating, and maintenance costs.

(4) Probability of successful development.

(5) Projected development requirements and costs.

To determine the relative capabilities of the feeders with respect to the above items, many additional criteria were considered, as is shown in the methodology evaluation flow diagram, Figure 2-1.

The evaluation steps included those listed in the selection strategy given in Table 2-1. The purposes of the selection strategy were (1) to arrive at a recommended set of feed systems which will best satisfy future requirements and (2) to recommend a development program which will maximize the chance of achieving commercially acceptable feeders with the investment of a reasonable amount of Federal development funds. At present, the candidate feed system capabilities and costs are not well characterized; if, at this time, a poor selection is made, large future costs in the use of feeders could possibly be incurred. Therefore, it is imperative that the development of feeders having the potential of low life cycle costs be continued through the stages in which development costs are relatively small. The feed system development recommendations in this report include this consideration by recommending parallel development of feed systems. Further reduction in the number of feed systems to be developed can be made later in the program, i.e., at the start of the demonstration phase, Phase IV, when development costs will increase significantly. At that time the feed systems' capabilities and costs will be known better and a better discrimination between systems can be made.

The evaluation methodology considers the factors above in comparing the candidate feeders with lockhopper and slurry pump baseline feeders. Specifically, feeder performance was assessed and applicability to a set of processes was determined. Feed system life cycle costs for commercial-scale systems were then projected. These costs were compared with baseline system costs for the selected set of processes, and a total cost savings for the process set was calculated. This value was divided by estimated relative feed system development costs. The resulting parameter provided an indication of potential cost savings for development cost invested, for any feed system set meeting all

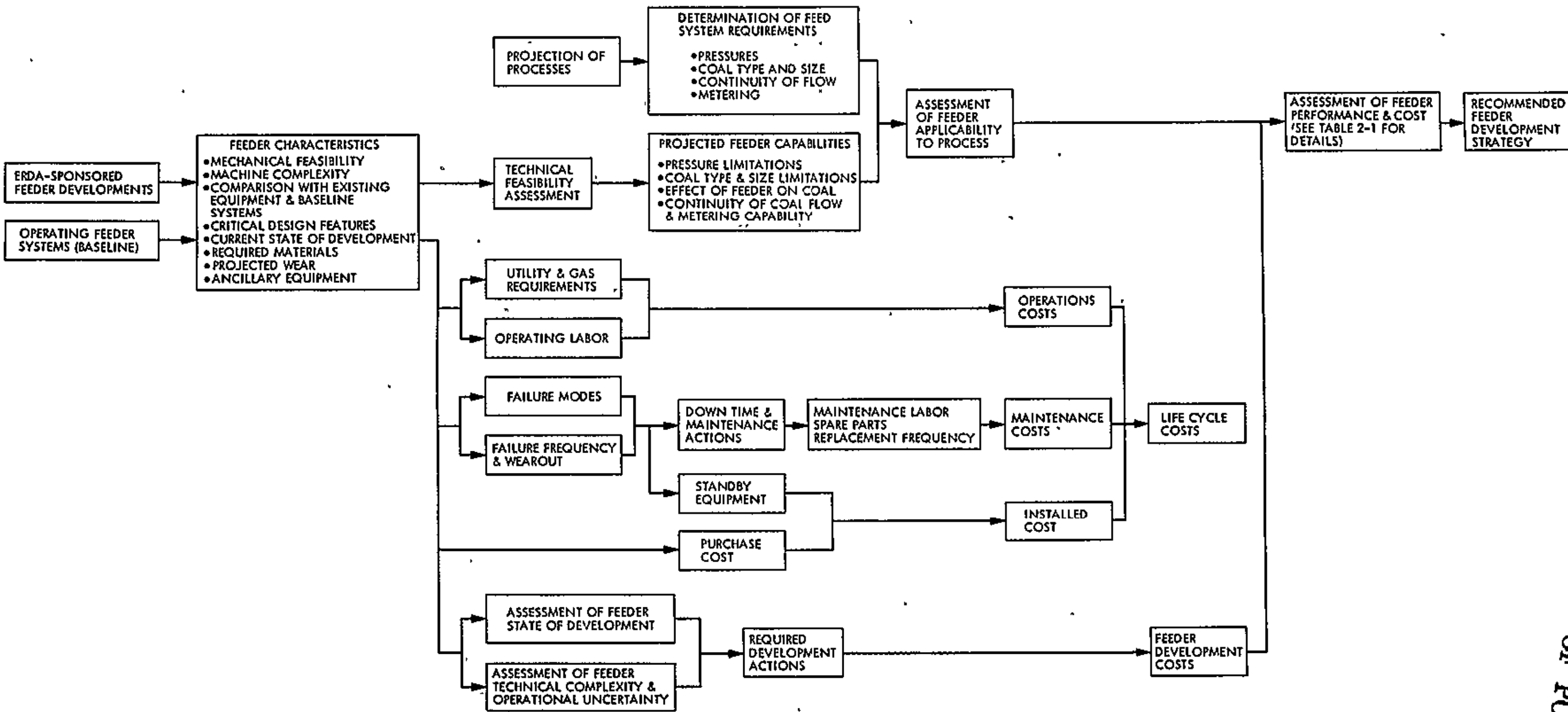

Figure 2-1. Coal Feed System Evaluation Methodology

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Table 2-1. Feed System Selection Strategy

(1)	Select feeders to be evaluated.
(2)	Assess feeder feasibility.
(3)	Project performance, considering factors shown in Figure 2-1.
(4)	Select processes to be considered for application of the feeders.
(5)	Determine feeder requirements for each process.
(6)	Determine applicability of each feeder to each process. (This was done on a go-no go basis for this initial evaluation.)
(7)	Estimate capital, operating, and maintenance costs of feeders to be evaluated and the baseline lockhopper and slurry pump systems, considering factors shown in Figure 2-1. (Independent cost estimates were provided by the three feeder contractors and by Icarus Corporation. Estimates were determined for commercial scale plants and for different pressures.)
(8)	Determine life cycle costs for each feeder for commercial scale plants having various pressure requirements, C_F.
(9)	Determine candidate feeders' life cycle cost difference from baseline systems for each process application. (This is a measure of the specific feeder's cost advantage vs the baseline feeder for application to each process.) $\Delta C = C_B - C_F$
(10)	For each candidate feeder applied to the set of processes selected, determine the sum of the life cycle cost advantage for each feeder, $\Sigma\Delta C$.
(11)	Determine the development uncertainties and required development actions for each candidate feeder, estimate the relative development difficulties between candidate feed systems, and establish a basis for estimating relative development costs for each feed system.
(12)	Estimate candidate feed system development costs, C_D. (C_D is the sum of development costs for a set of feeders.)
(13)	For each set of feed systems which meet the requirements of all processes, determine $L = \Sigma\Delta C/C_D$. (The value determined by this expression represents the potential life cycle cost savings for the set of feeders applied to the selected processes divided by the invested cost. It is a type of benefit/cost evaluator.)

Table 2-1. Feed System Selection Strategy (Continuation 1)

(14) Select feed systems for future development which, from the cost analysis, show the best chance of achieving low cost and wide applications to future processes, for specified development cost limitations.

(15) Consider risk reduction (or increased probability of successful feeder development) as a reason for continuing with specific development actions on otherwise unselected systems. Specifically, consider feeders which have potential cost advantages over baseline systems and a high probability of achieving commercialization for specific processes and process sets.

(16) Consider specific applications as a reason for continuing development of a concept which was not otherwise previously selected.

(17) Based on the technical assessment of the feed system, review and modify the selections above.

(18) Review the final selection by consideration of the following:

(a) The added Phase II development cost to include an additional feeder to increase probability of commercialization.

(b) The benefits or risks of selecting feeders with common technologies, as opposed to selecting feeders with diverse technologies.

(c) The benefits or risks of developing feeders with wide applicability compared with feeders having specific applications.

(d) Special advantages, if any, of modular or staged feeders.

of the process requirements. Based on this parameter a set of feeders was recommended for continued development. Additional feeders were also recommended as a means of increasing the chance of successfully developing commercial feeders.

All of the feed system developments recommended should be subjected to periodic review to determine if they continue to satisfy the criteria which were the basis for their selection for further development, i.e.,

(1) Low life cycle cost, wide application, and low development cost.

(2) High probability of achieving commercial development at a cost lower than baseline systems.

(3) Superiority for specific applications.

(4) Technical advantages compared with alternative systems.

SECTION III

FEED SYSTEM COMPARISON

A. TECHNICAL FEASIBILITY

The feasibility of each candidate feed system was assessed by reviewing the developmental problems associated with it, and by assessing its commercialization potential and reliability.

1. Development Problems and Commercialization Potential

The feed system development problems considered included both generic problems - those common to more than one feed system - and specific problems - those unique to a particular feed system. Evaluation of the feeder's development problems and status produced an assessment of each feeder's commercialization potential.

a. Generic Feeder Problems

1) Common Concerns. There are generic mechanical problems which apply to all feeders. For the high speed centrifugal pumps, the bearings and seals pose a common problem. For the conveyors and the extruders, piston seals will be a problem common to each.

For most of the machines under consideration, the bearing and seal problems should not be insurmountable. The technology which presently exists in the high speed rotating machinery and reciprocating engine industries can probably be utilized to overcome any problems which may arise in this application and no new technology or advancement of present technology is envisioned. The major concern with respect to the bearings and seals in all of the machines is that coal particle contamination and cooling requirements will result in shortened machine life.

Since a large number of the machines depend on the coal to act as a seal against the reactor back pressures, the permeability of the coal will be important. Although some work has been done in this area, additional data will be required for all types of coal.

The prime movers required to operate the machines - electric motors, steam turbines, compressors, hydraulic activators, and associated speed reducers and/or transmissions - are not expected to create major problems and should be readily available to meet the requirements. It should be noted, however, that extreme care should be taken in the system design; the prime mover and support systems are greater contributors to system unreliability than the feeder itself (see Section III-A-2).

2) Feeder Effects on Coal. A primary concern with all coal feeders is the potential effect on the coal conversion process of feeder-caused alterations of the feedstock. This effect is discussed in Section III-B-2 together with other effects of the feed system on the processes.

b. Specific Feeder Problems.

1) Positive Displacement Piston Feeder. The development of this pump concept will require drawing on reciprocating engine technology to provide valve sealing, control of valve sequencing and a low maintenance hydraulic support system. The primary concern in designing the valves is to assure that coal particles do not contaminate the seat face, causing leakage and reducing valve life. Purging can possibly minimize this problem, but there would be an attendant increase in make-up gas. The operating principle is fairly straightforward, and the efficiency of the machine will depend primarily on the volumetric efficiency attained in the cylinder.

2) Centrifugal and Kinetic Extruder Feeders. The centrifugal pumps, operating at high rotational speeds, will require some design emphasis on bearings and seals, and on dynamic balancing. A major concern is to design the rotor so as to achieve the desired control of coal flow through the rotors. The rotor passageway contours and shapes must be evolved in such a manner that coal is slung out peripherally at high rates against high back pressure. The centrifugal forces on the coal particles in these rotors must overcome the inertial forces due to the radial acceleration and the static forces due to the process pressure in order to avoid back leakage. Designing the rotors to ensure this force balance is not expected to be easy, especially since these concepts do not readily lend themselves to analytical modeling. A possible deficiency of this concept may be limitation of achievable pressure ratio.

3) Linear Pocket Feeder. The problems that will be encountered in developing this conveyor feeder involve the piston seal life, the introduction of coal to the pockets, gas leakage, seal-tube life, and the water lock or gas-water transfer pot. The machine feedstock capacity and efficiency will depend on how effectively the coal is introduced into and evacuated from the individual pockets. The upstream seal between the reactor and atmospheric hopper is a critical part of this machine and will require designing to close tolerances between the ceramic and trailing metal piston rings and the seal tube. Any significant wear in this region will increase the back leakage through the atmospheric hopper. In the downstream water lock area, the critical problem is how effectively the high pressure gas will be displaced with water. The gas has to percolate up through the water into a dryer over a relatively short distance. Depending upon the conveyor's speed, there may be insufficient time for completing the transfer. Drying of the pocket pistons to prevent a wetting surface for the accumulation of coal particles is also critical. This type of conveyor feeder should be capable of operating against back pressures up to about 500 psi.

4) Screw Feeder. The problems to be solved in developing the screw feeder will involve determining the method and extent of heating used for plasticizing the coal, designing the screw flights, and understanding the barrel friction properties and wear characteristics.

In theory, one can extrude dry pulverized coal against high back pressures using an auger type machine without plasticizing the coal. In the case of the screw machine under development, both heated and unheated types of extrusion are being evaluated. For the case of plasticized extrusion, two methods of heating are being considered: external heating through the barrel and internal heating via the screw. The plastic condition will tend to increase resistance to gas leakage; however, significant power is required to plasticize the coal. The optimization of coal heating will have to be experimentally determined and may vary with machine size and capacity.

The design of the screw flights will require drawing on plastic extrusion and injection moulding technology, taking into consideration the differences in the extrudates. This machine should be capable of feeding against high back pressure (1500 psi).

5) Single Acting and Rotary Piston Feeders. These two feeders are similar in concept and have similar development problems. In both concepts, coal is injected directly from an atmospheric hopper into the high pressure storage hopper by the use of pistons. The single acting piston machine is limited to translational motion only, whereas the rotating piston concept employs both translational and rotational motions. The major problem expected with both feeders is to achieve satisfactory seal integrity and life. Contamination of the seals with coal particles could cause leakage and increase the machine wear. The efficiency of both machines will depend on the effectiveness of the loading (coal metering) and volume reduction steps in the cycle.

6) Ball Conveyor Feeder. The major problem with the ball or standpipe conveyor is expected to be gas leakage through the standpipe column. The leakage rates will depend on the ball spacing and the permeability of the coal being transferred. If the balls touch, channeling and blowout will occur in the coal. Conversely, if the balls are too far apart, a lockup condition will occur wherein coal transfer ceases.

The rate at which coal can be transferred through a given standpipe/ball design will depend largely on the friction between the standpipe walls and the coal. The coefficient of friction is not well known and could vary significantly between different coal types, and size consists. Another problem is the control and subsequent drying of the balls through the water lock on the downstream side of the conveyor. This conveyor is limited in pressure elevation capability. However, because of standpipe height limitations, staging to achieve higher pressures is not practical. For example, if one assumes that a pressure differential per unit column height of 2 psi/ft can be sustained, a 100 foot tall standpipe would be required to feed a process reactor operating at an intermediate pressure level of 200 psi.

7) Fluid Dynamic Lock Feeder. The fluid dynamic lock concept imparts momentum to the fluidized coal by the skin friction between closely spaced rotating disks. In this case, the fluidizing gas will be injected into the reactor if not separated beforehand. Conversely, the other pumps, the kinetic extruder and centrifugal pump, must vent the gas at the rotor hub in order to operate properly.

Pump operation, then, based on a skin friction principle, is likewise going to be difficult to master, and the design of a full scale machine is going to have to rely on empirical techniques. It should be noted that disk spacings required to achieve pressure ratios of the order of 2 may approach the size of the coal particles.

8) Gas-Solids Injector Feeder. The gas-solids injector, unlike the centrifugal feeders, lends itself to analysis using internal aerodynamic fundamental principles; the momentum of the driver gas syphons the coal from the annular region in the nozzle, and the coal/gas mixture is decelerated in a diffuser section. Hence, one can fairly confidently rely on the scaling laws derived from the modeling. The problem areas in the development of this feeder are the life of the compressor required to drive the pump, mixing tube life, and ejector efficiency. The pressure ratio is limited to about 2 to 1, which severely restricts the performance of this machine, although it may find application as a topping state.

c. Commercialization Potential. The commercialization potential of each feeder has been estimated on the basis of its present state of development and the problems involved in further development. The following estimates (which are used in subsequent analyses) give the probability of successful commercialization, assuming continued development:

Positive displacement	0.80
Centrifugal	0.65
Linear pocket	0.80
Screw	0.90
Single acting piston	0.75
Rotary valve piston	0.75
Kinetic extruder	0.65
Standpipe-ball conveyor	0.60
Fluid dynamic lock	0.65
Gas-solids injector	0.85

2. Reliability Analyses

a. Feeder Failure Rates. Estimated failures, per 10^6 hours, for a single feeder or feeder train at 1500 psi are given in Table 3-1. Included are the major (but not all) high failure rate items, listed in order of decreasing failure rates.

b. Feeder Availability. If it is assumed that 1 day (24 hours) is required to repair a given failure then the "on line" availability of

Table 3-1. Feed System Failure Rates*

Feed System	Estimated Failures in 10^6 Hours	Mean Time to Failure	
		Hours	Days
Positive Displacement Intake/Exhaust Valves Pop-off and pressurizing valve Flushing valves Hydraulic system valves	39,540	25	1
Centrifugal Drive motor Sprues Gear box Conveying gas compressor Seals Bearings	3,890	257	11
Linear Pocket Sprocket motor Gear drive Sprocket Piston seals	7,530	133	6
Screw Feeder (heated) Motor (2600 hp) Reducer Extrudate breakup motor Heating bands Screw	1,490	671	28
Screw Feeder (unheated) Same as the heated screw	1,290	775	32
Single Acting Piston Hydraulic pumps Seal on No. 1 piston for coal throughput Motors on hydraulic pumps Release valves on hydraulic system Heat exchanger	4,800	208	9
Rotary Piston Hydraulic activator Hydraulic pumps Seals	4,850	206	9
Kinetic Extruder Same as centrifugal	4,230	236	10
Ball Conveyor Conveyor High Pressure water pump Ball meter wheel Valves Pump motor Conveyor motor	3,710	270	11
Fluid Dynamic Lock Disk plates Gear drive Drive motor Cooling system pump Hydraulic pump Hydraulic valve	10,180	98	4
Gas Solids Injector Compressor motor Compressor seals Filter Valves Injector	3,060	327	14
Lockhopper Compressor motor Compressor seals Hydraulic pressure valves	5,120	195	8
Slurry Pump Motor Seals Heat exchanger	2,430	411	17

*Data provided Kaman Sciences Corp., Ref. 1.

each feeder can be determined. Further, if the number of feeders or feeder-trains per gasifier is known, the availability of a gasifier can also be determined. Since it is desired to have a 95% "on line" capability, the number of backup feeders or feeder trains that would be required has also been determined. This information is given in Table 3-2. It is important to note that the screw feeder has the best projected reliability and that the positive displacement feeder has severe reliability problems, owing to its complexity and the large number required for each plant. Similarly, the fluid dynamic lock is predicted to be unreliable because of the large number of stages required.

The reliability of a feed system is largely determined by the reliability of its support systems. These support systems have not yet been considered in detail. System design needs much more attention in future development efforts.

3. Summary of Feed System Technical Feasibility

From the technical review of the feed systems it can be concluded that all are technically feasible. The feeders differ in their capabilities to meet the requirements, in their reliabilities, and in the uncertainties involved in their development. Table 3-3 ranks the feeders in these three areas and then provides an overall ranking. The following points are worthy of note:

(1) The screw feeder ranks high in all categories.

(2) The single acting and rotary piston feeders are projected to meet all the requirements, have good projected reliability, but have not yet received any development.

(3) In concept, the centrifugal feeder and kinetic extruder are promising for use with pulverized coal, but their operational capability is uncertain.

(4) The linear pocket feeder is limited to operating at pressures below 500 psi and ranks as average, compared to the other feeders, in reliability and development uncertainty.

(5) The positive displacement feeder suffers from severe reliability problems and is limited to use with pulverized coal.

(6) The gas-solids injector is limited to pulverized coal and, because of its pressure-ratio limitations, requires many stages for use at even moderate pressures. It may have applications at low pressures or as a topping stage.

(7) The fluid dynamic lock has all the disadvantages of the gas-solids injector plus low reliability because of its staging requirements to reach high pressure.

(8) The ball conveyor is complex and has very limited application, i.e., it can be used only with pulverized coal and with processes taking place at low pressure.

Table 3-2. Feed System Reliability Data[1]

Feeder (or Feeder Train)	Availability Per Feeder or Feeder/Train	Availability Per Gasifier	Feeders/Trains per Gasifier	Required Backup Feeders/Trains for 95% Availability
1. Positive Displacement	0.51	0.13	3	3[2]
2. Centrifugal	0.91	0.91[3]	1	1
3. Linear Pocket	0.85	0.61	3	2
4. Heated Screw	0.96	0.85	4	1
5. Unheated Screw	0.96	0.85	4	1
6. Single Acting Piston	0.90	0.66	4	2
7. Rotary Piston	0.89	0.63	4	2
8. Kinetic Extruder	0.91	0.83[3]	2	1
9. Ball Conveyor	0.92	0.85	2	1
10. Fluid Dynamic Lock	0.80	0.64	2	2
11. Gas Solids Injector	0.93	0.93	1	1
12. Lockhopper	0.89	0.79	2	2
13. Slurry Pump	0.95	0.90	2	1

(1) Data provided by Kaman Sciences, Corp., Ref. 1.

(2) Adding three additional banks per gasifier would only increase the availability to 52%. The number of additional feeders required to reach 95% availability was not determined.

(3) Based on contractor inputs, a one-stage feeder was assumed for the centrifugal feeder and a two-stage feeder for the kinetic extruder.

Table 3-3. Technical Assessment Ranking

Development Uncertainty Ranking		Ability to Meet All Requirements			Reliability Ranking		Overall Ranking	
1	Screw	1	Single acting and rotary piston		1	Screw	1	Screw
2.	Gas-Solids Injector	2	Screw	- Requires post feed grinding to achieve size consist	2	Gas-Solids Injector	2	Single Acting Piston Rotary Piston
3	Positive Displacement Linear Pocket	3	Positive displacement piston Centrifugal/kinetic extruder Linear Pocket	- Cannot feed coarse coal - Cannot feed coarse coal and may require two stages to feed 1500 psi - Limited to feeding 500 psi or less pressure	3	Ball Conveyor Centrifugal Kinetic Extruder	3	Centrifugal Kinetic Extruder Linear Pocket Positive Displacement Gas-Solids Injector
4	Single Acting Piston Rotary Valve Piston	4	Gas-Solids Injector Fluid Dynamic Lock	- Cannot feed coarse coal and requires many stages to reach 1500 psi - Cannot Feed coarse coal and requires many stages to reach 1500 psi	4	Single Acting Piston Rotary Valve Piston		
5	Centrifugal Kinetic Extruder Fluid Dynamic Lock	5	Ball Conveyor	- Cannot feed coarse coal and cannot feed to pressures above about 150 psi	5	Linear Pocket	5	Fluid Dynamic Lock
5	Ball Conveyor				6	Fluid Dynamic Lock	6	Ball Conveyor
					7	Positive Displacement		

B. PERFORMANCE AND APPLICABILITY TO COAL CONVERSION PROCESSES

A primary factor in the selection of a feeder for future development is an assessment of how well the feeder will perform with a specific coal conversion process and how wide an application the feeder will have for a projected set of processes. In this section, the effect of the candidate feed systems on projected processes, including the effect of the feeder on the coal and on the processes themselves, is considered. In addition, potential future processes are analyzed to arrive at a generic set of process conditions, from which the feeder's applicability is assessed. The feeder's applicability is then incorporated into the cost analysis, where broad applicability enhances a feeder's cost savings potential.

1. Effect of Feeder on Coal and Processes

The primary function of the feeder is to elevate coal from ambient to process pressure. In so doing, the feeder may alter the physical and chemical properties of the coal. The altered coal may then require post-feeder treatment to prepare it for the process or, if fed directly, may affect process conditions. The possible effects are peculiar to each feeder and to each process.

a. Effect of Feeder on Coal. In contrast to the wide diversity in mechanical action of the candidate feeders, the effects of the feeders on the coal fall into a limited number of classifications. A feeder may, through its actions, cause physical compaction of the coal feed. This is envisioned as the interlinking of particles induced by the application of pressure which reduces voids and brings coal particles into intimate physical contact. The coal is aggregated into particles larger than those originally fed and may, in the extreme, be formed into lumps. The Ingersoll-Rand unheated screw feeder is an example of a feeder which will cause compaction. Recovery of the original size distribution can be accomplished by crushing, grinding, screening, and similar physical operations.

The particle-particle and particle-machine contacts of the coal as it passes through the feeder can effect size reduction. This is caused by induced pressure, shear and impact forces and by grinding wear. For instance, if the high velocity outlet stream of the Lockheed gas-solids injector is allowed to impinge on a fixed surface, the particles can be shattered into smaller sizes. However, if the kinetic energy of the particles is dissipated more gently, as in the contoured housing of a centrifugal pump or by aerodynamic deceleration, size attenuation may not be significant. Therefore, with those feeders whose action is based on kinetic effects and centrifugal forces, particle size reduction depends on feeder design details. The pressures which induce compaction may also cause some size reduction. This would be masked until an attempt was made to recover the original size distribution. Reconstitution of comminuted coal would require aggregation with a binder and recycling through the grinding and screening steps.

Feeders which raise the coal to elevated temperatures can cause agglomeration and charring. Agglomeration is the coalescence of particles while in their plastic or fluid states. The globules thus formed are homogeneous and the original particles are indistinguishable. The physical integrity of an agglomerate is much greater than that of a compact. The onset of fluidity is accompanied by the evolution of the coal's volatile matter, leaving a residual char. The carbon-rich char differs in physical and chemical properties from the original coal feed. The size consist of the feed can be recovered by subjecting the agglomerated char to grinding and screening. The chemical values evolved in the volatiles are, however, lost to the char.

Some feeders dilute the coal in a carrier medium in order to exploit conventional technology. The slurry pump, in which the coal is suspended in a carrier liquid, is a prime example. Recovery of the original coal is effected either by physical means, such as cycloning or centrifugation, or by thermal means, such as evaporation or drying. Incomplete separation will leave some diluent carrier in the coal.

The anticipated effects of the feeders on the coal are summarized in Table 3-4. As discussed above, design details determine whether or not a feeder causes particle size reduction. In the table, this is indicated by the question marks. The hot screw feeder potentially will have the greatest effect on the coal. The lockhopper and the piston feeders are predicted to have the least effect.

b. Effect of Feeder on Processes. The feeder is but one equipment in a complex process train. Its intrinsic characteristics such as size, reliability, power requirements, etc., will directly affect the overall cost and efficiency of the plant. Indirectly, the effect of the feeder on the coal can impact the design and operation of the entire process.

Two approaches can be taken to compensate for the effects of the feeder on the coal. The first salvages existing reactor and processing technology by adding whatever pre- and post-feeder operations are required to recover a feed as specified for the reactor. This has the merit of confining the impact to that portion of the process that takes place before the coal reaches the reactor, and hence preserves the investment in reactor and processing technology. The operating costs of this approach can be high if, for instance, to achieve it, fines, char and/or volatiles are rejected. The second approach is to feed the altered coal directly to the reactor. In many cases this may require the development of new or extended reactor technology to accommodate the "as is" feed. Perturbations in reactor performance would, in turn, ripple through the design of the subsequent processing train.

Possible means of implementing the first strategy are summarized in Table 3-5. There the feeder effects are listed along with steps to recover coal feed of the original specification. Each of the recovery steps exacts a penalty in process capital and/or operating cost except B.3. There, some coal preparation cost might be saved by performing part of the comminution in the feeder.

Table 3-4. Effects of Feeder on Coal

Feeder	Effect: Compaction	Size Reduction	Agglomeration	Charring	Dilution
FMA Positive Displacement					
FMA Centrifugal		?			
FMA Linear Pocket Feeder					
IR Screw (heated)	X		X	X	
IR Screw (unheated)	X				
IR Single-Acting Piston					
IR Rotary Piston					
L Kinetic Extruder		?			
L Standpipe Ball Conveyer					
L Fluid Dynamic Lock		?			
L Gas Solids Injector		?			
Lock Hopper					
Slurry Pump					X

Table 3-5. Recovery Approach

Feeder Effect	Recovery Steps
A. Compaction	1. Subsequent size reduction and classification. 2. Grind undersize followed by aggregation in feeder up to specified size consist. 3. Reject oversize.
B. Size Reduction	1. Reject fines. 2. Aggregate fines with binder, grind, and classify. 3. Grind oversize followed by size reduction in feeder to specified size consist.
C. Agglomeration	1. Subsequent size reduction and classification. 2. Reject oversize. 3. Grind undersize followed by agglomeration in feeder up to specified size consist.
D. Charring	1. Reject char and/or volatiles. 2. Separate char and feed at appropriate point. 3. Collect volatiles and feed at appropriate point.
E. Dilution	1. Separate coal from carrier.

The reactor forms the interface between the feeder and the rest of the process. Since the post-reactor unit operations and processes are largely commercially proven, the reactor is the critical unit. It dictates the tolerance of the process to feed alterations induced in the feeder. Candidate coal conversion processes are listed in Table 3-6. Their capacity for accommodating altered feeds depends on the required size consist and on the availability of compatible feed points.

Those reactors which require lump feed would obviously be intolerant of fines and incompatible with feeders which create them. Fluidized bed or entrained flow reactors which required a closely graded, pulverized feed to maintain bed stability or residence time, would operate inefficiently on an altered feed. The complete size distribution can be critical to reactor operation, not just the under- and oversize tails.

If there is a possible feed point at some stage in the converter where a mixture of coal and char exists, a partially charred feed might be accepted. Likewise, in those converters with distinct coal and char streams such as Bigas, a segregated coal and char feed could be fed at the appropriate points.

The value of feeder side streams depends on the heat and material balances of the overall process. Rejected coal fines and char can be burned in boilers to generate process steam, to power drivers, and to generate electricity. This use is presumably of lower value than conversion to product. The actual value depends on the price of steam and electricity and whether the process is a net importer or exporter of them. Condensed volatiles evolved in the feeder might be merged with the product of a pyrolysis unit such as Cogas but could only be sold as a by-product of a pipeline gas plant. Gaseous volatiles can be burned as boiler fuel or combined with a process stream at a suitable point.

The existence of feeder side streams or the operation of the reactor at off-design points implies a perturbed material and energy balance for the rest of the plant. Operation under off-optimum conditions will result in reduced process efficiency. If the perturbation exceeds the operating range of the plant, a redesign will be necessary. Thus the effects of the feeder will permeate the entire process.

An additional consideration, which has not yet been subjected to analysis, is the effect of feed point location on feed system selection. A review of the feed points for selected processes indicates that feeding will be required at the top, or near the top, of many reactors. The data is summarized in Table 3-7. The selection of two feed systems could be affected by the need for feed points at the top of the gasifiers:

(1) Ball conveyor - The standpipe would have to extend above the gasifier, or a high pressure conveyor from the feeder outlet to the high pressure hopper would be required.

Table 3-6. Coal Conversion Processes

Process	Type				Feed Size				Feed Point			
	Fixed Bed	Fluidized Bed	Entrained Flow		Lump	Pulverized	Closely Graded	Loosely Graded	Coal	Coal and Char	Coal or Char	Comment
HYGAS		X				X	X				X	Slurry Spray
BIGAS			X			X	X				X	
Synthane		X				X		X	X			
McDowell-Wellman	X				X		X		X			
Agglomeration Burner		X				X	X			X		
CO_2 Acceptor		X				X	X				X	
Lurgi	X				X		X		X			
Foster-Wheeler			X			X		X ?			X	See BIGAS
Texaco			X			X		X	X			Slurry Spray
Synthoil	cat.					X		X	X			Slurry Feed
Fluidized Bed Boiler		X				X		X		X		
COGAS		X				X		X			X	Pyrolysis

Table 3-7. Process Feed Points

Process	Gasifier h & D (ft)	Feed Point (ft from bottom)
Lurgi	~24 x 12	Top
Woodall-Duckham	50 x 12	Top
Bigas	54 x 5	25
Texaco		Top
CO_2 Acceptor	70 x 6.4	24.5
Cogas		
Hygas	132 x 6	118
Synthane	101.8 x 6	80
U-gas	~30 x 23	~15
AI Molten Salt	34 x 7	12

(2) Screw feeder - If this feeder is located at, or near, the top of the reactor, its heavy weight may require an excessive support structure; if it is located at ground level, a high pressure conveyor would be required. In the latter case, retention of the heat added to the extrudate by the heated screw could be difficult.

c. <u>Sensitivities of Coal Conversion Processes to Feeder Characteristics</u>. The impact of a feeder on a process may be quantified if sufficient information about the feeder's performance and about the plant's design and performance is available. It is necessary to know how each feeder alters the physical and chemical properties of coal. Given these data, process designs to accommodate the feeders may be developed and performance consequences may be evaluated. As of this writing, measurements of feeder effects have not been made. Institution of such testing is recommended to permit assessment of feeder impact. Casual visual observations by the contractors have been reported to the effect that each feeder except the heated screw has little effect on the size consist of the coal. This is subject to confirmation by screen analysis and to investigation of the effect of scale.

Without quantitative data on feeder performance, specific impacts on plant design and performance cannot be determined. However, the sensitivities of conversion plants to those coal properties which are affected by feeders can be calculated by resorting to models of the processes. Process sensitivities reveal critical design areas and may be utilized to estimate the actual impacts on processes when specific feeder performance data become available.

Process sensitivities were calculated using the Materials-Process-Products Model (MPPM) under development for ERDA by the International Research and Technology Corporation (Ref. 2). This model is based on unit chemical processes (functional modules) tied together by the plant material balance. The Feed Preparation and Gasifier module algorithms were modified to be sensitive to coal size consist and to allow a side stream to be vented from the feeder. The feeders themselves were modeled as transparent black boxes. Their actions were entirely portrayed by variation of model input.

Two general classes of processes were studied: (1) Lump coal, low to medium pressure, represented by Lurgi and (2) pulverized coal, high pressure, represented by Synthane. The impact on these processes of variations in coal size consist and of the venting of volatiles at the feeder were investigated. As discussed above, these are the perturbations which will potentially be introduced by the feeders.

Table 3-8 lists the unit processes comprising the lump coal/medium-low pressure plant and gives the details of the several cases run. These cases simulate the effects of a screw feeder. Case 1 models complete recovery of fines, one of the advantages attributed to screw feeders. Cases 2-4 portray heated screw feeders which recover all fines but which vent an increasing fraction of the coal volatile matter. The last case illustrates a feeder which modifies the coal size consist. The sensitivities of various parameters of the process to these feeder actions are summarized in Table 3-9.

The sensitivities are expressed as the percentage deviation of the perturbed from the baseline value of the given parameter. Case 1 reveals that a significant improvement in Lurgi plant performance can be realized by recovery of fines. The results of cases 2-4 indicate the severe penalties are incurred if volatiles are vented from the feeder and thereby lost to the process. Two values are shown for operating cost and product price. The bare numbers are the results obtained when the vented side stream has zero value. The numbers in parentheses are the results when the vented side stream is valued at $1.00/MMBTU. Case 5 presents the adverse consequences of creating more fines by grinding in the feeder.

The plant description and the case details for the pulverized coal/high pressure process are given in Table 3-10. The only feeder impact explored for this plant was alteration of size consist. Since the action of the feeder was portrayed only by specification of program input, each case, in effect, modeled two opposite feeder actions. For example, in case 1 the perturbed value of the coarse coal size was increased to -4 mesh from the baseline value of -6 mesh. This

Table 3-8. Lump Coal/Medium-Low Pressures

Plant Description

Gasification: Lurgi
Purification: Rectisol
Shift Conversion: Chromium-promoted iron oxide catalyst
Methanation: Multiple fixed bed with product gas recycle
Sulfur Recovery: Claus
Utilities: Generated on-site from coal

Case Details

Case	Variable	Values		Feeder Action Simulated
		Baseline	Perturbed	
1	Size consist	1 1/2 x 1/8	1 1/2 x 0	Recovery of fines
2	Volatiles vented	0%	30%	Venting of volatiles and charring of coal
3	Volatiles vented	0%	60%	Venting of volatiles and charring of coal
4	Volatiles vented	0%	97%	Venting of volatiles and charring of coal
5	Size consist	1 1/2 x 1/8	1 1/2 x 1/4	Increased production of fines

Table 3-9. Lurgi Process Sensitivities

[(Perturbed-Baseline)/Baseline] x 100

Case	Capital Cost/ Gas Output	Operating Cost/ Gas Output	Product Price	Cold Gas Efficiency	Plate Thermal Efficiency
1	+0.29	-8.81	-4.60	+4.79	+4.70
2	-11.88	+50.69(+33.57)	+20.39(+11.18	+11.18	+7.3
3	-6.73	+85.37(+47.80)	+40.83(+21.37)	+1.20	-5.57
4	+0.31	+128.65(+54.65)	+66.65(+28.31)	-11.18	-21.6
5	+14.91	+21.96	+18.34	-6.79	+9.76
( ): Side stream value = $1.00/MMBTU					

simulates the impact on the feed preparation module of a feeder which grinds the coarse ends, since less grinding would then be required in the feed preparation circuit. It also simulates the effect on the gasifier of a feeder which agglomerates the coarse ends from -6 to -4 mesh.

The Synthane process sensitivities are presented in Table 3-11. As a result of the feeder simulation approach described above, the overall plant results reflect the net impact of the opposing feeder effects. The feed preparation and gasifier modules are affected the most. These results are displayed separately in the last three columns. The process, as modeled, is seen to be most sensitive to feeders which agglomerate the coal, particularly the fines. This results in an increased production of low value char in the gasifier.

Even small changes in plant efficiencies induced by the feeder are significant since the impact accumulate over the life of the plant. For instance, a 1.0% change in product price integrated over the 20 year life of a 250 MMSCF/day plant has a cost impact of 34 million dollars on the baseline Lurgi process and 35 million dollars on the baseline Synthane plant.

Table 3-10. Pulverized Coal/High Pressure

Plant Description

Gasification:	Synthane
Purification:	Benfield (hot potassium carbonate)
Shift Conversion:	Cobalt-molybdenum catalyst
Methanation:	Tubewall methanator with product gas recycle
Sulfur Recovery:	Claus
Utilities:	Generated on-site from coal

Case Details

Case	Variable	Values		Feeder Action Simulated	
		Baseline	Perturbed	On Feed Prep.	On Gasifier
1	Size consist	-6 x 0, 25% - 100	-4 x 0, 25% - 100	Grinding of coarse	Agglomeration of coarse
2	Size consist	-6 x 0, 25% - 100	-8 x 0, 25% - 100	Agglomeration of coarse	Grinding of coarse
3	Size consist	-6 x 0, 25% - 100	-6 x 0, 37% - 100	Agglomeration of fines	Grinding of fines
4	Size consist	-6 x 0, 25% - 100	-6 x 0, 13% - 100	Grinding of fines	Agglomeration of fines

Table 3-11. Synthane Process Sensitivities

[(Perturbed - Baseline)/Baseline] x 100

Case	Plant					Feed Prep.		Gasifier
	Cap. Cost/ Gas Output	Oper. Cost/ Gas Output	Product Price	Cold Gas Efficiency	Plant Thermal Efficiency	Cap. Cost/ Gas Output	Electric Power	Cap. Cost/ Gas Output
1	+7.19	+0.85	+7.50	+0.38	+0.36	-6.05	-1.07	+3.03
2	-0.37	-0.79	-0.65	-0.38	-0.55	-0.24	+0.74	-1.76
3	-5.81	-9.29	-1.91	-3.65	-4.37	-1.33	+5.87	-6.00
4	+15.56	+51.24	+37.17	-23.80	+36.61	+26.39	-6.86	+46.92

2. Process Selection

An objective of the Coal Feeder Development Program is to develop a coal feeder suitable for each of the coal conversion processes which are expected to reach commercialization. Similarly, a given feeder concept may be judged by the number of these processes which it is capable of serving well. It is therefore necessary to identify those conversion processes with high commercialization potential for the purpose of providing guidance to the Program.

The individual coal conversion processes which are in an advanced stage of development and which are slated for government or industry support are logical candidates for early commercialization. If these processes can be specified, they form the best basis for guiding the feeder program. Such processes have survived the filter of early development phases, and the funding interest shown by government and/or industry is some measure of their merits. They also offer experimental facilities at which feeders could be tested. However, it is recognized that many of the individual processes are similar in principle and performance and that all may not, therefore, survive in a competitive market. Also, it is desirable to develop feeders for those processes which, though only in an early state of development, show great promise.

A second approach to process selection may be based on the classification of processes by generic type. The bewildering array of individual processes then assumes some degree of order and duplications of type may be recognized. This approach is predicated on the assumption that the Government intends to support a diversity of process types until their relative merits are clearly demonstrated. A compilation of generic process types and representatives thereof is presented in Table 3-12. Note that, except for low Btu gas, the product gases can be upgraded to pipeline quality by shift and methanation. In attempting to be inclusive of types, the list turns out to be heavily weighted toward low and medium pressure processes.

The population of conversion processes may be further reduced from the list of representatives of generic types by recognizing that only a limited number of feeder effects and process attributes are important. This has been discussed in the previous subsection. There, coal size and grading, pressure, availability of compatible feed points, and process complexity were identified as the process characteristics which determine the impact of a feeder in a given process. The representative processes of Table 3-12 are reclassified in terms of these characteristics in Table 3-13. There, the duplication of critical interfaces is apparent. One can then consider reducing the generic list to a minimum subset which would still embody all of the critical feeder/process interfaces. Such a subset is designated by stars(*). Thus, if the feeder concepts are evaluated against only the Lurgi, Bigas, and Synthane processes, all important interactions will have been assessed. Note that SRC and Synthoil were dropped from further consideration since they appear to be logically suited to the slurry pump.

The immediate compatibility of a feeder and process may be judged by comparing coal size and process pressure capabilities and requirements.

Table 3-12. Process Types and Representative Candidates

P: indicates primary characteristic of representative process

REPRESENTATIVE PROCESSES	Process Type: Product*: High BTU Gas	Low/Medium BTU Gas	Liquid	Solid	Press.: High Pressure	Low/Medium Pressure	Media: Fixed Bed	Fluidized Bed	Entrained Flow	Flame	Molten	Other	Stages: Single Stage	Multiple State	Heat: Combustion	Other
Lurgi		X				X	P						X		X	
Texaco		X				X				P			X		X	
AI Molten Salt		X				X					P		X		X	
Fluidized Bed Boiler		X				X						P	X		X	
CO_2 Acceptor		X				X		X						X		P
BI Gas	X				X				P					X	X	
SRC				P	X							X	X			X
Synthane	X				X			P					X		X	
Synthoil			P		X							X	X			X

*Any medium BTU gas can be upgraded.

Table 3-13. Minimum Process Subset

PROCESS	Critical Feeder/Process Interfaces									
	Press.		Size			Feed			Process	
	High	Low/Medium	Lump	Pulverized, loosely graded	Pulverized, closely graded	Coal	Char	Volatiles	High BTU	Low/Medium BTU
* Lurgi		X	X			X		X		X
Texaco		X		X		X				X
AI Molten Salt		X		X		X				X
Fluidized Boiler		X		X		X				X
CO_2 Acceptor		X			X	X	X			X
* BI Gas	X				X	X	X		X	
SRC	X			X		X			----	Liquid feed
* Synthane	X			X		X			X	
Synthoil	X			X		X			----	Liquid feed

* Minimum subset

This neglects the other aspects of feeder/process interactions which would be reflected in economic impacts. A further simplification may be obtained if size and pressure are cataloged in a limited number of discrete classifications. The processes are so classified in Table 3-14 in anticipation of the preparation of a feeder/process compatibility matrix.

3. Feeder Applicability

The manner in which a feeder may impact a process through its actions on the coal being fed has been discussed. Those processes potentially most susceptible to these actions were also identified. The consequences of the effect of the feeder on the coal and the process may be expressed in terms of process design and performance which may, in turn, be translated into process economics. The economic impact of even small perturbations in process efficiency will be large since their effects accumulate over the long life of the plant.

In the absence of feeder performance measurements, an interim approach to assessing process impact has been taken in this preliminary evaluation. A feeder/process incompatibility matrix was developed. Those feeder/process combinations that result in an unreasonably large economic penalty were identified. The matrix is predicated on the following assumptions:

(1) All feeders except the heated screw have no effect on the size consist of the coal.

(2) All feeders except the standpipe ball conveyor and linear pocket feeder may be staged, if necessary, to achieve high pressures.

(3) Size comminution or reaggregation cannot be done economically at the high pressure (post-feeder) stage with present technology.

(4) Volatiles and char may be fed to the converter or introduced into the process at a suitable point without effect.

The incompatibility matrix based on these premises in presented in Table 3-15. The reason for the rejection of a feeder/process combination is indicated by a letter: "S" means that the size consist passed by the feeder is unsuitable for the converter; "P" means the feeder cannot meet the pressure requirement of the process. "+" intersections mark feeder/process combinations in which the feeder has no impact on the process (under the assumptions).

Table 3-14. Process Classification

Process	Size		Pressure					Remarks
	Lump	Pulver-ized	Atm.	150	500	1000	1500	
Hygas		X					X	
Lurgi	X				X			
Woodall-Duckham	X		X					
Cogas		X	X					
Texaco		X			X			
U-Gas		X			X			
AFBC		X	X					
SRC		X				X		Slurry feed
H-Coal		X						2250-2700 psi, slurry feed
Exxon Donner Solvent		X						2000 psi, slurry feed
Bigas		X					X	Slurry feed
Synthane		X				X		
Mcdowell-Wellman	X				X			
Agglomeration Burner		X		X				
CO_2 Acceptor		X		X				
Synthoil		X						2-4000 psi, Slurry feed
AI Molten Salt		X		X				

Table 3-15. Feeder/Process Combinations

Feed System	Process							
	Lump			Pulverized				
	Atm	150	500	Atm	150	500	1000	1500
Positive Displacement Feeder	S	S	S	+	+	+	+	+
Centrifugal Feeder	S	S	S	+	+	+	+	+
Linear Pocket Feeder	+	+	+	+	+	+	P	P
Screw Feeder								
Heated	+	+	+	+	S	S	S	S
Unheated	+	+	+	+	+	+	+	+
Single Acting Piston Feeder	+	+	+	+	+	+	+	+
Rotary Valve Piston Feeder	+	+	+	+	+	+	+	+
Kinetic Extruder Feeder	S	S	S	+	+	+	+	+
Standpipe Ball Conveyor Feeder	S	S	S	+	+	P	P	P
Fluid Dynamic Lock Feeder	S	S	S	+	+	+	+	+
Gas-Solids Injector Feeder	S	S	S	+	+	+	+	+
Lockhopper	+	+	+	+	+	+	+	+
Slurry Pump	S	S	S	+	+	+	+	+

+ – Compatible feeder/process combinations

S – Incompatible feeder/process combinations. Feeder cannot provide required coal size consist

P – Incompatible feeder/process combinations Feeder cannot feed to required process pressure.

C. COST ANALYSIS

1. Methodology

Previous sections have reviewed the technical feasibility and applicability of the feed systems for use with various coal conversion processes. The foundation for the feed system evaluation and the starting point for the selection of feeders for future development is a cost analysis which takes into account the following factors:

(1) Life cycle cost savings relative to baseline systems, ΔC. Life cycle costs are determined from capital, installation, operation, and maintenance costs and include consideration of the technical and performance factors illustrated in Figure 2-1. ΔC is the difference between the baseline system life cycle cost and the life cycle cost of the feeder of interest. A large ΔC indicates a high probability that the feed system will cost less than the baseline system.

(2) Applicability of feed systems to coal conversion processes. The applicability of a feed system is determined by the total life cycle cost savings resulting from application of the feed system set to the selected process set, $\Sigma\Delta C$. The best prediction of applicability would result if the actual processes and their numbers could be projected and feeders applied to them. It was not possible to do this. Instead, the generic set of processes given in Table 3-14, equally weighted, was used. A high value for $\Sigma\Delta C$, therefore, indicates that the feed system has a combined high probability of costing less than baseline systems. In the analysis, sets of feeders were selected which satisfied all of the process requirements. In these cases $\Sigma\Delta C$ indicates the life cycle cost savings for the set of feeders, and the highest value indicates the set of feed systems which would most likely provide the largest life cycle cost savings compared to the baseline systems.

(3) Development cost, C_D. Relative development costs were estimated for each feed system, based on machine complexity and development risk.

(4) Development cost leverage, $L = \Sigma\Delta C/C_D$. For a set of feeders that meets all the process requirements, a large development cost leverage will indicate a potentially large life cycle cost saving for the development cost invested.

The cost analysis of the feed systems consisted of estimating capital, operating, and maintenance costs from cost data provided by the contractors and, independently, by Icarus Corporation. Relative development costs for the feed system were estimated by JPL. Life cycle costs, $\Sigma\Delta C$, and L were determined for the generic process set and for each process type of the set.

2. Feed System Capital, Installation, Operating, and Maintenance Costs

Capital, installation, operating, and maintenance costs were provided by the three contractors. The initial data provided is given in Appendix A. These data were modified and upgraded through subsequent discussions between JPL and the contractors. In addition, Icarus Corporation provided an independent estimate of the feed system capital costs (Ref. 2). The cost estimates from the various sources were reconciled by JPL for use in the cost analysis.

a. Candidate Feed System Costs, Modified From Contractor Supplied Costs. The three contractors supplied costing data for 11 different feed system types. The costs were provided for 1500 psi, 1000 psi, 500 psi, and 150 psi gasification plants with throughputs of 625 tons/hour (TPH). The following assumptions were made: labor costs, \$20/hr; utility costs, \$0.025/kWh and \$2.50/10^6 Btu; a 90% operating factor (330 days/year); and three gasifier trains, each receiving 210 TPH dry coal. The costing data submitted included the erected feeder capital costs and yearly operational and maintenance costs broken down into utilities, labor, and materials. Feeder capital costs also included the auxiliary equipment required to support feeder operation, assuming the system boundaries to extend from feed hoppers (input) to high pressure storage bins (output) for the gasifiers. Cost summaries are given in Tables 3-16 through 3-19.

Both Foster-Miller Associates (FMA) and Ingersoll-Rand (IR) supplied costing data based upon 1977 dollars and 625 TPH plant throughputs. The IR utility costs were based upon \$0.020 per kWh and were multiplied by a factor of 1.25 so that they would be normalized to the \$0.025 per kWh rate. It should also be noted that energy for heating the coal for the heated screw feeder was assumed to be available at no cost (to the feeder) from plant process power generation. (The validity of this assumption should be subjected to further analysis in the future.)

Since the IR data was received on a "per feeder" basis, the capital, utility, and maintenance costs were multiplied by the number of feeders (12) to obtain total plant costs. The capital costs originally included a "spare parts" cost and an extrudate breakup device assigned to each screw feeder. The "spare parts" item was eliminated from each feeders' capital costs as this item was not considered independently by the other contractors. Also, the assumption of 12 extrudate breakup devices per plant for screw feeders was unrealistic and IR later modified the capital costs of these feeders by assuming two larger breakup devices per plant. The cost of the two devices was equally divided on a per-feeder basis for the screw designs. Operating labor was also costed on a per-feeder basis and was modified by IR to 2 man-years per plant for each feeder design.

The Lockheed Phase I report (Ref. 4) was used as the baseline for establishing costs for the Lockheed feeder designs. This report did not match the other contractor data in the areas of current dollars, throughput (limited to 50 TPH), and pressures (it only included 150 psi and 1500 psi).

Table 3-16. Cost ($1,000 1977 Dollars) Summary for Commercial Plant: 625 TPH Throughput/150 Psi Pressure

Feeder	R&D	Installed	Operating		Maintenance		Number of Banks	TPH/ Bank	Stage/ Bank	No. Feeders
			Labor	Utility	Labor[a]	Mat'l				
Foster Miller										
Positive Displacement		5,740	240	75	14.4	250	9	70	14[b]	126[b]
Linear Pocket		2,151	250	240	15	150	9	70	1	9
Centrifugal		1,971[c]	160	138	15	36	3	210	1	3
Ingersoll-Rand										
Heated Screw		5,533	350	1,180	605	573	12	52	1	12
Cold Screw		4,646	350	1,180	605	481	12	52	1	12
Single Acting Piston		4,210	350	89	605	435	12	52	1	12
Rotary Valve Piston		2,835	350	89	605	293	12	52	1	12
Lockheed										
Kinetic Extruder		4,864[c]	240	182	39	447	6	104	1	6
Standpipe Ball		11,520	350	383	230	922	6	104	1	6
Fluid Dynamic Lock		13,360	240	2,479	120	1,216	6	104	4	24
Injector		7,931	240	2,043	32	761	3	210	2	6
Lockhopper		4,080	350	271	147	98	6	104	1	6
Slurry Pump		4,675	350	7,642	168	112	6	104	1	6

(a) FMA-supplied labor costs appear low in comparison to those of other contractors.

(b) Number of cylinders per bank and feeder.

(c) Based on contractor-supplied data, one stage assumed for centrifugal feeder and two stages for kinetic extruder.

Table 3-17. Cost ($1,000 1977 Dollars) Summary for Commercial Plant: 625 TPH Throughput/500 psi Pressure

Feeder	R&D	Installed	Operating		Maintenance		Number of Banks	TPH/ Bank	Stage/ Bank	No. Feeders
			Labor[a]	Utility	Labor	Mat'l				
Foster Miller										
Positive Displacement		6,820	240	240	17	340	9	70	14[b]	126[b]
Linear Pocket		2,150	250	833	15	150	9	70	1	9
Centrifugal		2,358[c]	160	405	15	40	3	210	1	3
Ingersoll-Rand										
Heated Screw		6,577	350	1,593	605	680	12	52	1	12
Cold Screw		5,690	350	1,593	605	589	12	52	1	12
Single Acting Piston		5,613	350	295	605	589	12	52	1	12
Rotary Valve Piston		4,033	350	295	605	391	12	52	1	12
Lockheed										
Kinetic Extruder		6,043[c]	240	456	49	556	6	104	1	6
Standpipe Ball										
Fluid Dynamic Lock		17,344	350	4,185	156	1,578	6	104	6	36
Injector		9,632	240	2,859	39	925	3	210	4	12
Lockheed		5,316	350	1,355	191	128	6	104	1	6
Slurry		4,791	350	7,976	172	114	6	104	1	6

(a) FMA-supplied labor costs appear low in comparison to those of other contractors.

(b) Number of cylinders per bank and feeder.

(c) Based on contractor-supplied data, one stage assumed for centrifugal feeder and two stages for kinetic extruder.

Table 3-18. Cost ($1,000 1977 Dollars) Summary for Commercial Plant: 625 TPH Throughput/1000 psi Pressure

Feeder	R&D	Installed	Operating		Maintenace		Number of Banks	TPH/ Bank	Stage/ Bank	No. Feeders
			Labor	Utility	Labor[a]	Mat'l				
Foster Miller										
Positive Displacement		8,140	240	851	17	343	9	70	14[b]	126[b]
Linear Pocket										
Centrifugal		3,355[c]	160	788	15	178	3	210	1	3
Ingersoll-Rand										
Heated Screw		8,561	350	2,154	605	886	12	52	1	12
Cold Screw		8,053	350	2,154	605	833	12	52	1	12
Single Acting Piston		8,419	350	591	605	871	12	52	1	12
Rotary Valve Piston		5,670	350	591	605	587	12	52	1	12
Lockheed										
Kinetic Extruder		7,727[c]	240	848	64	711	6	104	1	6
Standpipe Ball										
Fluid Dynamic Lock		23,039	350	6,622	207	2,097	6	104	7	42
Injector		12,062	240	4,025	48	1,158	3	210	6	18
Lockhopper		7,074	350	3,388	255	170	6	104	1	6
Slurry		4,912	350	8,603	177	118	6	104	1	6

(a) FMA-supplied labor costs appear low in comparison to those of other contractors.

(b) Number of cylinders per bank and feeder.

(c) Based on contractor-supplied data, one stage assumed for centrifugal feeder and two stages for kinetic extruder.

Table 3-19. Cost ($1,000 1977 Dollars) Summary for Commercial Plant: 625 TPH Throughput/1500 psi Pressure

Feeder	R&D	Installed	Operating		Maintenance		Number of Banks	TPH/ Bank	Stage/ Bank	No. Feeders
			Labor	Utility	Labor[a]	Mat'l				
Foster Miller										
Positive Displacement		8,140	240	851	17	343	9	70	14[b]	126[b]
Linear Pocket										
Centrifugal		3,355[c]	160	788	15	178	3	210	1	3
Ingersoll-Rand										
Heated Screw		11,077	350	2,950	605	1,146	12	52	1	12
Cold Screw		11,074	350	2,950	605	1,146	12	52	1	12
Single Acting Piston		13,217	350	886	605	1,452	12	52	1	12
Rotary Valve Piston		9,450	350	886	605	816	12	52	1	12
Lockheed										
Kinetic Extruder		9,409[c]	350	1,239	75	866	6	104	2	12
Standpipe Ball										
Fluid Dynamic Lock		28,728	350	9,060	259	2,614	6	104	7	42
Injector		14,250	350	5,191	57	1,368	3	210	7	21
Lockhopper		8,771	350	6,030	316	211	6	104	1	6
Slurry		5,797	350	8,928	209	139	6	104	1	6

(a) FMA-supplied labor costs appear low in comparison to those of other contractors.
(b) Number of cylinders per bank and feeder.
(c) Based on contractor-supplied data, one stage assumed for centrifugal feeder and two stages for kinetic extruder.

Since the Phase I report included costing in 1975 dollars, a factor of 1/0.89 was used to upgrade costs to 1977 dollars. Relative to the required 625 TPH throughput, the costing was modified by a scaling law commonly used for estimating chemical process plant costs. The scaling formula is

$$C_N = CR^X$$

where

C_N = plant cost to be determined

C = known plant cost

R = new capacity/old capacity

X = 0.6

For the Lockheed data the costing factor is

$$C_N = C \left(\frac{625\ \text{TPH}}{50\ \text{TPH}}\right)^{0.6} = C\ 4.55$$

Therefore, Lockheed's erected capital costs were determined by multiplying the 50 TPH costs by 4.55 to account for the increased throughput of 625 TPH. Costs for maintenance, labor, and materials at the 625 TPH rate were assumed to have the same ratio, relative to the capital costs, as was indicated for the 50 TPH rates.

Operating labor, which was previously at a 3/4 man-year figure for the 50 TPH throughput rate, was increased to a 2 man-year annual rate. Utility costs were increased on the basis of the number of feeder trains (or feeder banks) per plant. In the case of the kinetic extruder, fluid dynamic lock, and ball conveyor, Lockheed assumed that each feeder train would deliver 104 TPH to a gasifier. Therefore, six feeder trains would be required per plant to fulfill the 625 TPH feed rate. Since the Phase I report was limited to 50 TPH feed rates for each feeder train, the 104 TPH rate represented double capacity. It was assumed the increased capacity would be obtained by a larger configuration and a 20% increase in power requirements. Therefore, the 50 TPH utility costs in the Phase I report were increased by a factor of 7.2 to obtain plant costs. The injector required only three feeder trains delivering 210 TPH as this design was more adaptable to increased throughput. Consequently, the utility costs were increased by a factor of 3.6 to obtain plant costs. Capital cost figures for 500 psi and 1000 psi reactor pressures were determined by ratioing the various equipment costs relative to the Lockheed costs for 150 psi and 1500 psi.

b. Baseline Feed System Costs. Lockhopper and slurry pump baseline costs were derived from the Lockheed Phase I report. As with the Lockheed designs, the lockhopper and slurry pump costs were modified to account for the increased throughput from 50 TPH to 625 TPH.

Erected costs for 1500 psi were obtained by multiplying the Phase I costs by 4.55, while the maintenance, labor, and materials costs were based upon a factor of 6% of the capital cost. Within this maintenance cost figure, 60% was labor and 40% was materials (Ref. 5). The erected costs for other pressures were assumed to follow cost reductions typical of pumps and pressure vessels. For the intermediate pressures, the following multipliers were used to modify the 1500 psi costs:

Erected Capital Cost Multipliers vs Pressure

	150 psi	500 psi	1000 psi
Lockhopper	0.47	0.61	0.81
Slurry pump	0.81	0.83	0.85

Operational labor was increased to a 2 man-year rate from the 3/4 man-year rate for the 50 TPH process. Since utility costs for the lockhopper are reflective of work required to deliver compressed gas, the costs for lower pressures were based upon curves for work required as a function of delivery pressure (Ref. 4). The lockhopper utility costs were reduced proportionately as reflected by this curve. The slurry pump utility costs at lower reactor pressures were ratioed down linearly with pressure except for the evaporation of the water which remained constant at all pressure levels.

The lockhopper and slurry pump costs are also summarized in Tables 3-16 through 3-19.

c. Costs Provided by Icarus Corporation. Icarus Corporation, under subcontract to JPL, provided an independent assessment of the feed systems' purchase and installed costs and utility requirements (Ref. 3). Table 3-20 shows a comparison of the contractor-supplied installed cost data and the Icarus data. Note that the data are in good agreement, typically within about 35%. In the case of the heated screw and injector the design assumptions of Icarus require review to assess the validity of the costs provided.

3. Development Costs

a. Introduction. The research and development costs for mechanical feeder equipment will depend largely on the amount of the technological advancement required for the particular application. Coal feeders included in this evaluation vary diversely in terms of operational concepts

Table 3-20. Comparison of Contractor-Supplied and Icarus Corp. Feed System Installed Costs (1500 psi, 625 TPH)

Feed System	Contractor-Supplied Costs (million $)	Icarus-Supplied Costs (Million $)	Average Costs (Million $)	Per Cent Difference From Average Costs
Positive Displacement	8.1	9.8	9.0 ± 0.9	10
Linear Pocket	2.2(1)	4.6	3.4 ± 12	35
Centrifugal	3.4	10.6(2) (5.6)	4.5 ± 1.0	24
Heated Screw	11.1	58.7(3)	-	-
Unheated Screw	11.1	6.0	8.6 ± 2.6	30
Single Acting Piston	13.2	26.9	20.1 ± 6.8	34
Rotary Valve Piston	9.4	14.0	11.7 ± 2.3	20
Kinetic Extruder	9.4(5)	4.7	7.1 ± 2.3	32
Standpipe Ball	11.5(4)	16.5	14.0 ± 2.5	18
Fluid Dynamic Leak	28.7	8.1(3)	18.4 ± 10.3	56
Injector	14.2	342.7(3)	-	-
Lockhopper	8.8	12.5	10.7 ± 1.8	17
Slurry Pump	5.8	2.9	4.4 ± 1.5	34

(1) 500 psi

(2) Review of design assumption suggests revision to $5.6 million

(3) Design assumptions require review to assess validity of costs

(4) 150 psi

(5) Two stages assumed

and development status. Some are only paper concepts while others have already been brought to a pilot plant scale of development. Considering diversity of concept and development status, a simplified method is advocated for this evaluation. It will be shown that development costs can best be represented as a function of installed hardware or equipment costs.

b. Method. To provide a common denominator for the development costs, the phase costs can be summed to arrive at the total feeder development costs:

$$C = \sum_{i=1}^{n} C_{\phi_i} = C_{\phi_I} + C_{\phi_{II}} + \cdots + C_{\phi_n}$$

where

C_{ϕ_i} is the i^{th} phase cost.

The development costs will be due to three major factors: (1) hardware, (2) manpower, which includes design and test time manpower, and (3) facilities costs.

Most of the facilities-related costs, with the possible exception of architectural services and structures, such as foundations, holding tanks, support structure, etc., have already been included in the contractor generated capital equipment costs. In addition, if one uses the "erected" or "installed" equipment costs, which were calculated by multiplying equipment costs by 1.5, then one has facility and hardware costs combined.

The manpower costs can be correlated with the combined facility and hardware costs by using a modulating factor which is based on machine complexity and development risks. This factor would adjust for the increased design and development time required for the higher risk and more complex machines. The phase cost, C_{ϕ_i}, is then the sum of the "erected equipment" and modulated manpower costs.

$$C_{\phi_i} = (1 + X)\, C_E$$

where

C_E = erected equipment cost

X = modulating factor, product of machine complexity and risk

For purposes of this evaluation, we can categorize the feeders into three classes of complexity, simple, average or complex; and two risk classes, high or low. If we arbitrarily assign a numerical value for complexity on a scale of, say, 1 through 3, and 1 and 2 for low and high development uncertainty, then multiply the product of these by the erected equipment costs, we in a sense have manpower costs. Although the absolute value of this cost may be an order of magnitude different than the real value, which is unknown, it is still a reasonable relative representation and differentiation is made between the feeders with regard to risk and complexity. The machine complexity, although somewhat subjective, was arrived at by considering the number of moving parts, tolerances, and auxiliary equipment. The risks were based on state of development, operational concept, and scaleability. Table 3-21 lists the feeders and their assigned complexities and risks.

The total research and development costs for a particular feeder can then be calculated using the relationship

$$C = (1 + X) \quad (C_{\phi_I} + C_{\phi_{II}} + \ldots + C_{\phi_n})$$

where C_{ϕ_n} is the cost of the n^{th} phase, which, as stated before, can be represented by the "erected equipment" cost for that phase. In the summing of phase costs, constant dollars were assumed.

For those feeders where available equipment cost data are limited to a particular scale (relates to a phase) the Peters and Timmerhaus chemical process plant scaling rule can be used to determine costs for other scales, or phases:

$$\frac{C_n}{C} = \left(\frac{Sn}{S}\right)^{0.6}$$

where C_n and Sn are the costs of the equipment scaled up or down to some different capacity Sn. (This is the same relationship as that used to scale installed costs.)

Although Phase I, some Phase II, and even some Phase III development costs have already been incurred, it is felt that it would be unfair to use these since we do not know how to treat the uncertainties associated with those feeders which have not progressed to a like stage of development. The estimated development costs, listed in Table 3-22, considered only the pilot Phase III and demonstration Phase IV costs as previously discussed.

Table 3-21. Coal Feeder Development Assessment

Feeder	Development Status	Scaleability	Machine Complexity*	Development Risk
Ball Conveyor	Bench Tests	Poor	C	High
Kinetic Extruder	Proto in Test	Poor	S	High
Fluid Dynamic Lock	Proto in Test	Poor	S	High
Jet Pump	Proto in Test	Good	S	Low
Centrifugal	Proto in Test	Poor	S	High
Positive Displacement Piston	Proto in Test	Good	A	Low
Linear Pocket Feeder	Proto being assembled	Good	C	Low
Screw	Proto/Pilot Sizes in Test	Poor	S	Low
Single Acting Piston	Paper Concept	Good	A	Low
Rotating Piston	Paper Concept	Good	A	Low

*S - Simple
A - Average
C - Complex

Table 3-22. Estimated Feed System Development Costs

Feed System	Relative Development Costs (Million $)		
	Phase III	Phase IV	Total[1]
Positive Displacement Feeder	1.3	8.3	8.0
Centrifugal Feeder	0.6	2.2	2.3
Linear Pocket Feeder	0.5	1.4	1.6
Screw Feeder	1.5	6.1 (heated) 5.8 (unheated)	6.4 6.1
Single Acting Piston Feeder	2.2	8.7	9.1
Rotary Valve Piston Feeder	1.6	6.2	6.5
Kinetic Extruder	1.4	5.5	5.8
Standpipe Ball Conveyor	4.0	15.7	16.5
Fluid Dynamic Lock Feeder[2]	4.2	16.8	17.6
Gas-Solids Injector[2]	1.4	5.6	5.8

(1) Constant dollars at beginning of Phase III

(2) Staged systems

4. Cost Analysis Results

Using the capital, installation, operating, and maintenance costs given in Tables 3-16 through 3-19, life cycle costs were calculated for each feed system. Cost savings, ΔC, for individual feeders and feeder sets compared with the baseline were determined. The sum of the cost savings applied to the process set, $\Sigma\Delta C$, and the cost leverage function, $L = \frac{\Sigma\Delta C}{C_D}$, were also determined. Table 3-23 shows these values for the feeder sets. The table lists the highest ranking sets consisting of up to four feeders. A total of 2047 sets may be formed by combining the 11 candidate feeders.

Review of Table 3-23 shows that the combination of the linear pocket feeder (for feeding lower pressures and lump coal) and the centrifugal feeder (for feeding fine coal) is best, based on the cost data used. Both of the systems are being developed by Foster-Miller Associates, whose cost estimates are judged to be optimistic compared with the other contractors. For example, the kinetic extruder, being developed by Lockheed, is essentially the same concept as the centrifugal pump, yet Lockheed's design and costs are more conservative. If it is assumed that the difference in costs between the centrifugal feeder and the kinetic extruder are representative of the errors in the cost data, then the following feeder sets can be considered to promise the maximum cost savings for application to the generic processes:

(1) Linear pocket/centrifugal.

(2) Rotary valve piston/centrifugal.

(3) Linear pocket/kinetic extruder.

(4) Linear pocket/rotary valve piston.

(5) Rotary valve piston.

These five feeder sets are combinations of just three feeders. These three feeders are recommended for further development:

(1) Linear pocket.

(2) Centrifugal or kinetic extruder.

(3) Rotary valve piston.

D. PROGRAMMATIC RISK REDUCTION

1.. Phases of Development

The phases of development are component, pilot, and demonstration. Goals during these phases are roughly categorized in Table 3-24.

Table 3-23. Feeder Cost Parameters

Feeder Sets*	C_D	$\Sigma\Delta$	L
One Member			
Rotary	6.52	22.75	3.48
Piston	9.12	11.53	1.26
U Screw	6.05	-15.98	- 2.64
Two Member			
Pocket, Centrifugal	3.93	40.17	10.19
Centrifugal, Rotary	8.85	35.55	4.01
Pocket, Extruder	7.38	29.42	3.98
Pocket, Pump	9.60	38.05	3.96
Pocket, Rotary	8.13	31.99	3.93
Centrifugal, Piston	11.45	33.19	2.89
Pos. Dis., Rotary	14.52	32.96	2.27
Pos. Dis., Piston	17.12	31.95	1.86
Three Member			
Pocket, Centrifugal, U Screw	9.27	40.17	4.33
Pocket, Centrifugal, Piston	12.35	40.17	3.85
Pocket, Centrifugal, Rotary	10.46	40.17	3.83
Pocket, Centrifugal, Pos. Dis.	11.93	40.84	3.42
Pocket, Extruder, Pos. Dis.	15.38	38.05	2.47
Four Member			
Pocket, Centrifugal, U Screw, Rotary	10.51	40.17	2.43
Pocket, Centrifugal, Piston, Rotary	19.59	40.17	2.05

*Definitions

Pos. Dis. - Positive displacement
Centrifugal - Centrifugal
Pocket - Linear pocket
U Screw - Unheated screw
H Screw - Heated screw
Piston - Single acting piston
Rotary - Rotary valve piston
Extruder - Kinetic extruder
Lock - Fluid dynamic lock
Ball - Standpipe-ball conveyor
Injector - Gas-solids injector

Table 3-24. Development Phase Goals

A = Major Objective
B = Minor Objective
C = Consideration Only

Goal \ Phase	Component	Pilot	Demonstration
1. Design	A		
Conceptual	A		
Detailed	A		
2. Technical Feasibility	A		
Function	A		
Life (stress, wear, etc.)	A		
3. Operational Feasibility	A/B	A	
System Function	A/B	A	
Process Compatibility Reliability	A/B	A	
Sealing	A/B	A	
4. Commercial Feasibility	B/C		A
Lifetime	B/C	A/B	A
Maintenance Task	B/C	A/B	A
Operating Costs	B/C	A/B	A
Capital Costs	B/C	A/B	A

2. Risk of Development

The development program should identify and solve critical functional or life problems in the component design phase such that major problems can be solved with small scale hardware and less expensive testing.

The component and pilot phases will reduce development risk early, leaving the final phase with the objective of demonstrating machine life, and defining maintenance operating and capital costs (see Figure 3-1).

3. Selection of Feeder Options for Continued Development

Considerations which apply to the selection of feeder options include

(1) Feeders selected must, singly or as a group, cover the range of pressure and coal size range requirements; i.e., function must be met.

(2) Development of a sufficient number of feeder concepts must be continued to assure that successful units reach commercialization.

(3) Potentially low life cycle cost feeders can pay off highly if commercialized; therefore, estimated high R&D cost or risk may be easily offset by future life cycle cost savings.

(4) ERDA R&D budget constraints must be met.

a. Item (1), Function. This consideration was accounted for in the applicability of the feeders to the process (Section III-B) and in the cost analysis (Section III-C).

b. Item (2), Parallel Development. The risk of not having a feeder successfully developed to be functionally and economically acceptable can be reduced by continuing the parallel development of several options. The increased probability of success is shown by the following hypothetical example:

(1) "Feeder Sets"

Case I — Feeder A can work with all required coal sizes and pressures.

Case II — Feeder B + C can work with all required coal sizes and pressures.

Case III — Feeder B + D can work with all required coal sizes and pressures.

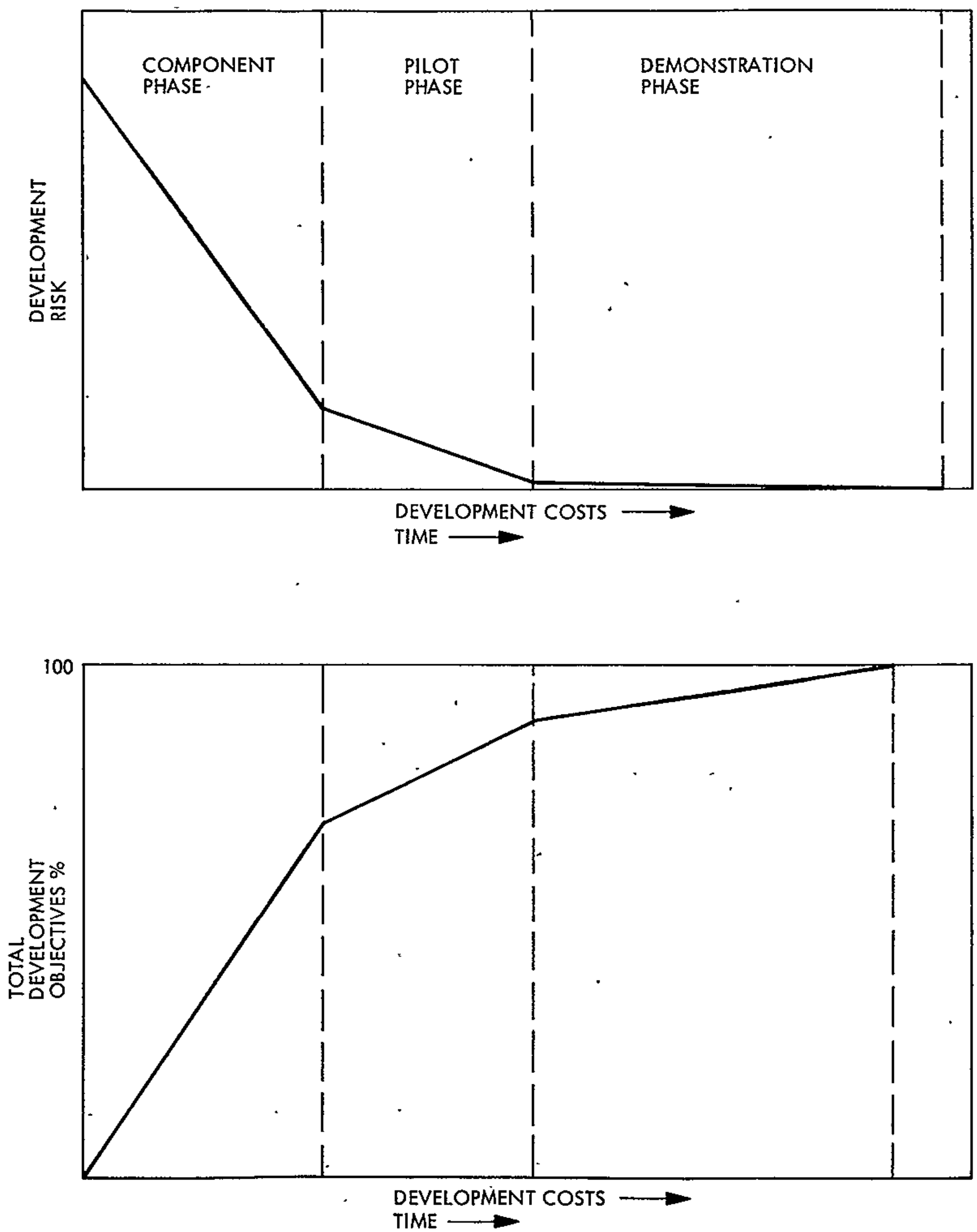

Figure 3-1. Development Risk Reduction

(2) What is the probability of success of each feeder set? Let component phase probability of success be 0.70 for each case. Let pilot phase probability of success be 0.90 for each case.

The probability of success is shown by Figure 3-2. Depending upon what the actual probabilities of success are, it would appear that parallel development of at least two feeder sets should be undertaken; and, if possible within the available development budget, continuing three parallel efforts through the pilot phase is recommended.

c. Item (3), Potential Life Cycle Cost Savings Compared to Development Cost Investments. The analysis thus far has considered only application of the feeders to generic process types. It has not considered potential future numbers of process plants and feeders to be installed. If this feeder market were considered it could be shown that even small differences in feeder life cycle costs could magnify into large cost savings, if the best feeder were developed. These life cycle cost savings could be orders of magnitude larger than the development costs for the component and pilot scale developments, which are the primary phases that improve the probability of successful developmen Therefore, from an investment point of view it is desirable to invest the added development costs early in the development program in parallel developments so that potentially low cost systems are not prematurely eliminated.

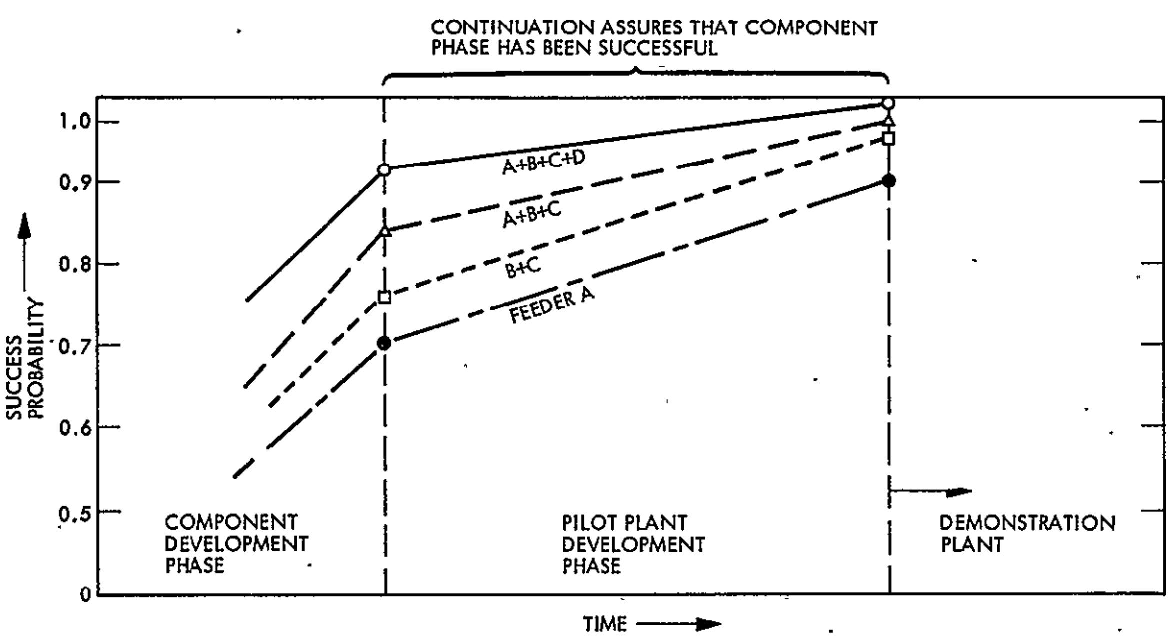

Figure 3-2. Example of Increased Probability of Success Through Parallel Development

d. <u>Item (4), Development Costs Limitations</u>. It is recognized that ERDA has development cost limitations for the feeder development program. The previous discussion has indicated the value of parallel development. Parallel development of two sets of feeders is essential at this stage of the program and it is recommended that three be so developed. The cost of adding a third set would be in the range of $5 to $10 million.

4. Feeder Sets Recommended as a Result of Programmatic Risk Reduction Considerations

Figure 3-3 illustrates the effect of undertaking parallel developmen The figure shows the cost saving, $\Sigma\Delta C$, and leverage, L, parameters as a function of development cost. Note that the centrifugal and linear pocket feeder set has the highest value for L. This, as stated previously was the reason for its selection on a cost basis. Notice also that the leverage function, L, decreases for all other feeder sets and for parallel development of feeder sets. This decrease in L results because the cost savings, $\Sigma\Delta C$, does not increase as rapidly as the development costs as parallel feeder developments are undertaken.

Also shown in the figure is the probability of successful commercial development (realizability, R) for the feeder sets. The values for R are taken from the estimates of probability for successful feeder development given in Section III-A-1-c. Note that the rotary valve piston has a higher value for R than the combination of centrifugal and linear pocket feeders. The combination of all three of these feeders, taken together, representing two parallel development sets, has an even higher value of R, but it is questionable that these two sets will give adequate assurance of commercialization. A third set, based on maximizing $\Sigma\Delta C$, L, and R, results in the selection of the unheated screw feeder. As can be seen from the figure, this additional development will add to the development cost, but the probability of realizing commercialization now exceeds 98%.

The positive displacement feeder, if added to the above set, would only slightly increase the commercialization realizability, but would increase the development cost by about 30%. The additional cost for little gain, coupled with the feeder's projected unreliability, leads to the recommendation that development of the positive displacement feeder be discontinued, or be limited to the testing of the present system and concentrating on improving the system's reliability.

None of the other systems offer any additional cost or realizability advantage over (1) the three systems selected on the basis of low costs and (2) the unheated screw, selected to increase the probability of developing a commercially acceptable feeder.

Thus, feeder sets recommended for parallel development are

(1) Centrifugal (or kinetic extruder) and linear pocket.

(2) Rotary valve piston.

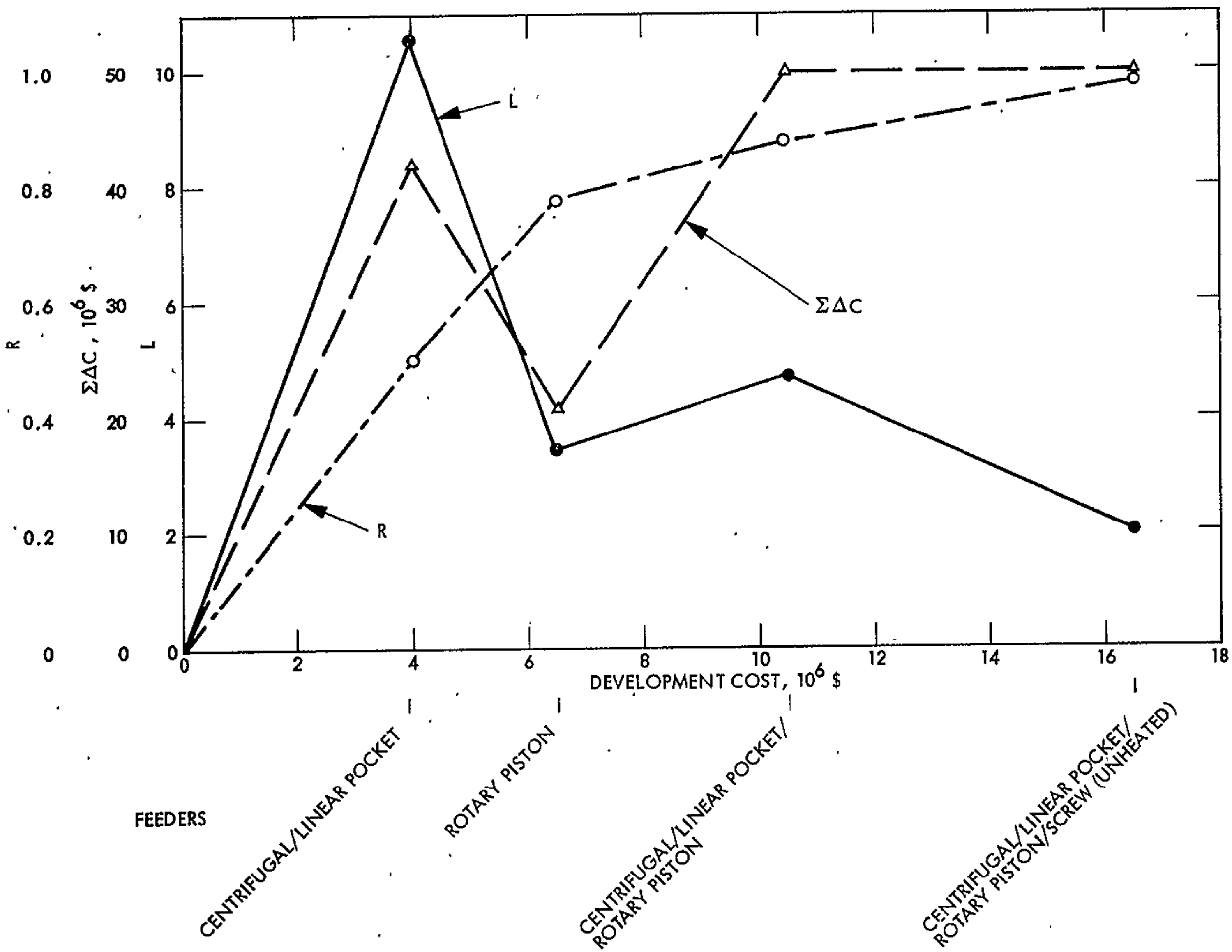

Figure 3-3. Feed System Selection Parameters

(3) Unheated screw.

E. REVIEW OF FEEDER SELECTIONS FOR SPECIFIC APPLICATIONS

The feeders selected on the basis of low cost and for parallel development were reviewed to determine if any other feeder should be selected for application to a specific process of the process set. No feeder, other than those previously selected, was found to produce increased cost savings or have any special attributes for the specific process applications considered. The gas-solids injector, however, may have application to low pressure processes or as a topping stage and should be considered for such applications.

F. REVIEW OF FEEDER SELECTIONS FOR TECHNICAL ADVANTAGES

From Table 3-3 it can be seen that the feeders previously selected include all of the feeders having high technical ranking. Because of the poor relative technical ranking of the other feeders, none of them are recommended for further development.

G. SENSITIVITY ANALYSIS

An analysis was conducted to determine the sensitivity of feeder selections to variations in the data base. This was done by repeating the cost study of Section III-C using

(1) The Icarus Corporation data for feeder unit installed costs and for utility costs.

(2) Standby feeders in the number recommended by Kaman Sciences to achieve 95% availability, Table 3-2.

(3) Operating cost savings creditable to the heated screw due to its utilization of coal fines which would otherwise be rejected.

A new data base was prepared incorporating all these factors, Tables 3-25 to 3-30. The cost/benefit parameters of various feeder sets were then calculated by the same methods employed to generate Table 3-23.

A total of 2,047 distinct sets can be formed from the 11 candidate feeders. The highest ranking of these sets, comprised of up to four feeders, are presented in Table 3-29. These results, derived from the new data base, may be compared with the results of Table 3-23 to determine the sensitivity of feeder set ranking to data extremes, Table 3-30. Comparison of the rankings reveals that, except for the single feeder set, the same feeder sets would be selected for development predicated on either data base. This inspires confidence in the recommendations and indicates that the selections are insensitive to the extremes in the available data.

Table 3-25. Cost ($1,000 1977 Dollars) Summary for Commercial Plant: 625 TPH Throughput/150 Psi Pressure/95% Availability

Feeder	R&D	Installed[a]	Operating		Maintenance		Number of Banks	TPH/ Bank	Stage/ Bank	No. Feeders
			Labor	Utility	Labor[b]					
Foster-Miller										
Positive Displacement		13,821[c]	240	197	14.4	250	9	70	14[d]	126[d]
Linear Pocket		7,660	250	187	15	150	9	70	1	9
Centrifugal		4,380	160	93	15	36	3	210	1	3
Ingersoll-Rand										
Heated Screw		9,447	350	20,337	605	573	12	52	1	12
Cold Screw		7,448	350	212	605	481	12	52	1	12
Single Acting Piston		6,315	350	472	605	435	12	52	1	12
Rotary Valve Piston		6,299	350	220	605	293	12	52	1	12
Lockheed										
Kinetic Extruder		5,359	240	146	39	447	6	104	1	6
Standpipe Ball		16,874	350	383	230	922	6	104	1	6
Fluid Dynamic Lock		7,534	240	130	120	1,216	6	104	4	24
Injector		257,075	240	249,619	32	761	3	210	2	6
Lockhopper		5,810	350	42	147	98	6	104	1	6
Slurry Pump		2,338	350	1,149	168	112	6	104	1	6

(a) Includes cost of backup feeders to achieve 95% availability.
(b) FMA-supplied labor costs appear low in comparison to those of other contractors.
(c) Three trains per gasifier were assumed for backup, which provides a 52% availability.
(d) Number of cylinders per bank and feeder.

Table 3-26. Cost ($1,000 1977 Dollars) Summary for Commercial Plant: 625 TPH Throughput/500 Psi Pressure/95% Availability

Feeder	R&D	Installed[a]	Operating		Maintenance		Number of Banks	TPH/ Bank	Stage/ Bank	No. Feeders
			Labor	Utility	Labor[b]	Mat'l				
Foster-Miller										
Positive Displacement		16,410[c]	240	631	17	340	9	70	14[d]	126[d]
Linear Pocket		7,660	250	648	15	150	9	70	1	9
Centrifugal		5,240	160	276	15	40	3	210	1	3
Ingersoll-Rand										
Heated Screw		11,229	350	20,412	605	680	12	52	1	12
Cold Screw		9,122	350	287	605	589	12	52	1	12
Single Acting Piston		8,419	350	1,564	605	589	12	52	1	12
Rotary Valve Piston		8,961	350	731	605	391	12	52	1	12
Lockheed										
Kinetic Extender		6,699	240	365	49	556	6	104	1	6
Standpipe Ball		7								
Fluid Dynamic Lock		9,780	350	219	156	1,578	6	104	6	36
Injector		312,211	240	349,320	39	925	3	210	4	12
Lockheed		7,576	350	208	191	128	6	104	1	6
Slurry		2,390	350	1,201	172	114	6	104	1	6

(a) Includes cost of backup feeders to achieve 95% availability.
(b) FMA-supplied labor costs appear low in comparison to those of other contractors.
(c) Three trains per gasifier were assumed for backup, which provides a 52% availability.
(d) Number of cylinders per bank and feeder.

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Table 3-27. Cost ($1,000 1977 Dollars) Summary for Commercial Plant: 625 TPH Throughput/1000 Psi Pressure/95% Availability

Feeder	R&D	Installed[a]	Operating		Maintenance		Number of Banks	TPH/ Bank	Stage/ Bank	No. Feeders
			Labor	Utility	Labor[b]	Mat'l				
Foster-Miller										
Positive Displacement		19,600[c]	240	2,237	17	343	9	70	14[d]	126[d]
Linear Pocket		7								
Centrifugal		7,460	160	537	15	178	3	210	1	3
Ingersoll-Rand										
Heated Screw		14,617	350	20,510	605	886	12	52	1	12
Cold Screw		12,911	350	385	605	833	12	52	1	12
Single Acting Piston		12,628	350	3,133	605	871	12	52	1	12
Rotary Valve Piston		12,597	350	1,464	605	587	12	52	1	12
Lockheed										
Kinetic Extruder		8,566	240	650	64	711	6	104	1	6
Standpipe Ball		7								
Fluid Dynamic Lock		12,991	350	346	207	2,097	6	104	7	42
Injector		410,426	240	491,785	48	1,158	3	210	6	18
Lockhopper		10,080	350	518	255	170	6	104	1	6
Slurry		2,450	350	1,293	177	118	6	104	1	6

(a) Includes cost of backup feeders to achieve 95% availability.
(b) FMA-supplied labor costs appear low in comparison to those of other contractors.
(c) Three trains per gasifier were assumed for backup, which provides a 52% availability.
(d) Number of cylinders per bank and feeder.

Table 3-28. Cost ($1,000 1977 Dollars) Summary for Commercial Plant: 625 TPH Throughput/1500 Psi Pressure/95% Availability

Feeder	R&D	Installed[a]	Operating		Maintenance		Number of Banks	TPH/ Bank	Stage/ Bank	No. Feeders
			Labor	Utility	Labor[b]	Mat'l				
Foster-Miller										
Positive Displacement		19,600[c]	240	2,237	17	343	9	70	14[d]	126[d]
Linear Pocket		7								
Centrifugal		7,460	160	537	15	178	3	210	1	3
Ingersoll-Rand										
Heated Screw		18,913	350	20,655	605	1,146	12	52	1	12
Cold Screw		17,755	350	530	605	1,146	12	52	1	12
Single Acting Piston		19,825	350	4,698	605	1,452	12	52	1	12
Rotary Valve Piston		20,996	350	2,195	605	816	12	52	1	12
Lockheed										
Kinetic Extruder		10,431	350	994	75	866	6	104	2	12
Standpipe Ball		7								
Fluid Dynamic Lock		16,200	350	422	259	2,614	6	104	7	42
Injector		461,900	350	634,250	57	1,368	3	210	7	21
Lockhopper		12,500	350	925	316	211	6	104	1	6
Slurry		2,900	350	1,343	209	139	6	104	1	6

(a) Includes cost of backup feeders to achieve 95% availability.
(b) FMA-supplied labor costs appear low in comparison to those of other contractors.
(c) Three trains per gasifier were assumed for backup, which provides a 52% availability.
(d) Number of cylinders per bank and feeder.

Table 3-29. Feeder Sensitivity Cost Parameters

Feeder Sets*	C_D	ΣΔC	L
One Member			
U Screw	6.12	-34.31	-5.60
Rotary	6.54	-36.03	-5.50
Piston	9.13	-60.34	-6.60
Two Member			
Pocket, Centrifugal	3.97	4.50	1.13
Centrifugal, Rotary	8.89	-1.35	-0.15
Centrifugal, U Screw	8.47	-3.22	-0.38
Centrifugal, Piston	11.48	-5.66	-0.49
Pocket, Extruder	7.40	-7.41	-1.00
Three Member			
Pocket, Centrifugal, U Screw	10.09	4.50	0.44
Pocket, Centrifugal, Rotary	10.51	4.50	0.42
Centrifugal, U Screw, Rotary	15.02	-1.35	-0.09
Centrifugal, U Screw, Piston	17.61	-2.63	-0.15
Pocket, U Screw, Extruder	13.52	-7.41	-0.54
Pocket, Rotary, Extruder	13.94	-7.41	-0.53
Four Member			
Pocket, Centrifugal, U Screw Rotary	16.63	4.50	0.27
Pocket, Centrifugal, Piston, Rotary	19.64	4.50	0.22
Pocket, Extruder, U Screw, Rotary	20.06	-7.41	-0.37
Pocket, Extruder, Piston, Rotary	23.07	-7.41	-0.32
Pocket, Lock, U Screw, Rotary	31.87	-18.34	-0.57
Eleven Member			
All	85.81	4.50	0.05

*Definitions

Pos. Dis. - Positive displacement
Centrifugal - Centrifugal
Pocket - Linear pocket
U Screw - Unheated screw
H Screw - Heated screw
Piston - Single acting piston
Rotary - Rotary valve piston
Extruder - Kinetic extruder
Lock - Fluid dynamic lock
Ball - Standpipe-ball conveyor
Injector - Gas-solids injector

Table 3-30. Highest Ranking Feeder Sets

Number of Set Members	Reconciled Data Tables 3-16 to 3-19	Sensitivity Data Tables 3-25 to 3-28
One	Rotary valve piston	Unheated screw
Two	Linear pocket Centrifugal	Linear pocket Centrifugal
Three	Linear pocket Centrifugal Unheated screw	Linear pocket Centrifugal Unheated screw
Four	Linear pocket Centrifugal Unheated screw Rotary valve piston	Linear pocket Centrifugal Unheated screw Rotary valve piston

H. RECOMMENDED SYSTEMS

As a result of the above analyses the following feed systems are recommended for further development:

(1) Foster-Miller centrifugal feeder or Lockheed kinetic extruder.

(2) Foster-Miller linear pocket feeder.

(3) Ingersoll-Rand rotary valve piston feeder.

(4) Ingersoll-Rand unheated screw feeder.

The recommended actions for each feeder and the basis for the recommendations are summarized in Table 3-31. The recommended development actions are described in more detail in the Coal Feed System Development Plan, JPL Document No. 5030-94. For all selected feeders the development uncertainty is high. Continued evaluation of the selected concepts is required and is reflected in the Development Plan.

Table 3-31. Recommended Coal Feed System Development Actions

Feed System	Recommended Action	Basis for Recommendation
Positive Displacement Feeder	Discontinue major development effort. Limited testing of available equipment and design analysis to verify cost and reliability assessment	• No cost advantage relative to selected systems • Serious reliability problems
Centrifugal/Kinetic Extruder Feeder	Continue component testing to verify concept functional capability, and pressure ratio potential(1)	• Potential low cost system for high pressure processes using fine coal. • System simplicity
Linear pocket feeder	Conduct pilot-scale development. Assess sealing, leakage and pressure capability. Verify coal metering to the pockets and water lock design(2)	• Potential low cost system for low pressure systems (to 500 psi) using fine to coarse coal
Screw Feeder	Conduct pilot scale development. Emphasize the unheated screw(3)	• Provides parallel development alternative to other recommended developments to increase probability of commercial feed system development. • One of only two feeders capable of meeting all process requirements (piston feeders are only in conceptual stage of development).
Single Acting Piston Feeder	Discontinue development efforts in favor of rotary piston feeder development	• Cost savings potential is not as great as rotary piston. Development problems may be easier, however.
Rotary Valve Piston Feeder	Conduct component development, emphasizing piston sealing and wear, solids loading and unloading to prevent jamming and system design to minimize power requirements	• Potential cost savings compared to baseline. • Potential application to all process requirements.
Standpipe Ball Conveyor Feeder	Discontinue development	• Complex. • Applicable only to low pressures (below 150 psi).
Fluid Dynamic Lock Feeder	Discontinue development	• Complex staging required to reach even 150 psi. • High cost compared to baseline systems.
Gas-Solids Injector Feeder	Discontinue development(4)	• Complex staging required to reach even 150 psi. • High cost compared to baseline systems.

(1) Because of development uncertainties parallel development efforts should be considered.
(2) Recommendation contingent on results of prototype testing.
(3) This system has questionable cost advantages. Requires application analysis during Phase III to determine best applications.
(4) This system should be analyzed for application to low pressure systems and topping stages.

REFERENCES

1. Williams, R. L., Stoddard, D. W., and Gateley, Failure Mode and Frequency Analysis of Candidate Coal Feeders, Kaman Sciences Corp. Report K77-42U(R), June 1, 1977.

2. Roig, R. W., Jogata, A., and Leggett, N., MPPM Study of Coal Feed Variations for Synthane and Lurgi Gasifiers for Jet Propulsion Laboratory, International Research and Technology Corp. Report 486-R, July 6, 1977.

3. Stanley, G. M., Estimated Costs of Coal Feeders, Icarus Corp. Letter Report to JPL, May 19, 1977.

4. Coal Feeder Development Program, Phase I Report, Lockheed Missiles and Space Co. FE 1792-8, December 24, 1975.

5. Skamser, R., Coal Gasification Commercial Concepts Gas Cost Guidelines, C. F. Braun and Co., FE-1235-1, January 1976.

APPENDIX A

COAL FEED SYSTEM DESCRIPTIONS

1. INTRODUCTION

The coal feed systems evaluated are characterized in the following sections. The feeders are being developed by three companies under contract to ERDA:

Foster-Miller Associates (FMA)

Ingersoll-Rand Research, Inc. (IR)

Lockheed Missiles and Space Corp. (LMSC)

The following information is included for each feeder:

(1) Feeder description.

(2) System features and ancillary equipment.

(3) Cost estimates.

(4) Coal type, size, and preparation limitations.

(5) Development considerations.

2. FOSTER-MILLER POSITIVE DISPLACEMENT FEEDER

a. Description

The positive displacement feeder is a cycled cavity feeder that raises the pressure in a single stage. The operation of the positive displacement feeder can be visualized by referring to the design presented in Figure A-1. This figure represents a likely design utilizing a hydraulically operated plunger, poppet valves throughout, and working on the pop-off cycle. Its operation is described as follows: With the plunger (1) at its outermost position (the position shown in the figure), the cylinder is filled with coal-gas mixture. All valves are closed, the inlet valve (2) seat is purged by gas prior to closure. The plunger starts to move in and when the volume of the mixture is reduced to the gas/solids volumetric fluidization ratio limit, the pressurizing valve (3) opens, filling the cylinder with gas through ports 3a and 3b. When the cylinder pressure exceeds the reactor pressure, the spring-loaded exhaust valve (4) opens and the coal, suspended in high pressure gas, is pushed into the gasifier. When the plunger stops at the innermost position, the dead volume is cleared of solids by gas flowing through the pressurizing ports and both the pressurizing and the exhaust valve close. Subsequently, the pop-off valve (5) opens, venting the clearance volume gas into an atmospheric receiver. The plunger starts to retract. The pop-off valve closes when cylinder

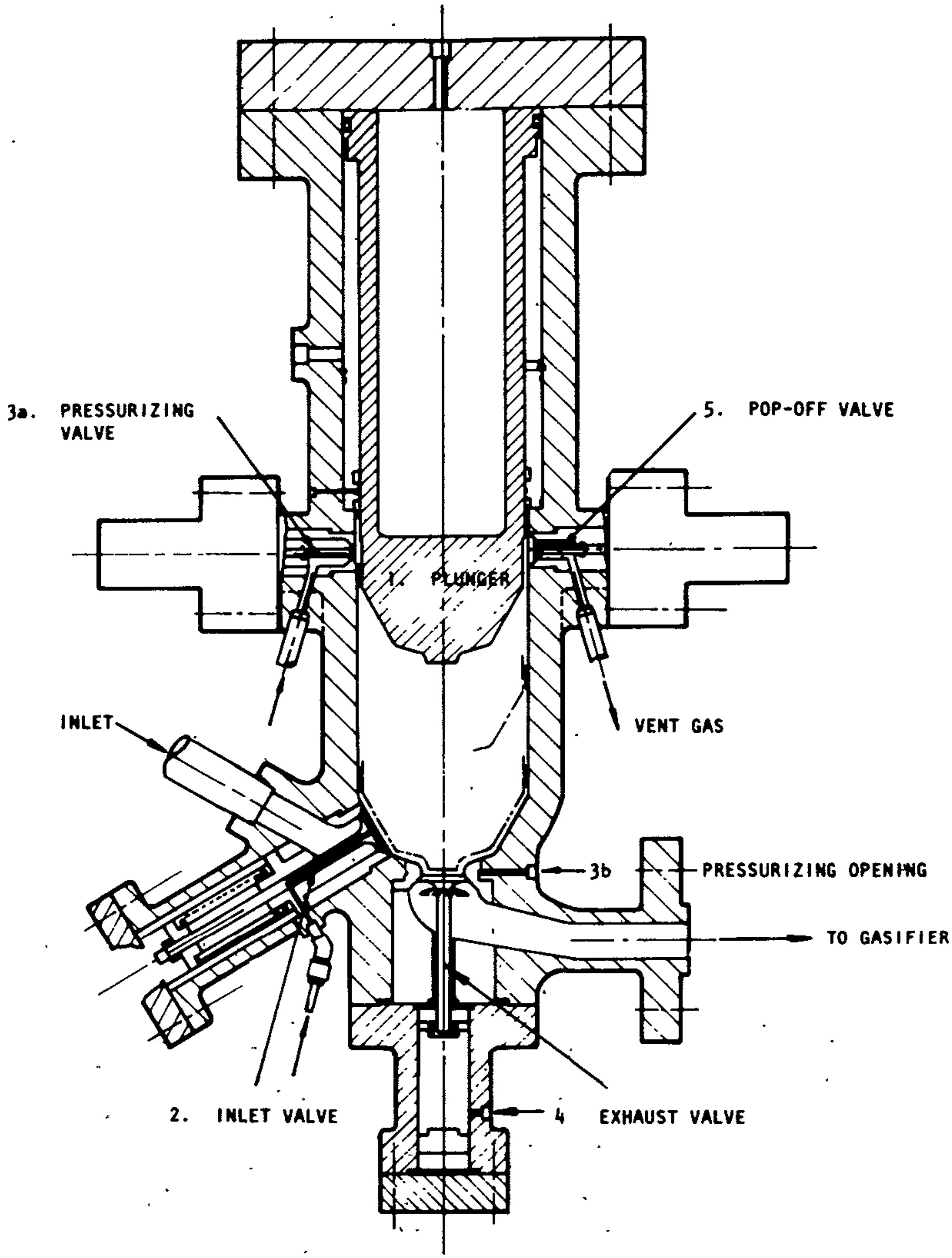

Figure A-1. Positive Displacement Feeder pressure drops to the inlet pressure level, and the inlet valve opens the passage from the storage bin into the cylinder. The inlet valve closes at the plunger's outermost position and the cycle repeats.

b. System Features and Ancillary Equipment

The size of a fluidized piston feeder is optimized on the bases of capital costs and utility costs and is limited by the sizes of valve ports, particularly the coal intake valves, and operating speed (cycle time). The following description of a feeder system is based on using one cylinder for up to 5 TPH and multiple cylinders with some common ancillary equipment for higher capacities. Only a single cylinder feeder is shown in Figure A-2.

The feed hopper is designed to operate at up to 15 psig pressure. The included cone angle is 40 degrees with provisions for fluidizing the cone, if necessary. A rotary airlock permits continuous replenishment of the hopper inventory and an isolation valve partitions the feeder from the hopper. It is envisioned that, if the hopper requires fluidization, the duration of the fluidization will match the duration of the intake stroke, in order to minimize gas usage.

It should be noted that the high pressure gas used to flush a cylinder supplements the coal-conveying gas, proposed as a part of the downstream equipment by others, and as such does not contribute to gas loss.

The hydraulic power supply system will be of the "boiler feed" type, which is expected to permit high flow rates and pressures from a common system, allowing operation of several cylinders simultaneously. The hydraulic fluid is cooled using commercially available heat exchangers and utility cooling water.

The main ancillary equipment for the fluidized piston feeder comprises the feed hopper with facilities for pressurization and fluidization, a hydraulic power supply system with 4-way block valves to operate the feeder piston as well as all the feeder valves and hydraulic fluid cooling system using cooling water. High pressure and low pressure gases and cooling water are assumed to be available on site as a by-product of the gasification process.

System characteristics are summarized in Table A-1.

c. Cost Estimates

Capital, operating, and maintenance costs for the positive displacement feed system are given in Table A-2 for a commercial scale plant. Standby equipment has been allowed for in the costing. Also, the costs reflect the dead volume gas that is vented as well as all fluidizing gases.

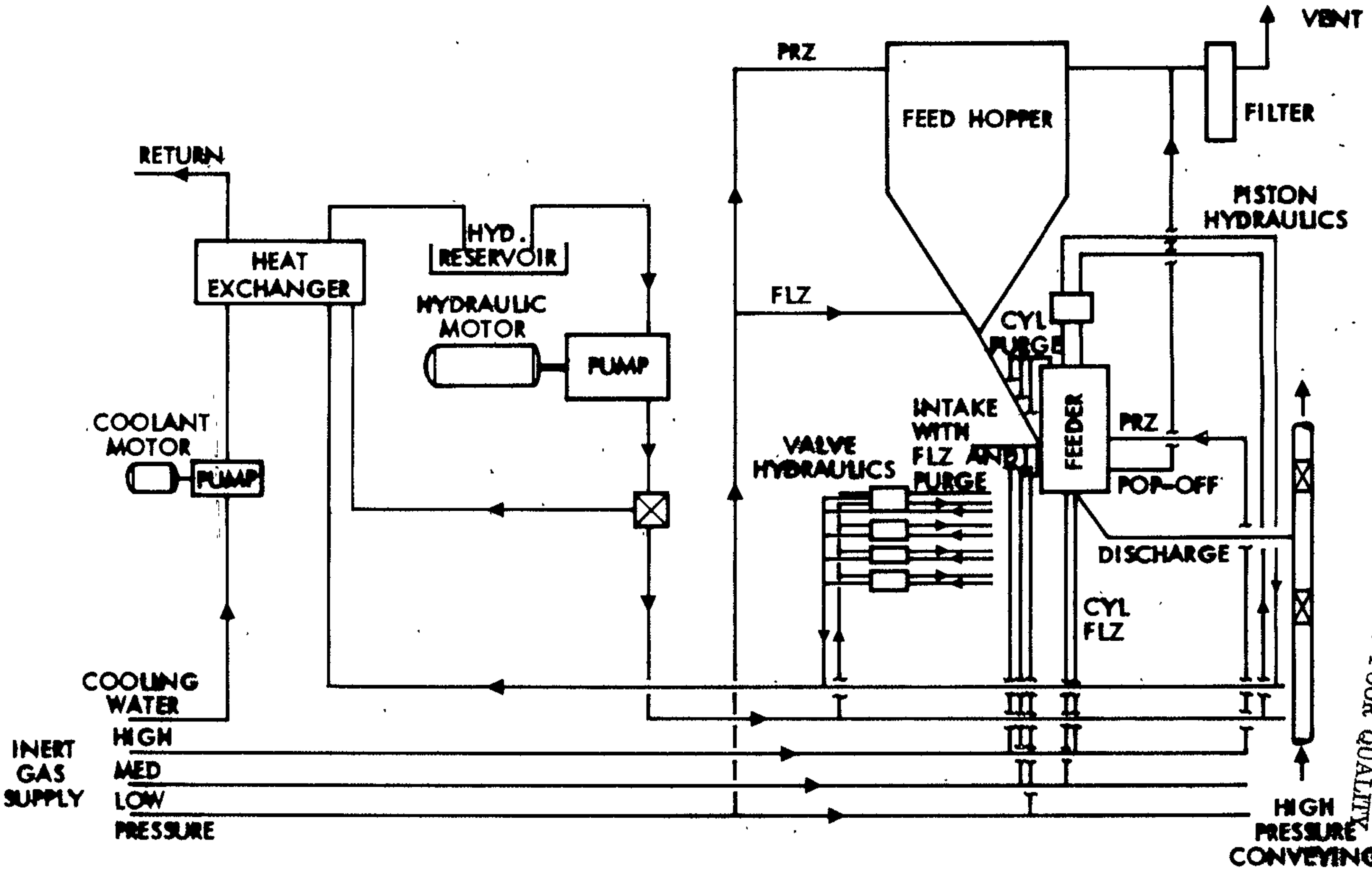

Figure A-2. Positive Displacement Feeder System

Table A-1. Positive Displacement Feeder Characteristics

Size	Commercial
Throughput	
(TPD)	15000
(TPH)	630
Pressure, psi	1500
Number of Feeders	
(trains)	9
Number of Cylinders	9 x 14
Number of Standby Cylinders	9 x 2
Feeder Train Capacity, TPH	70
Feeder Capacity/Cylinder, TPH	5
Approximate Size	
dia. ft.	2.5
stroke, ft	3.125
Cycle Time, sec	36
Power Required, hp	5670

Table A-2. Positive Displacement Feeder System Costs - Commercial Plant (15,000 TPD)

Feeder	864,000	
Hydraulics	864,000	
Feed Hopper	384,000	
Misc	384,000	
	2,496,000	
Installation (1.5)	3,744,000	
Debugging	900,000	
Installed equipment cost	7,140,000	
Design services	1,000,000	
Capital costs	8,140,000	
Operating costs/year		
Labor	240,000	
Utilities	850,000	
	1,090,500	
Maintenance cost/year		
Labor	16,800	
Material	343,000	
	359,800	
TOTAL DIRECT COST		1,450,300
Annual capital cost (12%)	976,800	
TOTAL INDIRECT COST		976,800
TOTAL ANNUAL COST		2,427,100
Operating cost \$/ton		0.4816
Unit cost \$/10^6BTU		0.01926
Equipment cost \$/TPH		12,920

d. Coal Type, Size, and Preparation Limitations

The type of valves used in the feeder and the maximum intake and discharge valve openings permitted by the feeder configuration and speed of operation will limit the maximum particle size in the coal being passed through the feeder. Within this limitation, the fluidizing velocity and fluidized bulk density will affect the operation of the feeder. The first of these two factors alters the ease of transportation into and out of the cylinder and the second the maximum coal intake per stroke.

It should be noted that, by altering the valve configurations and changing from fluidized transport to gravity feed and discharge, the maximum particle limitation can be raised significantly.

Process-required pretreatment of coal will affect the performance of the feeder, if it causes swelling or moisture variations. The first factor is expected to alter the size and hence must meet the maximum particle size limitation for a given material. As such, transportation of the coal and the capacity of the feeder will be dependent on these variables.

No specific post-treatment of coal is expected to be necessitated by its passage through the feeder.

e. Development Considerations

An inherent problem with the positive displacement feeder, for which there may be no solution, is that purging gas requirements may become large in larger size feeders and therefore many small feeders will be required for throughput.

Critical design areas for this feeder are:

(1) Valve sequencing and sizing.

(2) Material selection.

(3) Seals.

Critical wear components are

(1) Valve seats.

(2) Seals.

3. FOSTER-MILLER CENTRIFUGAL FEEDER

a. Description

The design of the centrifugal feeder is illustrated in Figures A-3, A-4, and A-5. The heart of the centrifugal feeder is a set of rotating arms (rotor) through which shaped channels (sprues) have been bored. Coal is fed into the eye (hub) of the feeder from an atmospheric storage hopper by gravity. It is expected that the coal will have to be fluidized to assist in the feeding. The coal particles are thrown radially outwards as a result of high speed feeder rotation. The choice of feeder speed and sprue shape are such that coal, under centrifugal body forces, packs in the sprues sufficiently to form a seal against downstream pressure and minimize gas leakage while permitting the coal to move outwards in a contact flow mode. The rotor is placed in a "pump" housing into which is brought high pressure conveying gas to transport the coal. The coal and gas are separated. The coal is directed to a high pressure storage hopper and the gas is boosted in pressure and returned to the conveying line. Double face seals with coolant flowing in between are used to isolate the rotating parts from the pressure zones. The coolant, in turn, passes through a heat exchanger where water is used to cool it. The drive train and power supply package could be hydraulic or electrical depending on total power requirements. Back leakage gas and fluidizing gas pass through a filter and are vented.

The rotor is illustrated schematically in Figure A-3 with a half-section view of a straddle-mounted bearing and seal arrangement. The rotor could also be over-hung from the shaft.

Figure A-4 shows the rotor to be fairly thin compared to its diameter, with two long, narrow, radial, tapered tabular passages, or sprues, for the flow of coal. With this geometry the coal is slung out at high velocity. However, the exiting coal "streams" will break up and disperse rapidly in the surrounding gas. Thus the particulates will settle rather slowly by gravity, and will not cause erosion of the reactor pressure housing. Figure A-4 depicts a two-sprue centrifugal feeder.

b. System Features and Ancillary Equipment

The centrifugal feeder system is illustrated in Figure A-6. The coal feed hopper operates at atmospheric pressure and is designed to hold coal for 15 minutes at feeder operating capacity. The cone included angle is 40 degrees to aid gravity flow. However, provisions have been included for continuous fluidization of the cone. This, in turn, requires an air lock in the feed intake and a vent with a filter for the gases.

The feeder consists of the "pump" casing, rotor with sprues, the drive shaft with seals, bearings, cooling and pressurizing ports, and a rotating coal intake port with its own seals and seal cooling pressurizing ports. Advanced, but state-of-the-art, hardware will be used for the bearings and seals with gas or liquid cooling. Fluidized coal

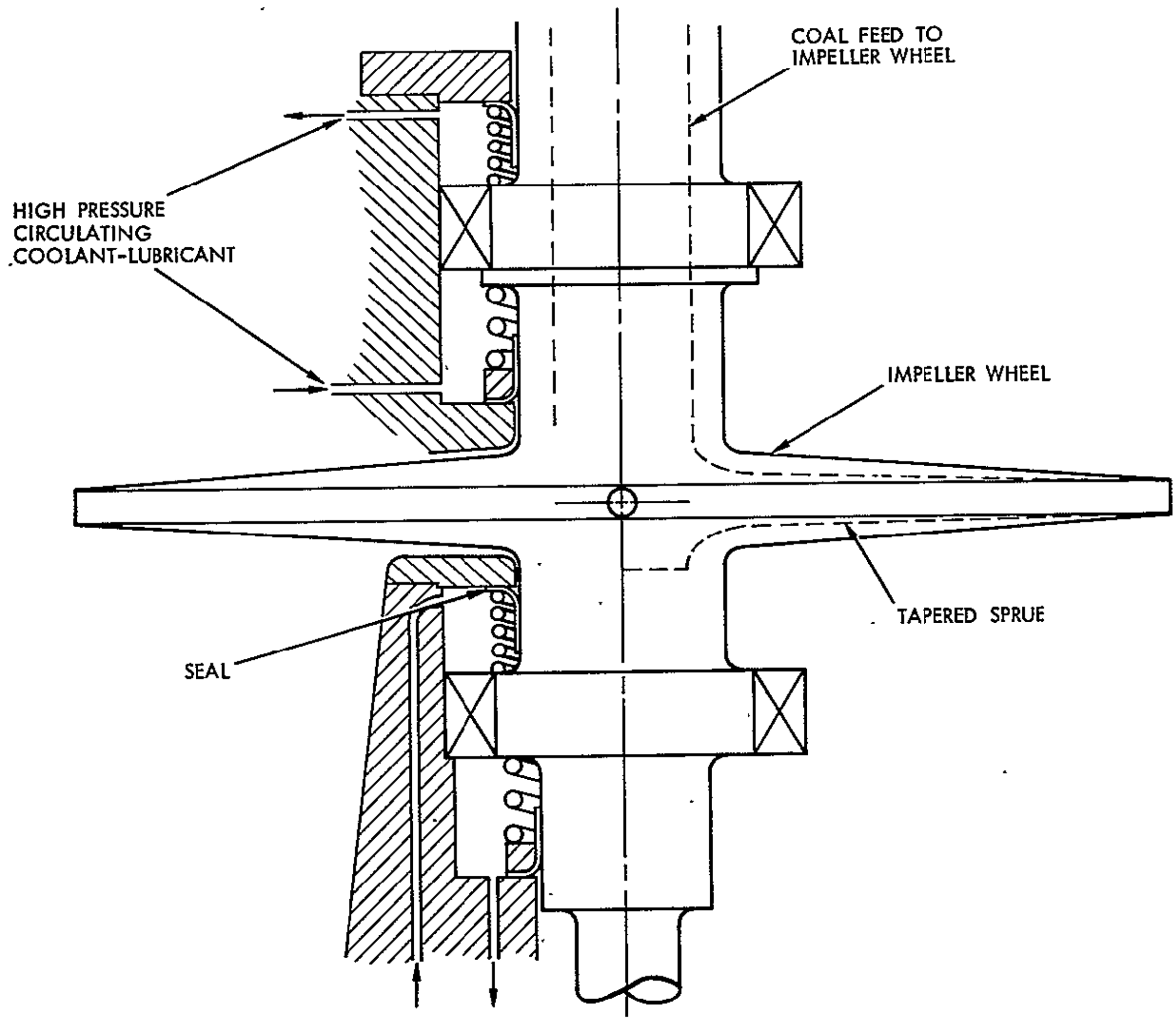

Figure A-3. Rotor Schematic

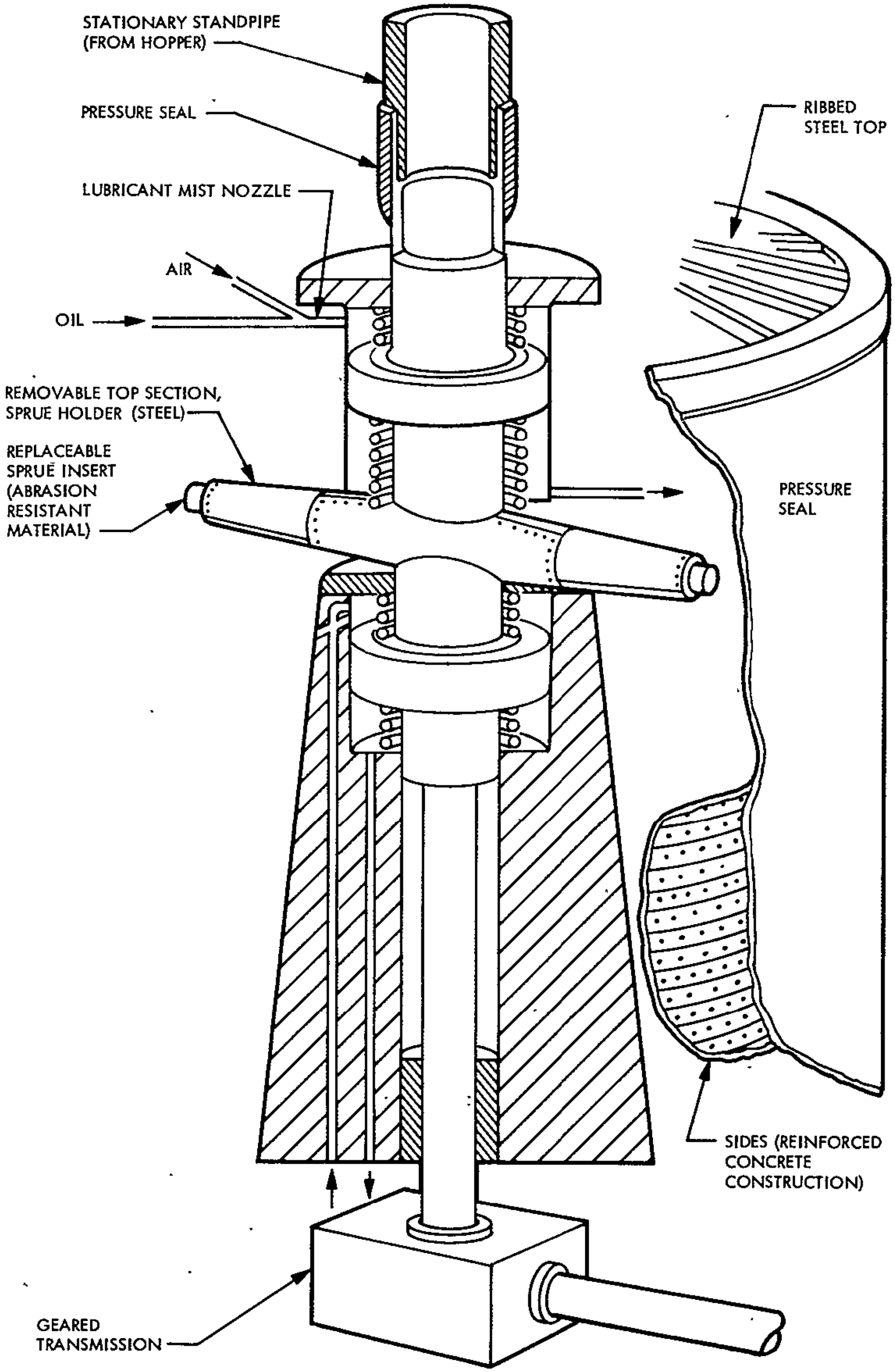

Figure A-4. Centrifugal Coal Feeder (Two-Sprue Design)

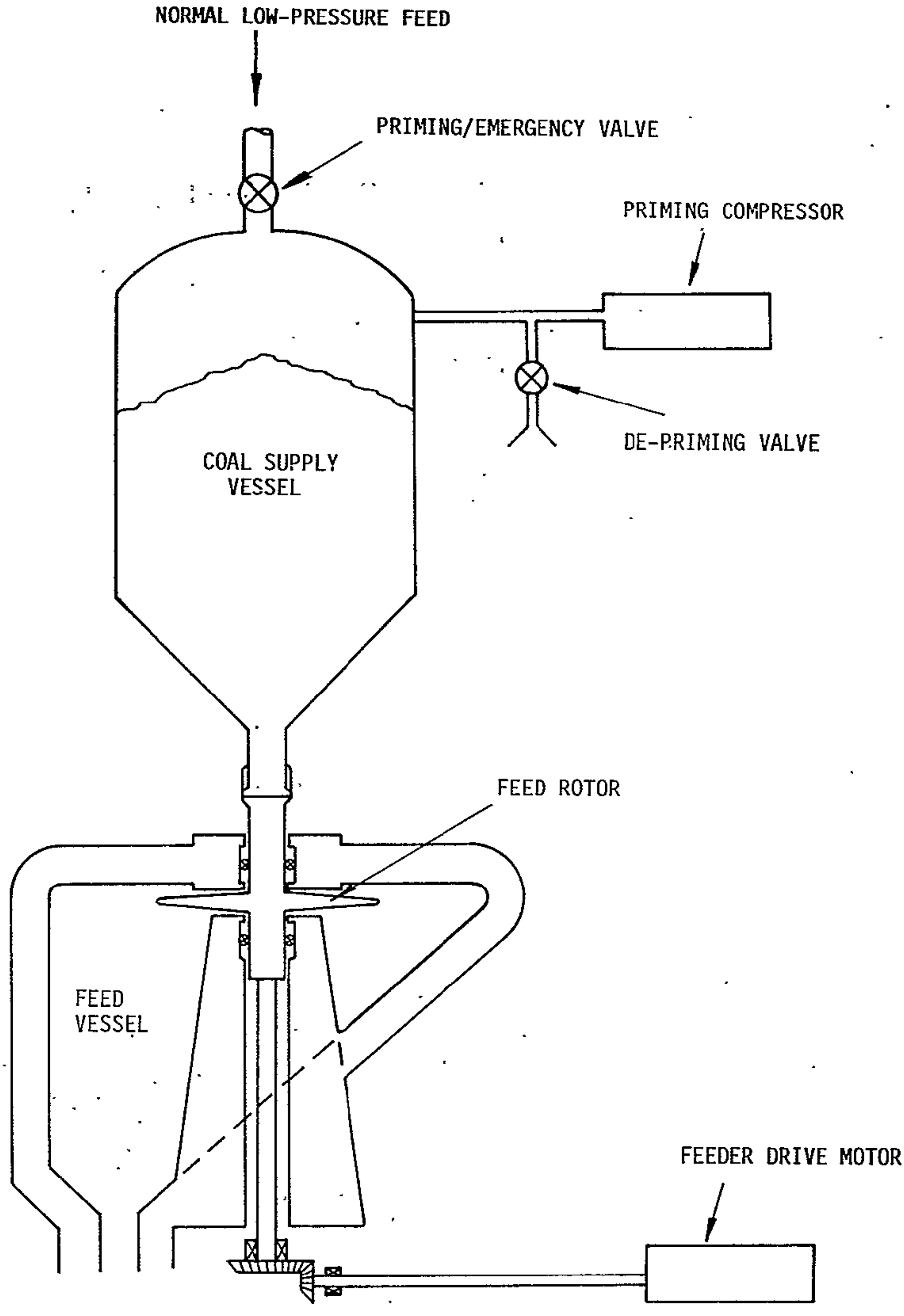

Figure A-5. Schematic Arrangement of Centrifugal Feeder System

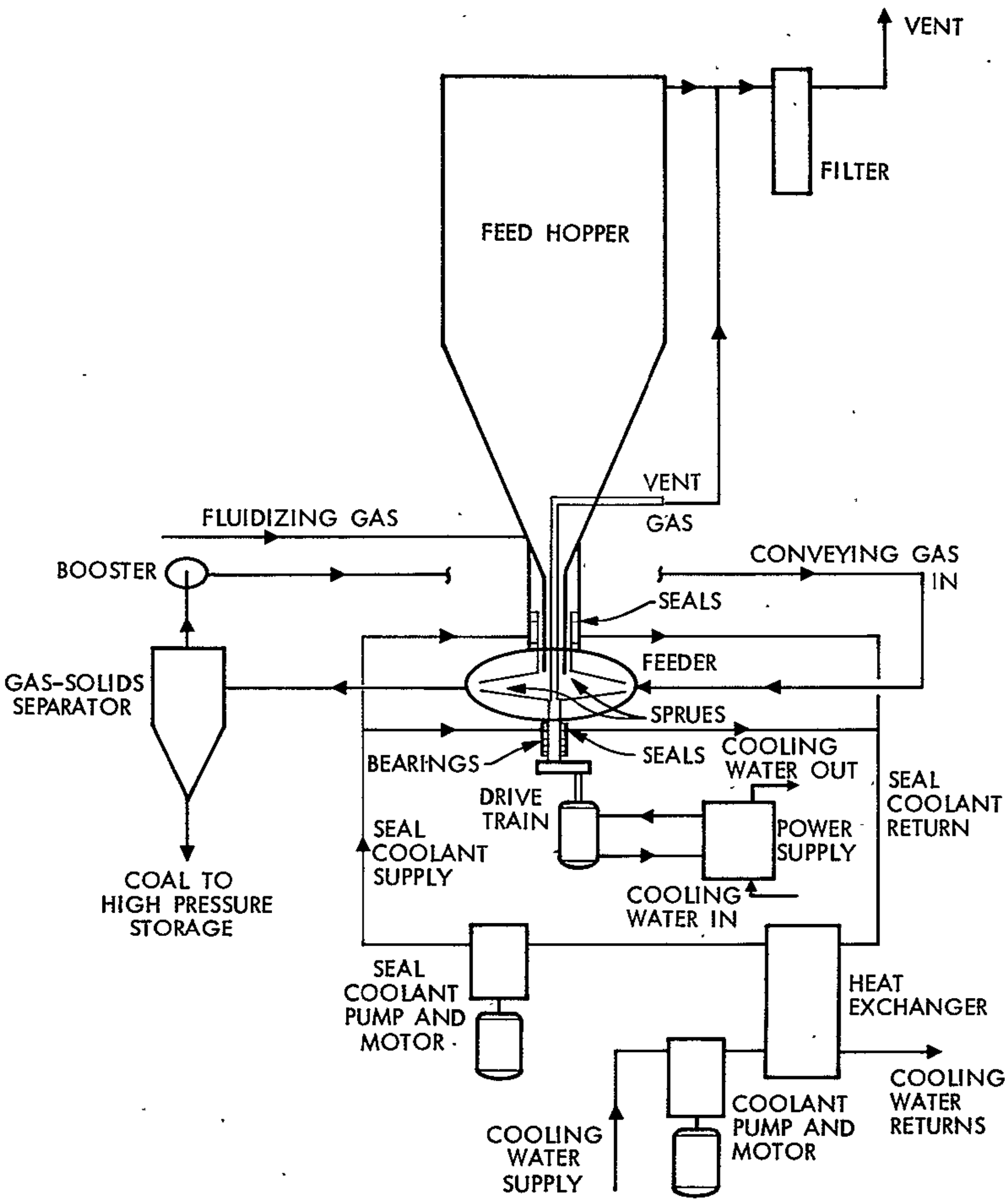

Figure A-6. Centrifugal Feeder System

flows down the inlet tube to the hub of the rotor where the solids are separated from the gases. The solids are directed into the sprues while the gases are vented, at near atmospheric pressure, through a filter.

"Boiler feed" type hydraulic power supply system has been proposed for the power package to the rotor, being commercially available in large capacities and at high pressures. The seal and bearing coolant system, shown in the figure, is the liquid type. The package comes with a coolant pump, reservoir, and a heat exchanger where the cooling liquid, in turn, is cooled with utility cooling water.

The pneumatic conveying and recirculating system comprises the conveying pipe, pick-up section around the feeder casing, gas/solids separator, and recirculating gas booster.

Ancillary equipment will comprise the atmospheric pressure feed hopper, power supply to the drive train, face seal coolant system, and the conveying gas recirculating system. Pressurized inert gas is assumed to be available on site as a by-product of the gasification process and cooling water as well.

System characteristics are summarized in Table A-3.

c. Cost Estimates

Capital, operating, and maintenance costs for the centrifugal feeder system are given in Table A-4 for a commercial scale plant operating at 1500 psi. The pneumatic conveying and recirculating system has not been included in the estimates.

d. Coal Size, Type, and Preparation Limitations

The pressure sealing capability of a given centrifugal feeder, that is, a feeder of fixed size operating at a fixed speed, is dependent on the coal's specific gravity, particle size, particle size distribution, and particle shape.

Available data is restricted to gravity conditions and are empirical in nature. The actual limitations in the high pressure/high centrifugal force regime in which this feeder operates will have to be established as a part of the development program.

Except insofar as it affects the coal characteristics and its effects on feeder performance as elucidated in one paragraph above, the only other factor that will be a prerequisite in any pretreatment (not demanded by the process), for predictable feeder performance, is the moisture in the coal. FMA expects an upper limit to be established during the feeder development program.

No specific post-treatment is expected to be necessitated due to passage of the coal through the feeder.

Table A-3. Centrifugal Feeder System Characteristics

Size	Commercial
Throughput	
TPD	15,000
TPH	630
Pressure, psi	1,500
Number of Feeders (trains)	3
Unit Capacity (TPH)	210
Approximate Rotor Size diameter, ft	6
Speed, rpm	2,000
Down comer diameter, in.	7
Power Required, hp	5,250

Table A-4. Centrifugal Feeder System Costs - Commercial Plant (15,000 TPD)

Feeder	129,000	
Hydraulics	150,000	
Feed Hopper	75,000	
Misc	10,000	
	364,000	
Installation (1.5)	546,000	
Debugging	75,000	
Installed equipment cost	985,000 for 210 TPH	2,955,000 for 630 TPH
Design services	400,000	
Capital cost	3,355,000	
Operating costs/year		
Labor	160,000	
Utilities	262,500	
	422,500	
Maintenance costs/year		
Labor	15,000	
Material	178,000	
	193,000	
TOTAL DIRECT COST		615,500
Annual Capital cost (12%)	402,600	
TOTAL INDIRECT COST		1,018,100
Operating cost \$/ton		0.202
Unit cost \$/10^6BTU		0.0081
Equipment cost \$/TPH		5,325

e. Development Considerations

Inherent problems with the centrifugal feeder are

(1) Pressure sealing capabilities are highly dependent on coal properties (specific gravity, particle size, particle size distribution, and particle shape) and sprue packing.

(2) Successful sprue configuration requires developmental effort to understand coal flow theory.

Critical design areas are

(1) Feed throttling for control of throughput.

Critical wear components are

(1) Seals, sprues.

4. FOSTER-MILLER LINEAR POCKET FEEDER

a. Description

The linear pocket feeder, shown in Figure A-7, is essentially a tubular conveyor in which internal pistons are connected together with spaces or "pockets" between them. These pistons are connected to form a continuous chain, the pockets of which are continuously filled with coal and then emptied. Referring now to the schematic (Figure A-7), coal will enter through a gravity hopper, is pulled along through a close tolerance sealing tube, and dumped by gravity into a high pressure chamber (up to 500 psig). The pockets exchange the coal for high pressure gas at the unloading station, and this gas is, in turn, displaced by high pressure water. The gas is dried and returned under a small differential to the pressure vessel. The high pressure water is then dumped, the chain moves over the drive sprocket, returns to the idler sprocket, and then to the inlet at the hopper to begin the cycle again.

The system is composed of

(1) Variable speed drive system (motor, gearboxes, chains, controls) to drive the "chain" and overcome friction produced between the pistons and the wall of the tube.

(2) High pressure water system (centrifugal pump, level controls, plumbing) to displace the high pressure gas from the "chain" and "force" it back into the pressure vessel while doing the most efficient "PV" work.

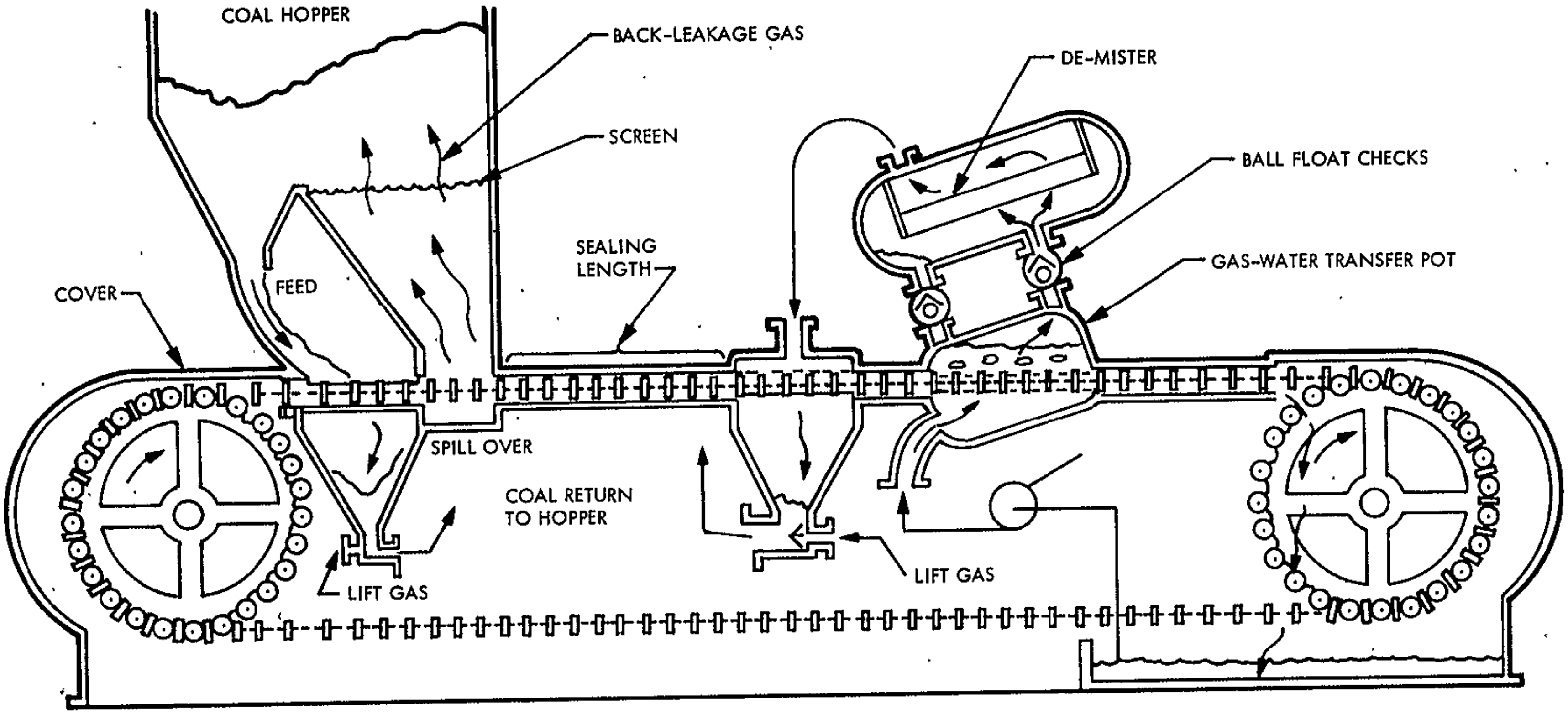

Figure A-7. Schematic of Linear Pocket Feeder

(3) Chain system (pistons, alumina wear rings, automotive type hook rings, stainless piston sub assemblies, and connecting rods, antiballeting design) which is the heart of the entire design for moving coal with minimum leakage and maximum reliability.

(4) Structural system (support frames, alignment systems, small pressure vessels) to support the system.

(5) Tube specifications (hopper, sealing, dropout, demister, return inlet and outlet) coated, hardened and treated for specific wear and corrosion protection.

(6) Peripheral systems (gas leakage recompression devices, chain drying systems, safety controls for explosion protection due to chain breakage, maintenance devices).

b. Estimates of Wear, Parts Replacement, Down Time, and Life Time for the Feeder

Wear life has been a major consideration in this particular design. Quantitative analysis for the wear rate based on the best available data in the literature has been applied to the areas felt most critically subject to abrasive wear. These areas are

(1) The alumina piston ring.

(2) The sealing tube.

The design utilizes ultra-hard materials sliding on each other to minimize wear due to abrasive conditions caused by silica in the coal.

The wear rate is calculated from the following equation:

$$V = \frac{K\ L\ T}{3H} V_e$$

where V is the worn volume (mm^3), K is the wear coefficient, L is the normal load (kg), T is the time in seconds, V_e is the sliding velocity in mm/sec, and H is the hardness (kg/mm^2). Wear lifes using this model are linear with time and thus a three-year wear life (0.002 inch worn thickness) will be a limiting factor.

Parts replacement will include the alumina and automotive rings (total replacement cost ~$2000) and the main sealing and unloading tubes (~$1000 each) at periods of two to three years. Pump maintenance will be done at 4 month intervals requiring shutdown, teardown, maintenance (inspection and lubrication), and reassembly. Drive system maintenance will most likely be done concurrently with pump maintenance but only yearly or as required.

C-2

Estimated downtime for these operations will be

Rings and tubes	2 man-days (technician)
Pump maintenance	1 man-day (technician)
Drive system	1/2 man-day (mechanic)

The feeder life is projected to be 15 to 20 years. At that time major items such as the drive motor, gear reducer sprockets, and the centrifugal pump will need replacement.

c. Costs

Capital, operating, and mantenance costs for the linear pocket feeder are given in Table A-5 for a commercial scale plant.

d. Coal Type, Size, and Preparation Limitations

The linear pocket feeder is capable of feeding a wide range of coal particle sizes from pulverized to 2-inch lumps. There are no restrictions on its use with different types of coal.

e. Development Considerations

Problem areas requiring further development are:

(1) Wear life vs. calculated wear life.

(2) Survival of expandable rings and chain.

(3) Driving forces and leakage of feeder vs. laboratory results.

(4) Gas/liquid interface problems in water section.

(5) Operating rate limits - determination of the upper limit on speed.

5. INGERSOLL-RAND SCREW FEEDER

a. Description

This feeder is a type of auger, conveying coal axially down its length as the screw is rotated as shown in Figure A-8. In addition, the coal is plasticized by the addition of heat along the tube with heating bands or by heating the hollow screw. The plasticized coal forms a seal between the low pressure inlet and the high pressure discharge. A continuous flow of dry coal is supplied across the pressure interface in a single stage.

Table A-5. Linear Pocket Feeder System Costs - Commercial Plant (15,000 TPD)

Feeders (9)	607,500		
Feed Controllers (9)	18,000		
Feed hoppers (6)	200,000		
Miscellaneous	25,000		
	850,500		
Installation	1,000,000		
Debugging	150,000		
Total Installation Cost	2,000,500		
Design Services	150,000		
Total Capital Costs			2,150,500
Operating Cost/year			
Labor	250,000		
Utilities	833,000	($.025/kwh)	
	1,083,000		
Maintenance costs/year			
Labor	15,000		
Materials	150,000		
	165,000		
TOTAL DIRECT COST			1,248,000
Annual capital cost (12%) (Total Indirect cost)			258,060
Total Annual Cost			1,506,060
Annaul operating cost/ton	$/ton		$.301
Annual unit cost/10^6 BTU	$/$10^6$ BTU		$.012
Equipment Cost	$/TPH		$3,441

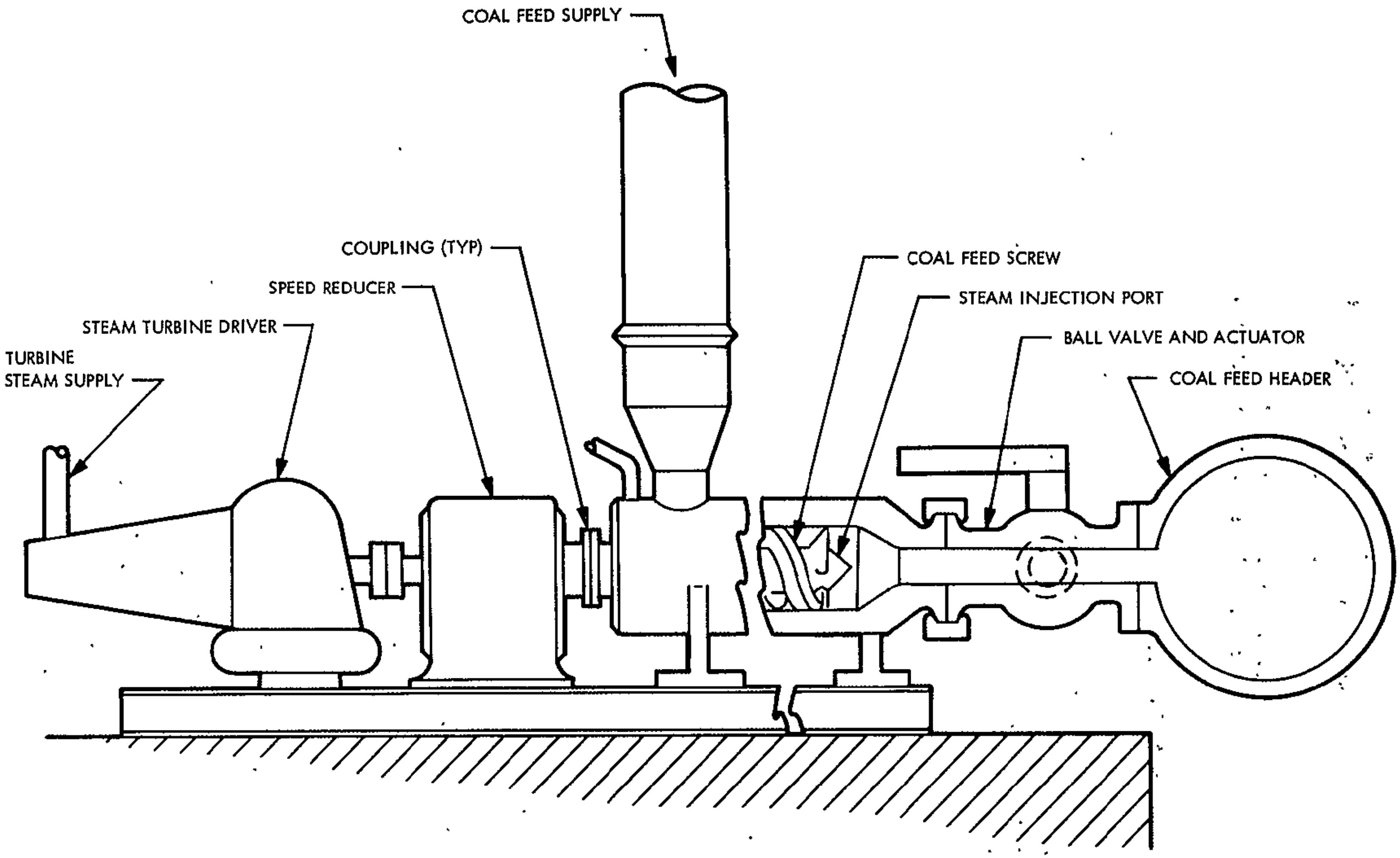

Figure A-8. Dry Coal Screw Feeder System.

b. System Features

A system for a 15,000 TPD plant using the screw feeder will include 12 feeders, operating at 1500 psi. Support and drive systems for one feeder is shown in Figure A-9.

An extrudate breakup device is required on the high pressure side just ahead of the high pressure storage bin.

c. Cost Estimate

Cost estimates are provided for both the extrusion mode, which utilizes external heat to partially plasticize the coal (Table A-6), and for the injection mode of operation, which does not utilize external heat (Table A-7). The following cost assumptions were used in establishing the costs.

Labor Rate		= \$20/hr
Power Cost:	Steam	= $\$2.50/10^6$ BTU
	Electric	= \$0.02/kWh
1 ton of coal		= 25 MM BTU

d. Coal Type, Size, and Preparation Limitation

The heated screw feeder is limited to the use of bituminous, agglomerating coals. The feeder can accomodate a wide variation in input coal size (fines to 1 inch). Input coal should be subjected to pretreatment to reduce the moisture content to 3-4% max. The extrudate must be reduced to the size required by the process.

For the unheated injection mode of operation there are no coal type limitations. The input coal size variations are the same as for the heated screw; pretreatment of the coal is not required. The extrudate must be reduced to the size required by the process.

e. Development Considerations

Possible inherent problems with the screw are

(1) Possibly large power requirements (and heat addition for the heated screw).

(2) The requirement for a high pressure crusher to reduce the extrudate to the required size.

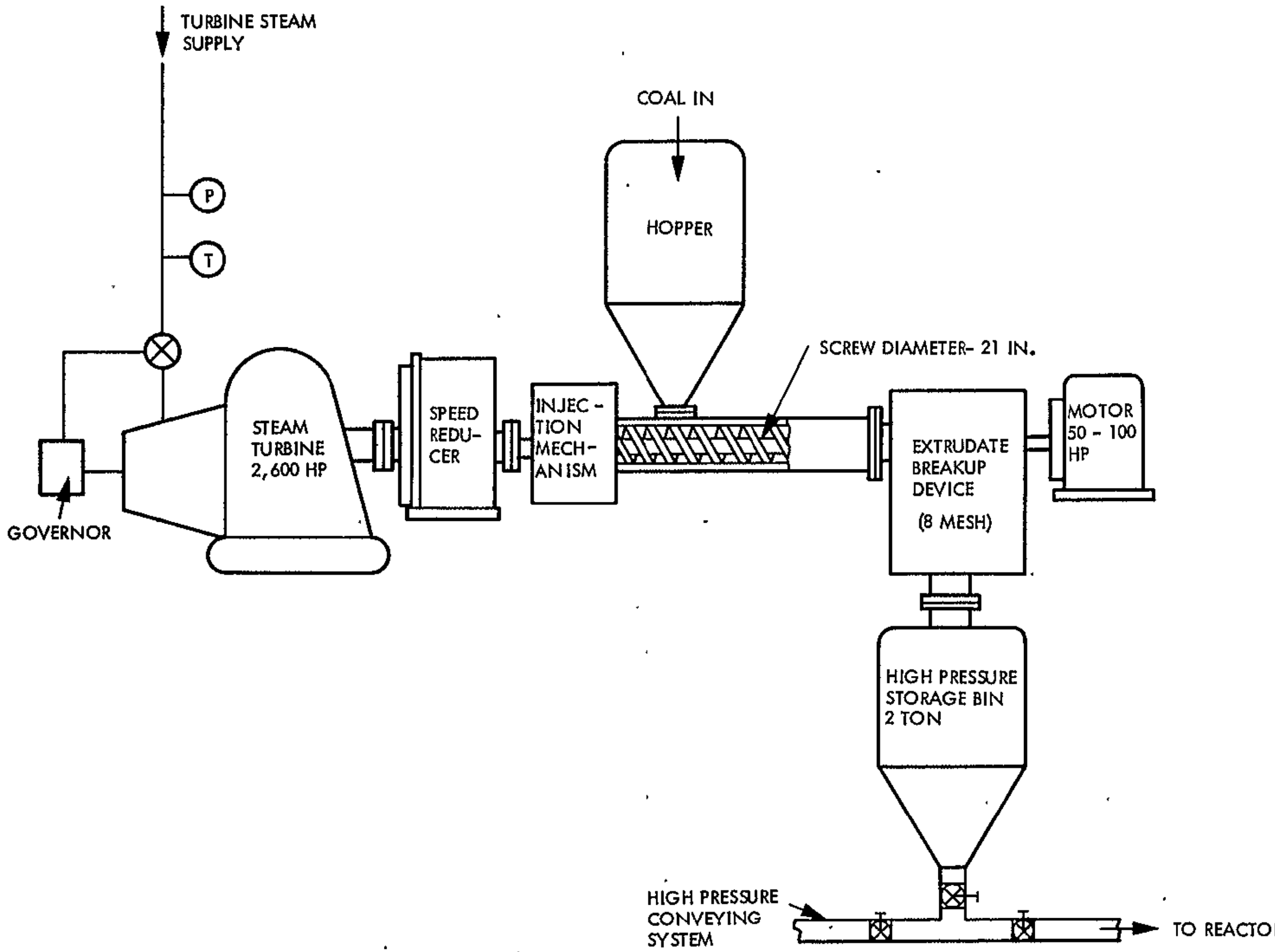

Figure A-9. Screw Feeder System

Table A-6. Screw Feeder System Costs (Extrusion Mode, With External Heat

CAPITAL COST OF FEEDER

Major Equipment

Screw & barrel assembly	$ 76,000	
Screw reciprocation system & thrust plate	40,000	
Mounting, frame, hopper, guards, etc.	31,000	
Couplings	6,000	
Speed reduction system	117,000	
Steam turbine drive system	200,000	
Coal heating system	30,000	
Controls and consoles	20,000	
Extrudate brake up device	200,000	
High pressure storage bin	30,000	
High pressure conveying system	25,000	
Blow back prevention system	20,000	
TOTAL MAJOR EQUIPMENT COSTS (TMEC)		$ 795,000
Initial spare parts (10% TMEC)	$ 79,500	
Installation cost (20% TMEC)	159,000	
Contingency (25% TMEC)	198,750	
CAPITAL COST OF FEEDER		$1,232,250
		(1,152,750)

Table A-6. Screw Feeder System Costs (Extrusion Mode, <u>With</u> External Heat (Continuation 1)

COST OF CAPACITY	$23,697 / tph	
OPERATING COSTS/YEAR		
Labor		$175,200
Power		496,443 *
	Total	$671,643
MAINTENANCE COSTS/YEAR		
Labor		$ 50,400
Parts (15% TMEC)		119,250
	Total	$169,650
ANNUAL COST		
Operating Costs/year		$671,643
Maintenance Costs/year		169,650
Capital Cost (12% per year)		147,870
	Total	$989,163
$ / MILLION BTU		.096

* Includes the heat required to semi-plasticize the coal. Majority of this heat is not lost as far as the total system is concerned.

Table A-7. Screw Feeder System Costs (Injection Mode, Without External Heat)

CAPITAL COST OF FEEDER

Major Equipment

Screw & barrel assembly	$ 50,660	
Screw injection system	80,000	
Mounting, frame, hopper, guards, etc.	46,500	
Couplings	6,000	
Speed reduction system	117,000	
Steam turbine drive system	200,000	
Controls and consoles	30,000	
Extrudate brake up device	150,000	
High pressure storage bin	30,000	
High pressure conveying system	25,000	
Blow back prevention system	20,000	
TOTAL MAJOR EQUIPMENT COSTS (TMEC)		$ 755,160
Initial Spare parts (10% TMEC)	$ 75,516	
Installation Cost (20% TMEC)	151,000	
Contingency (25% TMEC)	188,790	
CAPITAL COST OF FEEDER		$1,170,466
		(1,094,950)

Table A-7. Screw Feeder System Costs (Injection Mode, <u>Without</u> External Heat) (Continuation 1)

COST OF CAPACITY	$22,508 / tph	
OPERATING COSTS/YEAR		
Labor		$175,200
Power $(\frac{25}{20})$		196,692
	Total	$371,892
MAINTENANCE COSTS/YEAR		
Labor		$ 50,400
Parts (15% TMEC)		113,274
	Total	$163,674
ANNUAL COST		
Operating Costs/year		$371,892
Maintenance Costs/year		163,674
Capital cost (12% per year)		140,456
	Total	$676,022
$ / MILLION BTU		0.065

Developmental areas of work include

(1) Scale-up of the feeder with respect to the heat input to the coal.

(2) Determination of operating parameters to achieve required throughputs with minimum power.

(3) Determination of screw and barrel material wear and impact on operating cost and downtime.

6. INGERSOLL-RAND SINGLE ACTING PISTON FEEDER

a. Description

The principle of this feeder is to physically move a fixed amount of coal from the low to the high pressure area for discharge in a single stage; the coal is not compressed.

The feeder concept is shown schematically in the several stages of its operating cycle in Figure A-10. The concept utilizes two coaxial delivery pistons operating in a common cylindrical housing. These pistons are actuated by drive pistons situated at one end of the cylinder. Feed and discharge ports are situated on opposite sides of the cylinder and are displaced from one another. A pneumatic or hydraulic power supply actuates the drive pistons, utilizing a suitable control system to sequentially time each event in the delivery cycle as follows:

(1) Step 1 - Load.

(2) Step 2 - Advance.

(3) Step 3 - Delivery.

(4) Step 4 - Volume reduction.

(5) Step 5 - Retreat.

(6) Step 6 - Open and reload.

The cavity volume containing the material to be conveyed is maintained constant during the conveying period. Thus, undesirable compaction of the coal is avoided and precise metering of the coal with each stroke is attained. Furthermore, a continuous head of coal may be applied to the inlet port. In addition, with both driving pistons situated on the same end of the machine, it would appear that a small overall physical size can be achieved.

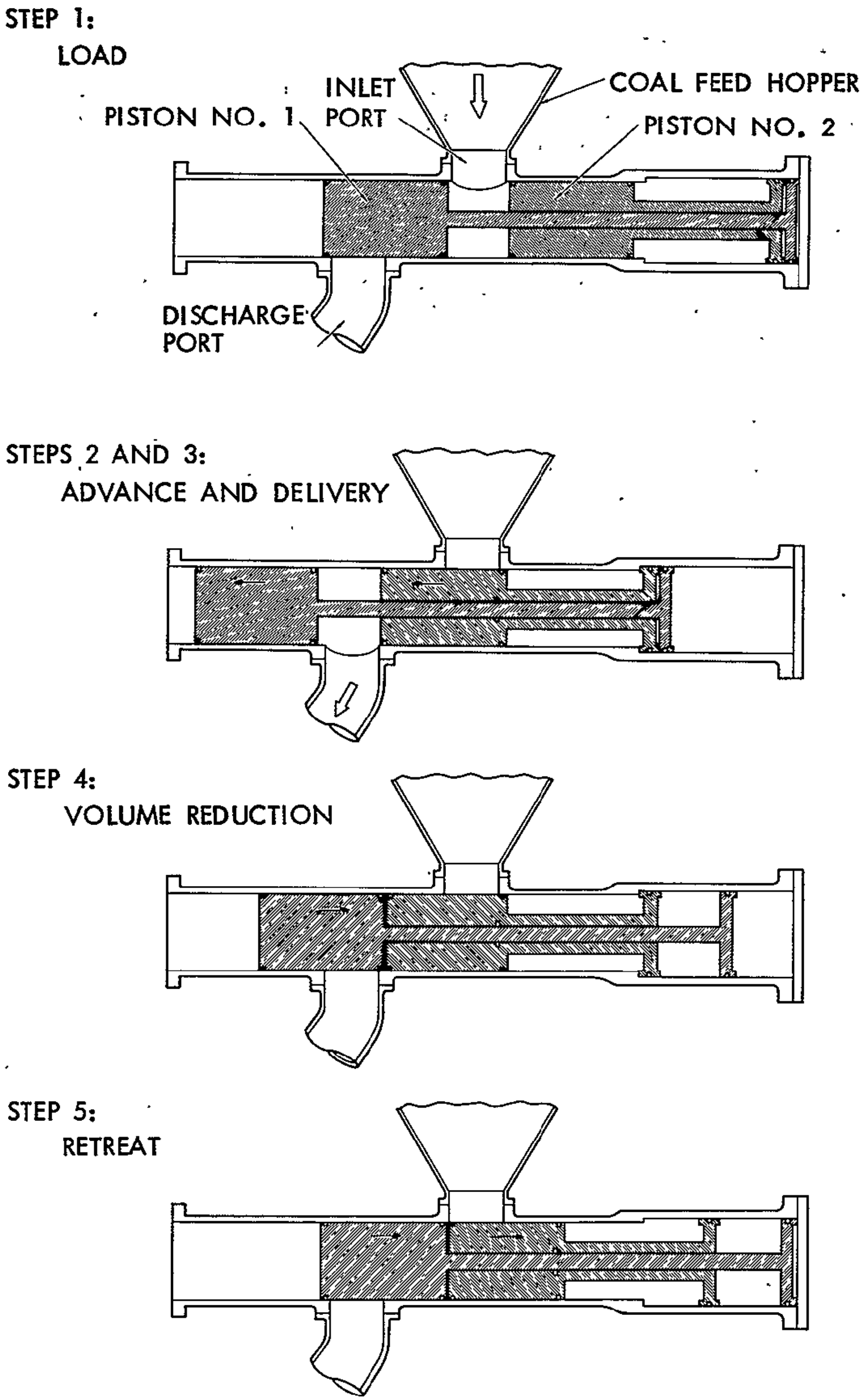

Figure A-10. Single Acting Piston Feeder Operating Sequence

b. System Features

The system for a 15,000 TPD plant using the single acting piston feeder has 12 feeders per plant. Figure A-11 is a schematic drawing of the single acting piston feeder showing ancillary equipment.

c. Cost Estimates

Cost estimates for the single acting piston feeder are given in Table A-8. Cost assumptions are the same as given in Section 5-c of this appendix.

d. Coal Type, Size, and Preparation Limitations

The single acting piston feeder has no coal type limitations, can accomodate a wide range of coal sizes (fine to coarse), and does not require any special coal pre- or post-preparation.

e. Development Considerations

The single acting piston feeder is presently only in the conceptual stage of development. Primary development requirements are in the areas of sealing and material wear. Additional development problems to be assessed include complete removal of the coal from the piston cavity during unloading, and prevention of coal jamming with the piston/ sleeve interface during loading and unloading.

7. INGERSOLL-RAND ROTARY VALVE PISTON FEEDER

a. Description

This concept transfers the coal by a sleeve rotation from the low pressure area to the high pressure discharge area. Upon discharge, a piston is actuated, emptying the cavity of high pressure gas in a single stage. The sleeve is then rotated back to its initial position and the piston is retracted.

Referring to Figure A-12, Step 1 depicts the system in the coal loading mode. Coal falls by gravity into the zone bounded by the walls and end of the rotating cylinder and the piston face. In this mode, gasifier pressure is sealed by the stationary seals around the ports, preventing blow-back through the hopper. Steps 2 and 3 represent the delivery mode. This position was obtained by rotating the cylinder 180 degrees. Once coal is delivered to the gasifier system, hydraulic pressure is introduced to Port A and Port B is vented. This action actuates the piston which expels the gas back into the gasifier system as shown in Step 4. The next action, Step 5, sees the simultaneous rotation of the hollow cylinder back to open the inlet feed hopper and retraction of the piston (by venting Port A and pressurizing Port B). This completes the cycle and coal loading commences anew.

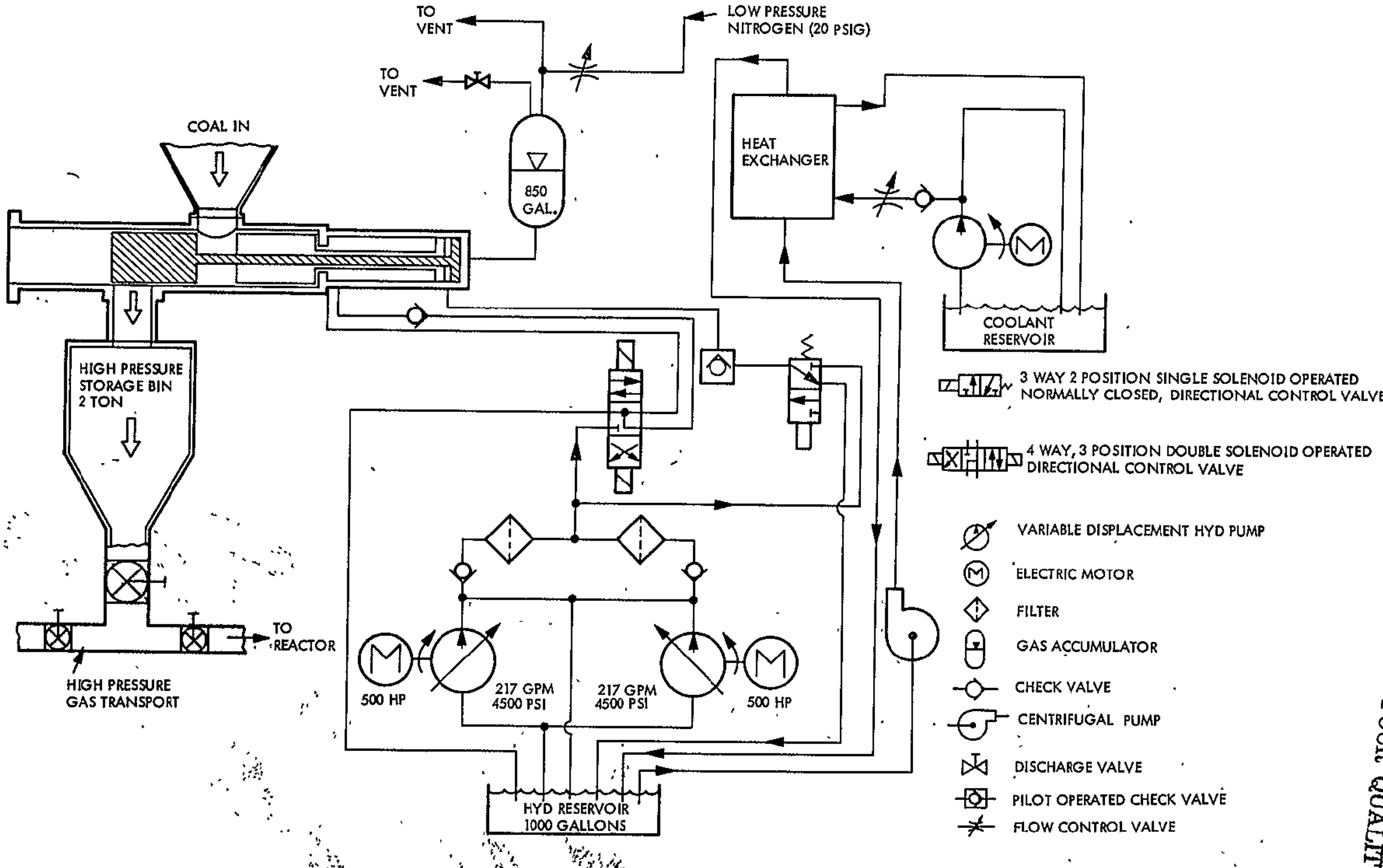

Figure A-11. Single Acting Piston Feeder System

Table A-8. Single Acting Piston Feeder System Costs

CAPITAL COST OF FEEDER

Major Equipment

Feeder Casing and Hydraulic Cylinder	$257,100	
Feeder Pistons	218,300	
Hydraulic Pumps and Motors	67,600	
Valves, Pipings, Filters, Gages, Reservoir, etc. for hyd. Cct.	22,700	
Hydraulic oil cooling System	7,200	
Frame, Supporting Structure & Packaging	158,500	
Controls & Consoles	30,000	
High Pressure Storage Bin	30,000	
High Pressure Coal Conveying System	15,000	
TOTAL MAJOR EQUIPMENT COSTS (TMEC)		$ 806,400
Initial Spare Parts (10% TMEC)	$ 80,640	
Installation Cost (20% TMEC)	131,107	
Contingency (25% TMEC)	163,884	
CAPITAL COST OF FEEDER		$1,182,031
		(1,101,391)

COST OF CAPACITY $ 22,731 / tph

Table A-8. Single Acting Piston Feeder System Costs (Continuation 1)

OPERATING COSTS/YEAR		
Labor		$175,200
Power		59,083
	Total	$234,283
MAINTENANCE COSTS/YEAR		
Labor		$ 50,400
Parts (20% TMEC)		161,280
	Total	$211,680
ANNUAL COST		
Operating Costs/year		$234,283
Maintenance Costs/year		211,680
Capital Cost (12% per year)		141,843
	Total	$587,806
$ / MILLION BTU		0.057

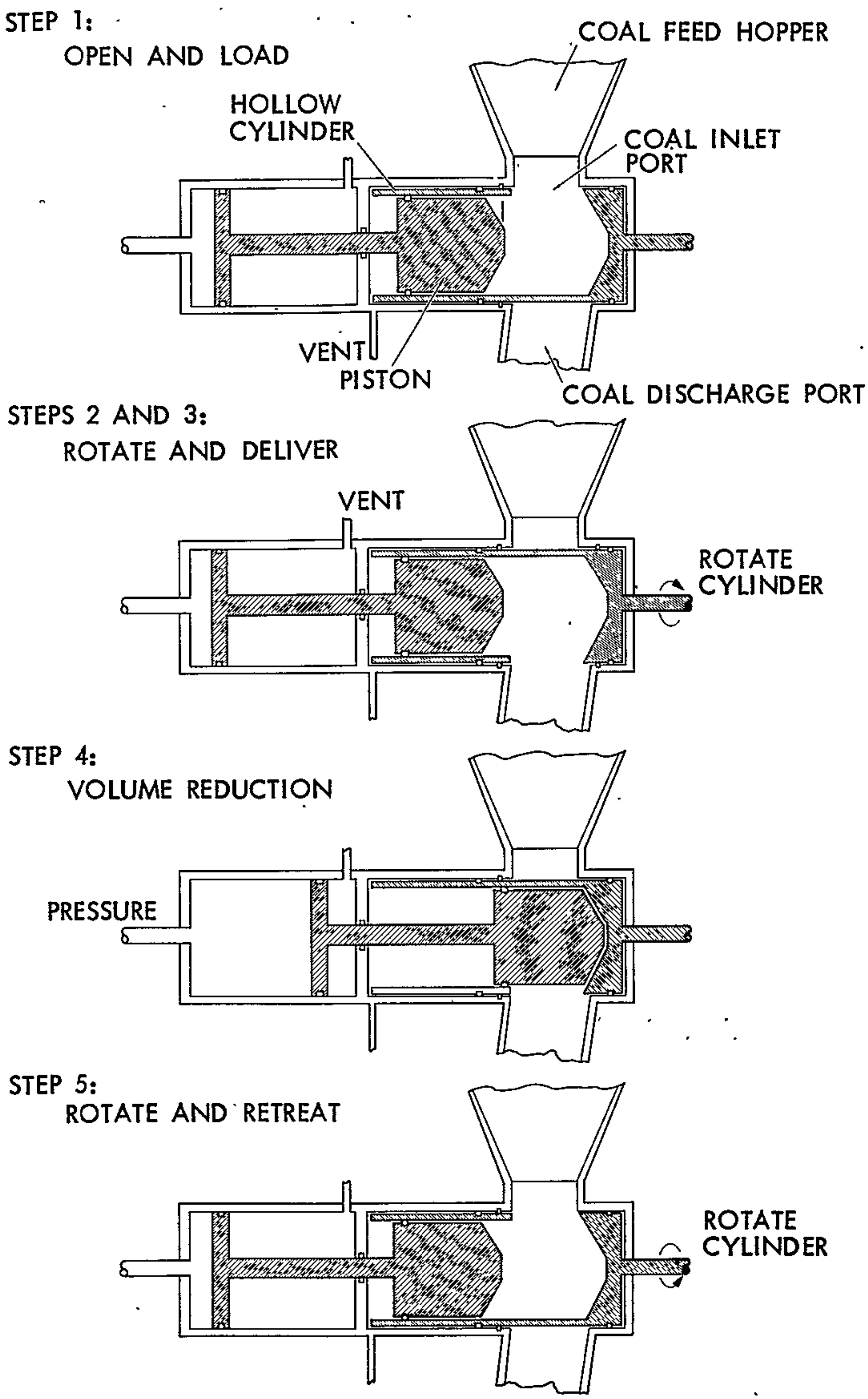

Figure A-12. Rotary Valve Piston Feeder Operating Sequence

b. System Features

A system for a 15,000 TPD plant will use 12 rotary valve piston feeders.

Figure A-13 is a schematic drawing of the rotary valve piston feeder showing ancillary equipment.

c. Cost Estimates

Cost estimates for the rotary valve piston feeder are given in Table A-9. The cost assumptions used are the same as those given in Section 5-c of this appendix.

d. Coal Type, Size and Preparation Limitations

The rotary valve piston feeder has no coal type limitations, can accomodate a wide ranger of coal sizes (fine to coarse), and does not require any special coal pre- or post-preparation.

e. Development Considerations

The rotary valve piston is presently only in the conceptual stage of development. Primary development requirements are in the areas of sealing and material wear. Additional development problems to be assessed include the clearing of the coal from the piston cavity during unloading and prevention of coal interference with the piston/sleeve interface during loading and unloading.

8. LOCKHEED KINETIC EXTRUDER FEEDER SYSTEM

a. Description

The kinetic extruder shown in Figures A-14 and A-15 uses centrifugal force to compact the solids particles and move them continuously through the high speed rotor channels, either at a speed faster than the gas leakage superficial velocity back through the coal bed, or with sufficient compaction so that the leakage is negligible.

It should be noted that the forces acting on the particles are predominately body forces caused by the centrifugal force field. Thus the particles are not pushed on by a cylinder or feed screw through the flow channel and bridging or similar phenomena may not interfere in the flow of particles through the channel.

The moving coal bed itself forms the gas seal and the forces are caused by the centrifugal force field, which is of much greater magnitude than the gravitational force. Coal is extruded continuously through a high speed rotor at a speed faster than the gas leakage superficial velocity back through the coal bed. The term extruder is used

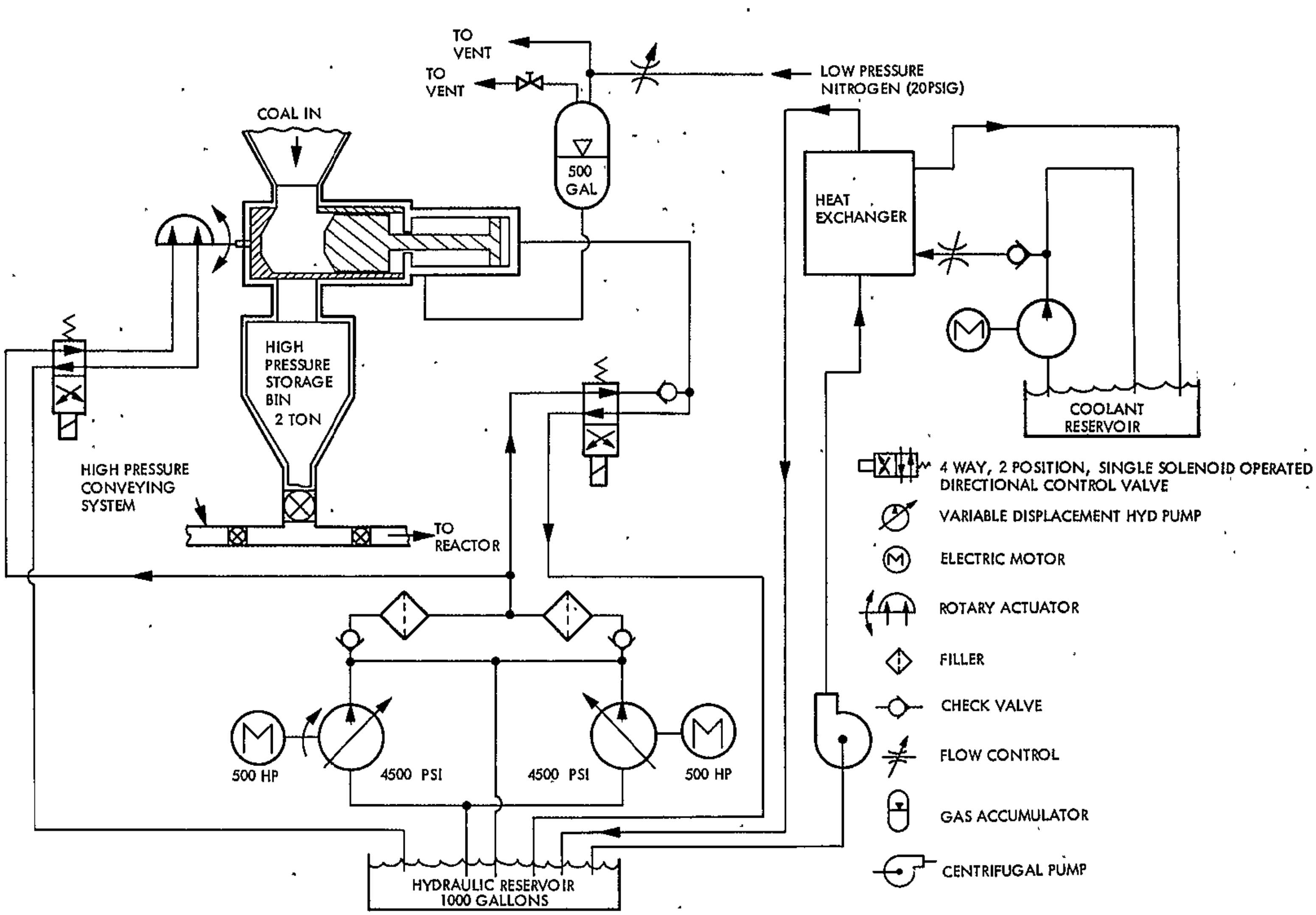

Figure A-13. Rotary Valve Piston Feeder System

Table A-9. Rotary Valve Piston Feeder System Costs

CAPITAL COST OF FEEDER

Major Equipment

Feeder Casing and Hydraulic Cylinder	$125,000	
Feeder Pistons	165,100	
Hydraulic Pumps and Motors	73,600	
Valves, Pipings, Actuator, Filters Gages, Reservoir, etc. for hyd. Cct.	22,500	
Hydraulic Oil Cooling System	7,200	
Frame, Supporting Structure & Packaging	74,700	
Controls & Consoles	30,000	
High Pressure Storage Bin	30,000	
High Pressure Coal Conveying System	15,000	
TOTAL MAJOR EQUIPMENT COSTS (TMEC)		$543,100
Initial Spare Parts (10% TMEC)	54,310	
Installation Cost (20% TMEC)	108,620	
Contingency (25% TMEC)	135,775	
CAPITAL COST OF FEEDER		$841,805
		(787,495)

COST OF CAPACITY $ 16,188 / tph

Table A-9. Rotary Valve Piston Feeder System Costs (Continuation 1)

<u>OPERATING COSTS/YEAR</u>		
Labor		$175,200
Power		59,083
	Total	$234,283
<u>MAINTENANCE COSTS/YEAR</u>		
Labor		$ 50,400
Parts (20% TMEC)		108,620
	Total	$159,020
<u>ANNUAL COST</u>		
Operating Costs/year		$234,283
Maintenance Costs/year		159,020
Capital Cost (12% per year)		101,016
		$494,319
<u>$ / MILLION BTU</u>		0.048

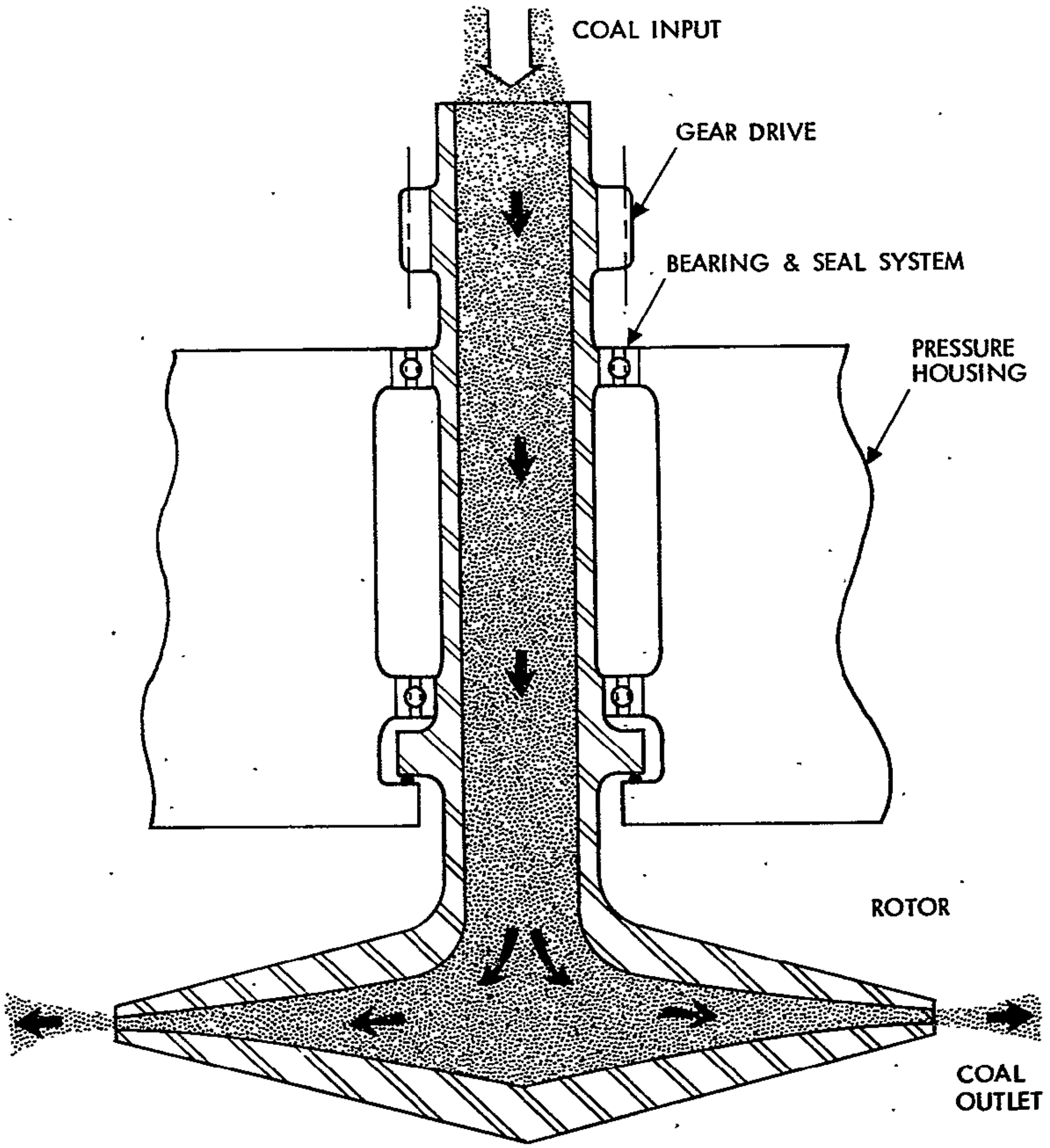

Figure A-14. Kinetic Extruder

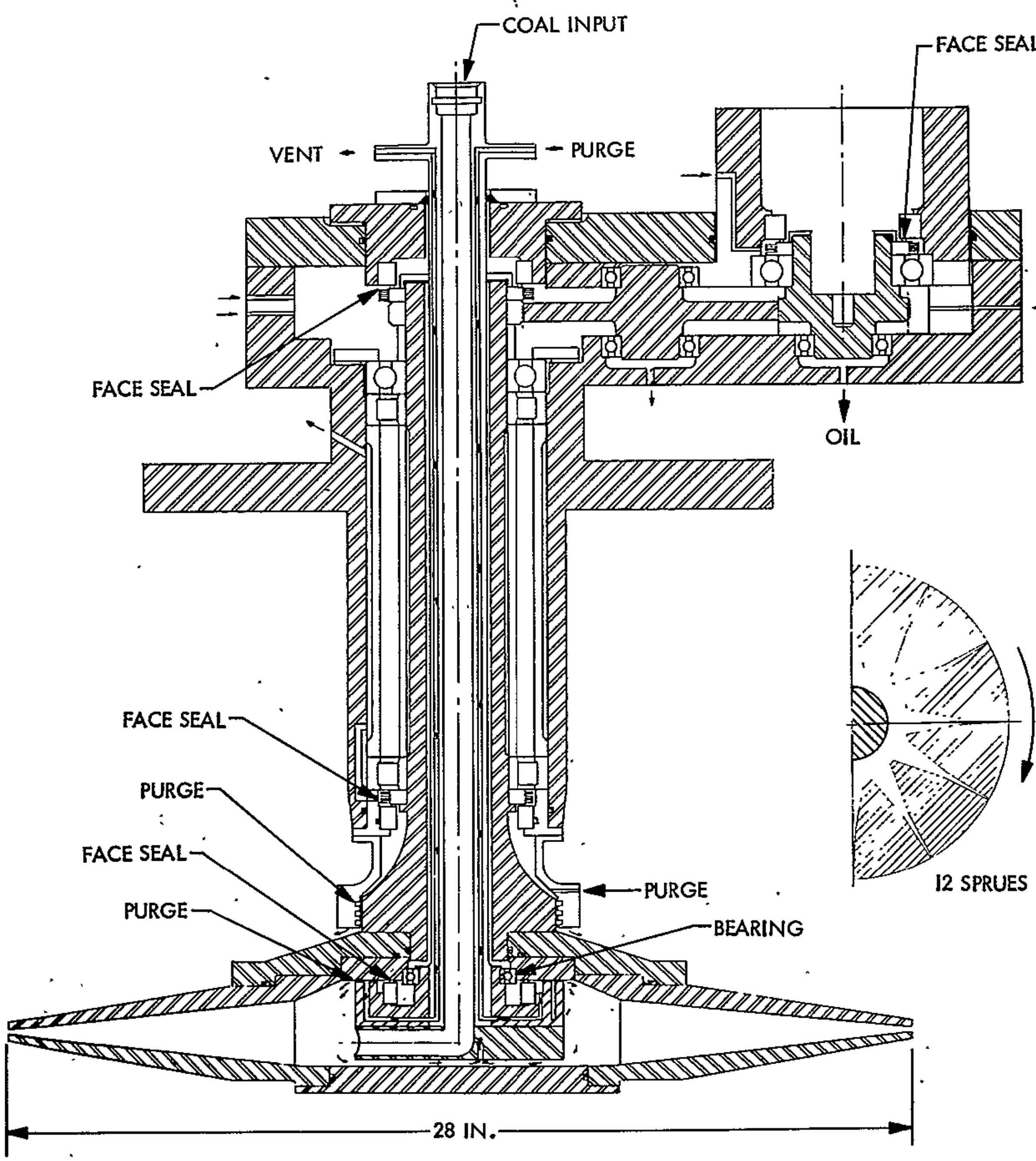

Figure A-15. Kinetic Extruder - Model No. 2

loosely here, since the coal ideally enters the rotor channels in a fluidized or near-fluidized state. A gas vent is provided by an annular passageway between the stationary feed tube and the coal inlet so that the fluidizing gas can be separated from the coal at the rotor hub.

b. System Features and Ancillary Equipment

Each feeder bank, Figure A-16, utilizes two kinetic extruders which deliver coal at 104 TPH. Six feeder banks would be required for a commercial plant handling 625 TPH. Figure A-16 shows the schematic of a 1500 psi feeder bank.

Each feeder bank consists of the following major equipment:

(1) Atmospheric storage bin.

(2) Atmospheric metering and transport system.

(3) Rotor assemblies.

(4) Rotor drive systems.

(5) Bearing and seal cooling and lubricating system.

(6) Seal pressurizing system.

(7) Rotor cooling system.

(8) High pressure storage bin.

(9) High pressure metering system.

The <u>atmospheric storage bin</u> is designed to hold 48 tons of pulverized coal. It is fitted with a 70 degree included angle cone to allow gravity feed to the atmospheric metering screw.

The <u>atmospheric metering and transport system</u> consists of a mechanical screw driven by a variable speed motor, a Venturi coal/gas pickup section, a compressor, a mass flow indicator, and a mass flow meter with a data feedback loop which monitors and controls the screw drive-motor. The transport line from the bin to the feeder rotor is a low pressure steel pipe.

The <u>rotor assemblies</u> consist of the rotors, bearings, seals, and support housing. The rotors consist of a rotor shaft and rotor extruder disks. The rotor bearings are of two types. Two cylindrical roller bearings are used for rotation and to absorb the dynamic unbalance forces which may be set up in the rotor due to the feeding characteristics. A hydrostatic thrust bearing is used to take the thrust loads on the rotor due to the differential pressure across the stage.

The two stage <u>rotor drive systems</u> consist of an electrical motor and a right angle gear system connecting the motor and the rotor.

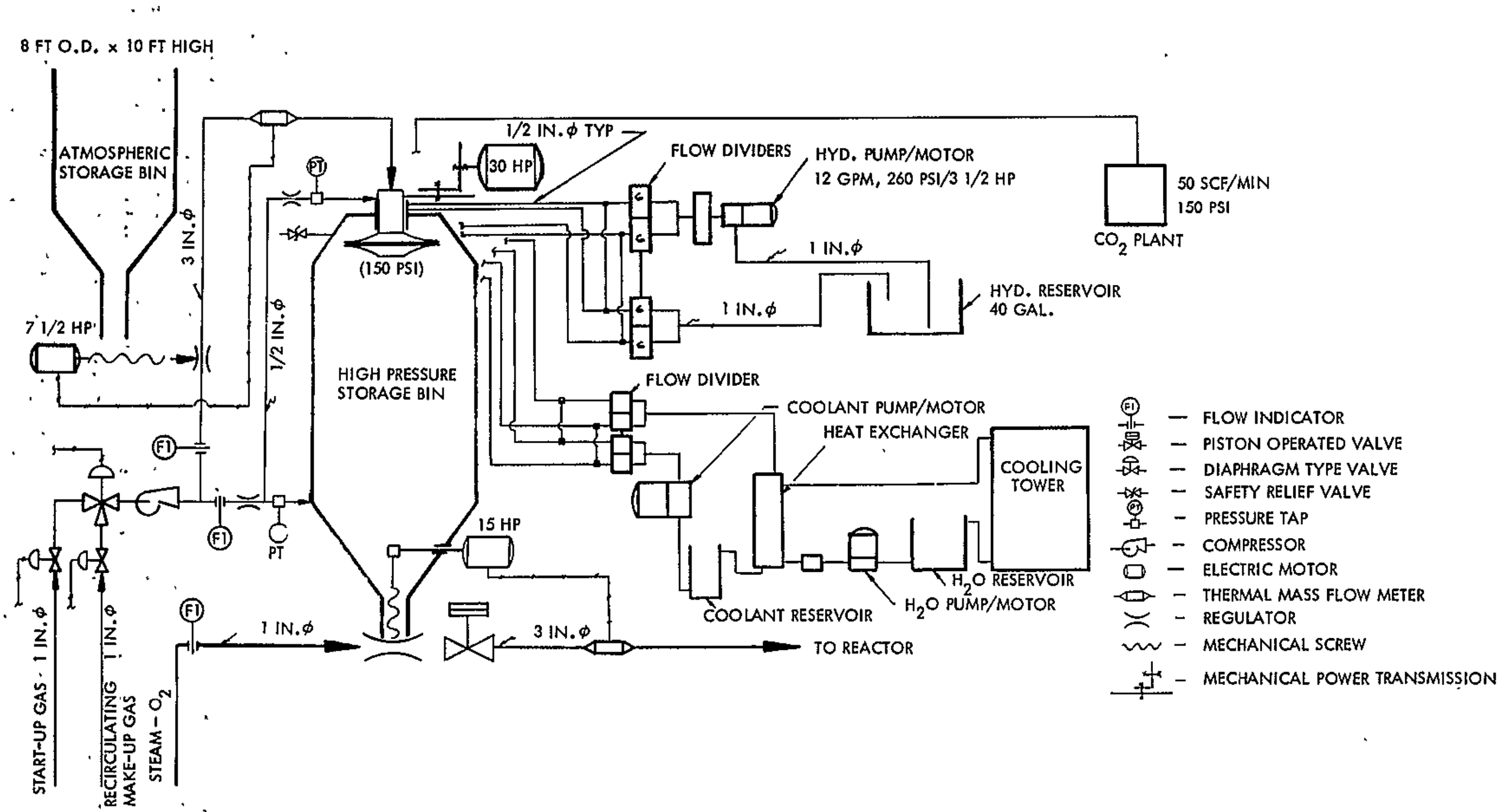

Figure A-16. Kinetic Extruder Feeder System

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The bearing and seal cooling and lubricating system supplies oil to the hydrostatic bearing, the gear drive, and the roller bearings and seals.

The seal pressurizing system supplies CO_2 to the bearing cavity at a pressure slightly elevated with respect to the stage pressure. This accomplishes two important functions: The pressure differential across the internal seal is low which enhances the life of the "hard-to-maintain" seal, and the direction of leakage is into the vessel, which precludes product gas leakage out of the vessel.

The rotor cooling system is a water-ethylene glycol closed loop coupled to an atmospheric water cooling tower via a heat exchanger.

The high pressure storage bin is sized to contain coal at an average density of 30 lb/ft^3. It is equipped with a 70 degree included angle cone to facilitate unloading.

The high pressure metering system consists of a variable speed drive motor, a mechanical screw, a coal/steam pickup Venturi section, a steam flow indicator and a mass flow meter with a data feedback loop which monitors and controls the screw drive-motor. The steam/coal transport line to the reactor is a high pressure steel pipe. A piston-operated shutoff valve is placed in this line.

c. Feeder Operation

During coal preparation, the coal is cleaned, dried, and pulverized. The coal enters the atmospheric coal bin. The rotors are brought up to speed, and all cooling and lubrication systems are operating. The start-up gas and the atmospheric metering systems are activated. The coal is metered to the pickup Venturi and subsequently deposited in the high speed rotors in a fluidized state. The coal/gas mixture is separated at the rotor hub prior to entry into the sprue. The sprue compresses the coal and forms a pressure seal and the gas is returned. When this seal has been established, pressure is applied to the bins using the start-up gas supply.

When system pressure is reached, the steam/O_2 transport valve is opened and the high pressure metering system is activated. When the point is reached at which make-up gas can be drawn from the plant, the start-up gas is turned off and the make-up gas is recirculated through the plant and feeder.

d. Cost Estimates

The estimated costs of the six bank 1500 psi kinetic extruder 625 TPH system are given in Table A-10.

Table A-10. Kinetic Extruder System Costs

Major Equipment		
Feeder rotor assemblies		773,500
Rotor cooling system		382,700
Seal pressurization system		70,070
Bearing/seal lube & coolant systems		482,882
Controls and consoles		91,000
Tanks, support structures & foundation		656,155
Valves, gages, pipe, etc.		208,485
Coal metering system (low press.)		51,651
Coal metering system (high press.)		81,900
Atmospheric storage bins		38,893
Rotor drive systems		481,080
TOTAL MAJOR EQUIPMENT		3,318,316
Other equipment & installation costs		5,033,892
ERECTED COST OF FEEDER		8,352,208
Feeder cost/throughput		$13,363/TPH
OPERATING COSTS PER YEAR		
Labor	$522,000.00	
KWh 0.25/KWh	947,360.00	
MAINTENANCE & OVERHAUL		
Labor	66,818.00	
Materials & Equipment	768,402.00	
TOTAL DIRECT COST	$2,304,580.00	
INDIRECT COSTS		
Annual cost of capital (12% of erected cost)		1,002,265.00
TOTAL ANNUAL COSTS		$3,306,845.00

e. Coal Type, Size, and Preparation Limitations

The kinetic extruder is limited to the use of fine or pulverized coal. The actual size limitations, and allowable moisture content, must still be determined through experimentation.

f. Development Considerations

Inherent problems with the kinetic extruder are

(1) It is currently projected to require two stages to reach 1500 psi.

(2) Limited to fine coal.

Critical design areas are

(1) The feed delivery system that throttles the standpipe requires further design and development. If the rotor demand is too high, the standpipe starves and if too low, the coal builds up and grinds away.

(2) Sprue design and modeling techniques require development.

Critical wear components are

(1) Seals.

(2) Bearings.

(3) Rotor sprues.

9. LOCKHEED STANDPIPE-BALL CONVEYOR FEEDER

a. Description

The standpipe conveyor shown in Figure A-17 is basically a standpipe filled with metal balls and coal conveyed in the spaces between the balls. The weight of the column overcomes the static pressure and the downward motion, due to gravity, of the balls and coal counterbalances the gas flow up the standpipe. On the return leg of the standpipe, a liquid seal is provided to prevent gas leakage.

In this coal feeder system, the pressure difference is overcome by the weight of a downward moving column of heavy metal balls in a standpipe. Coal is transported in the spaces between the balls. The balls need not have a good fit to the standpipe, since the long column of coal itself is relatively impermeable. Extra gas from the coal accumulator will be bled into the pipe at various levels so that the coal arrives at the bottom almost fully pressurized. The ball column is supported by pressure forces; there is no solids friction if the coal itself is not stressed. It should be noted that there is no need for an outside service of pressurized gas for this system.

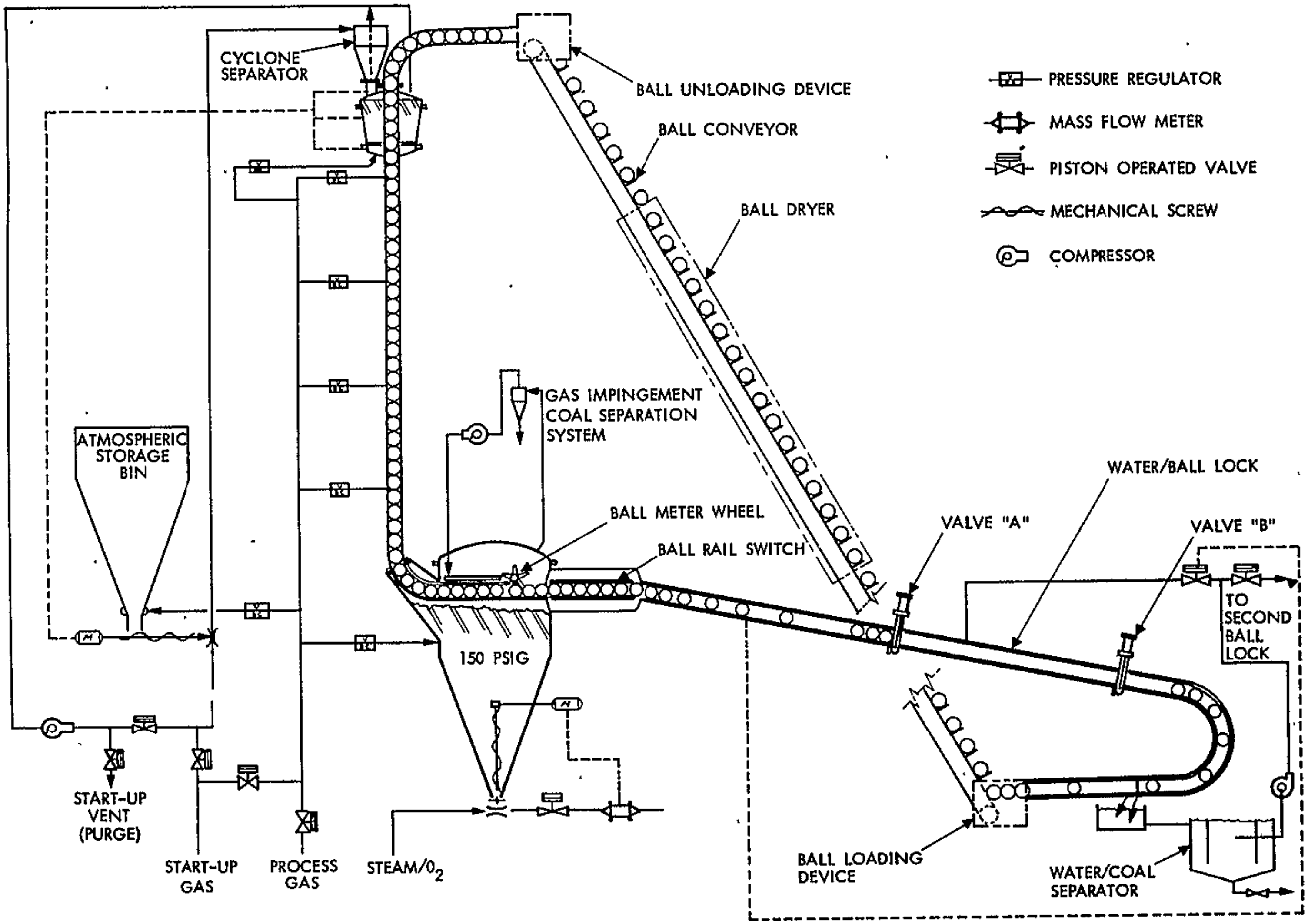

Figure A-17. Ball Conveyor (105 psi)

The balls are removed from the accumulator, again without gas leakage, through a liquid-filled ball lock as shown in Figure A-18. In this pipe lock, gate Valve A is closed, while B is open letting the liquid and ball load out to ambient pressure. Valve B is then closed, the lock is pressurized with liquid from the holding tank, and then Valve A is opened, admitting another set of balls. Dual locks could be used, one filling as the other is emptying. Note that the main Valves A and B seal against liquid instead of gas.

Balls are transported to the top of the pipe by a mechanical elevator. Pneumatic equipment is not feasible since gas leakage around the balls is calculated to be very great when coal is not present in the pipe.

Two balls conveyors each having a coal throughput of 104 TPH are used for each gasifier. For a 625 TPH plant three gasifiers would be used; this requires six conveyor feeders.

Each ball conveyor feeder consists of the following major equipment:

(1) Atmospheric storage bin.

(2) Atmospheric metering and transport system.

(3) Fluidizing hopper.

(4) Standpipe.

(5) High pressure storage bin.

(6) Ball cleaning and metering system.

(7) Ball switching system.

(8) Fluid pressure lock system.

(9) Ball elevator system.

(10) Balls.

(11) High pressure metering and transport system.

The atmospheric storage bin is designed to hold 48 tons of pulverized coal. It is fitted with a 70 degree included angle cone to allow gravity feed to the atmospheric metering system.

The atmospheric metering and transport system consists of a mechanical screw driven by a variable speed motor, a Venturi gas/coal pickup section, a compressor, and a pressure-tap system with a data feedback loop which monitors and controls the screw drive-motor. The transport line from the bin to the fluidizing hopper is a low pressure pipe.

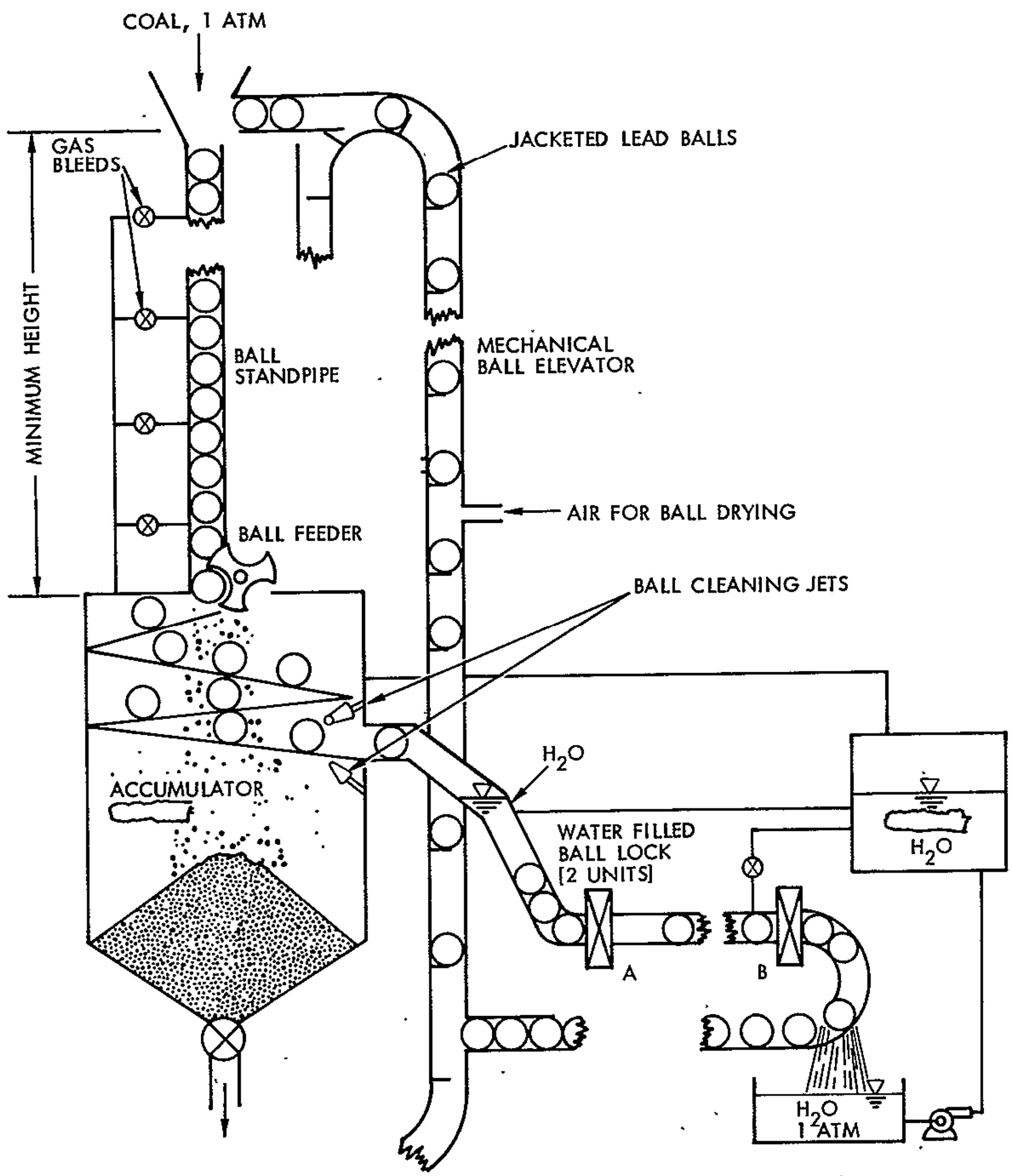

Figure A-18. Standpipe-Bell Conveyor

The fluidizing hopper system consists of a cyclone separator, and a coal hopper which surrounds the entrance to the standpipe.

The standpipe is a segmented pipe with pressurizing ports spaced down the length of the pipe at specified intervals.

The high pressure storage bin is sized to contain coal at an average density of 30 lb/ft^3. It is equipped with a 70 degree included cone to facilitate unloading.

The ball cleaning and metering system consists of a cyclone separator, compressor, and gas jet manifold, and a star-wheel ball velocity control.

The ball switching system consists of a rail switching structure and actuator and a ball counter.

The fluid pressure lock system consists of an entrance and exit pressure valve, a water/coal collector and separator, and a water recycling pump.

The ball elevator system consists of a loading and unloading mechanism, an inclined ball conveyor, and a hot gas heater enclosing the conveyor.

The balls are made of steel-jacketed lead.

The high pressure metering and transport system consists of a variable speed drive motor, a mechanical screw, a coal/steam pickup Venturi section, a steam flow indicator, and a mass flow meter with a data feedback loop which monitors and controls the screw drive motor.

The steam coal transport line to the reactor is a high pressure pipe. A piston-operated shutoff valve is placed in this line.

b. Feeder Operation

During coal preparation, the coal is cleaned, dried, and pulverized. The coal enters the atmospheric bin. The startup gas and the atmospheric metering systems are activated. The coal is metered to the pickup Venturi and subsequently deposited into the fluidizing hopper system through the cyclone separator. When the coal in the fluidizing hopper has reached the operating level, the ball metering mechanism is activated which allows the balls to pass through the fluidized coal bed in the hopper, thereby collecting the proper coal load upon entry into the standpipe. System pressure begins to elevate as the ball/coal column proceeds down the pipe. Upon entry into the high pressure bin, the coal dumps and the balls are cleaned and proceed through the switching mechanism and through the fluid pressure locks to recycle back through the feeder. At a specified time after startup, the steam/O_2 valve is opened and the high pressure metering system is activated and coal is transported and injected into the reactor.

c. Cost Estimates

Estimated costs for six ball conveyors, which collectively deliver coal at 625 TPH, are given in Table A-11.

d. Coal Type, Size, and Preparation Limitations

The ball conveyor is limited to the use of medium to coarse coal.

e. Development Considerations

The primary inherent problem with the ball conveyor is that it is limited to 150 psi pressures.

Critical design areas are:

(1) Purging gas out of the H_2O feed line.

(2) Ball letdown and spacing is a major feeding and control requirement.

Wear does not appear to be a critical development area, being limited to the balls and pipes.

10. LOCKHEED FLUID DYNAMIC LOCK FEEDER

a. Description

The bladeless disk pump shown in Figure A-19 is operated near stall conditions to obtain a pressure differential across the device. Coal particles, entrained in a gas transport system, enter the device and pass through it under the influence of viscous drag and centrifugal forces. The bladeless pump is designed to maintain a pressure ratio of about 2:1.

The advantages of this device in the present application stem from the fact that wear is greatly reduced since blades are not present; the solid particles do not leave at the full peripheral disk speed, thus particle velocity and the resulting power to impart the high kinetic energy to the particles are reduced when compared to conventional centrifugal devices. Owing to the simple shapes used, the device should be inexpensive to manufacture from wear-resisting materials, expecially if flat disks of uniform cross section are used.

The schematic diagram for a single feeder bank of staged pumps for a 1500 psi system is shown in Figure A-20.

Table A-11. Ball Conveyor System Costs

MAJOR EQUIPMENT	
Ball Conveyor	551,337
Balls	236,509
Ball Circuit	54,991
Feed Hopper	16,107
Atmospheric Hopper	27,281
Pressurized Hopper	61,870
Ball Dryer	341,250
Switch	13,590
Meter Wheel	15,647
Compressors	41,769
Cyclones	29,120
Conveyor Loading & Unloading Device	163,800
Valves, gages, regulators, pipe & fittings	379,001
Settling Tank & pump	20,866
Screw Feeder Systems	78,260
MAJOR EQUIPMENT COST	$2,031,398 X 2
Sub Total	$4,062,796
Other Equipment & Installation Costs	6,163,270
ERECTED COST OF FEEDER	$10,226,066
Feeder Cost/Throughput	$16,371 / TPH

Table A-11. Ball Conveyor System Costs (Continuation 1)

OPERATING COST/YEAR	
Labor	$ 522,000
Utility Power	1,651,090
MAINTENANCE & OVERHAUL	
Labor	$3,681,384
Material & Equipment	2,454,256
TOTAL DIRECT COSTS	$8,308,730

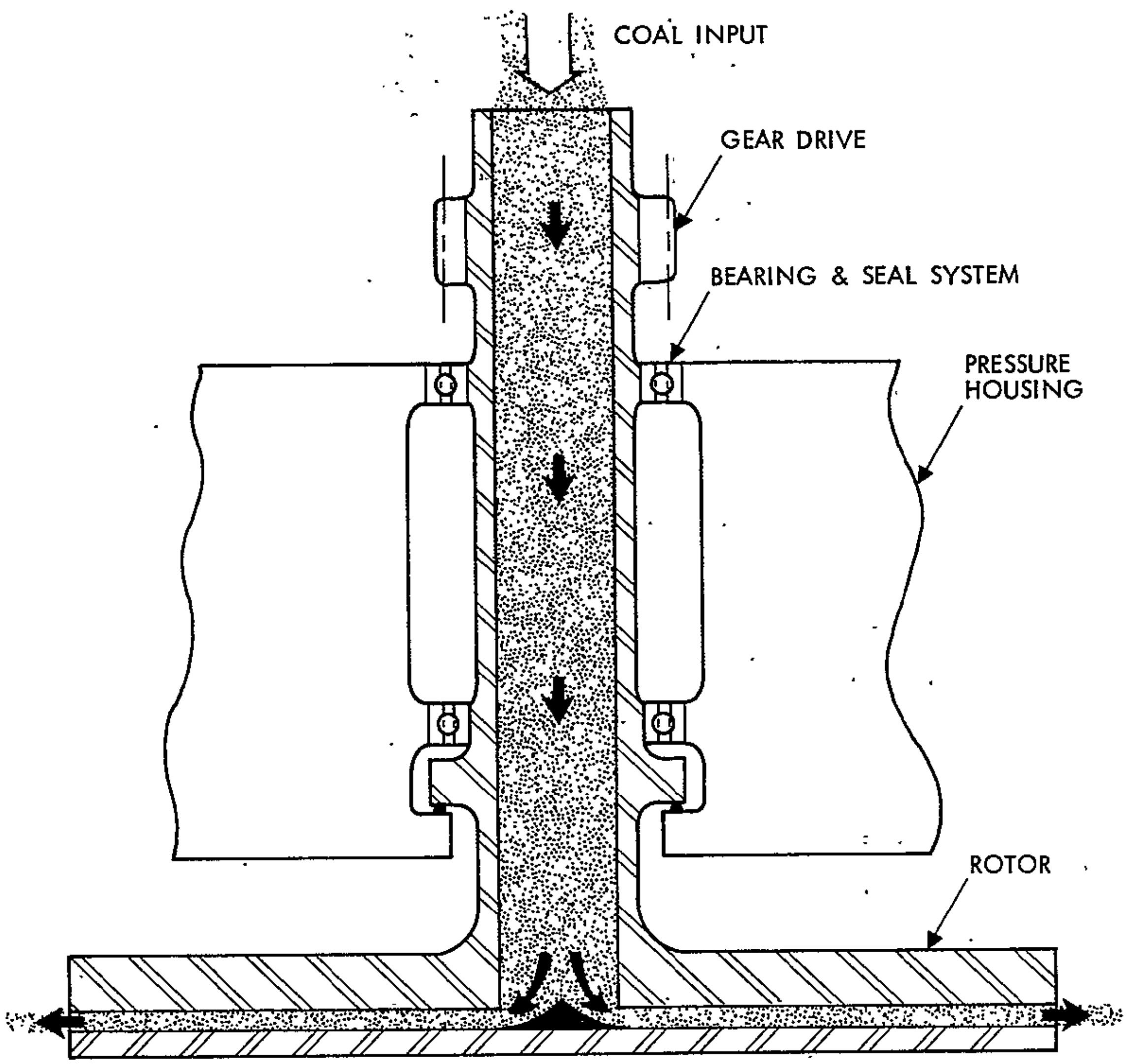

Figure A-19. Fluid-Dynamic Lock

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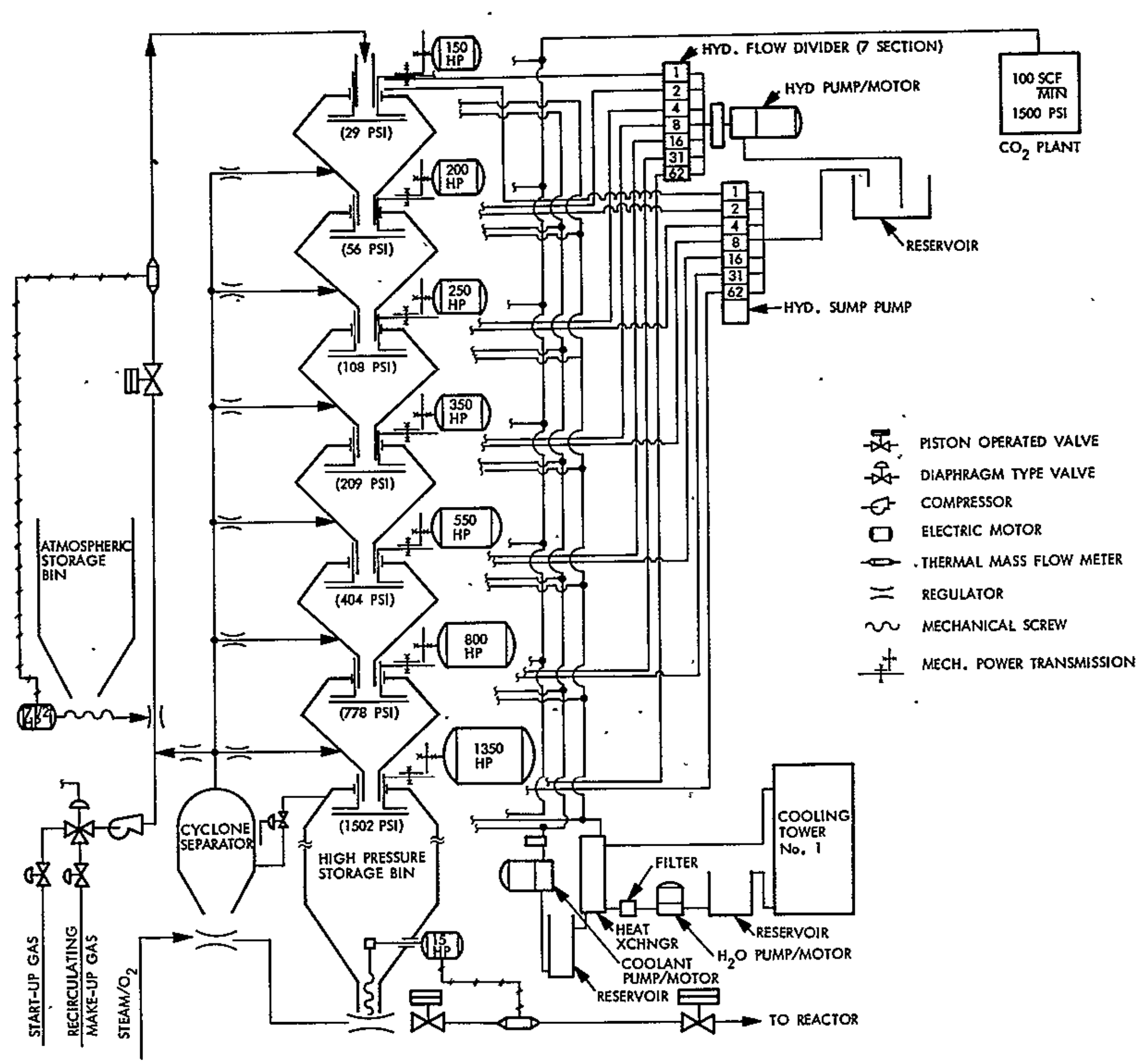

Figure A-20. Fluid-Dynamic Lock System

Two banks of staged pumps are used in the feeder system. Since each bank is designed for a throughput of about 104 TPH, a commercial plant requiring 625 TPH would have six feeder banks. Assuming three gasifiers per plant, there would be two feeder banks per gasifier.

A single feeder bank consists of the following major equipment:

(1) Atmospheric storage bin.

(2) Atmospheric metering and transport system.

(3) Rotor assemblies and housings.

(4) Rotor drive systems.

(5) Bearing and seal cooling and lubrication system.

(6) Seal pressurizing system.

(7) Rotor cooling system.

(8) High pressure storage bin.

(9) Cyclone separator and recirculating manifold.

(10) High pressure metering system.

The atmospheric storage bin is designed to hold 48 tons of pulverized coal. It is fitted with a 70 degree included angle cone to allow gravity feed to the atmospheric metering screw.

The atmospheric metering and transport system consists of a mechanical screw driven by variable speed motor, a Venturi coal/gas pickup section, a compressor, a gas flow indicator, and a mass flow meter with a data feedback loop which monitors and controls the screw drive motor. The transport line from the bin to the first stage feeder rotor is a low pressure steel pipe.

The rotor assemblies consist of the rotors, bearings, seals, and support housing. The rotors consist of a rotor shaft and disk. The rotor bearings are of two types. Two cylindrical roller bearings are used for rotation and to absorb dynamic unbalance forces which may be set up in the rotor due to feeding characteristics. A hydrostatic thrust bearing is used to take the thrust loads of the rotor due to a differential pressure across the stage.

The rotor drive systems consist of an electric motor and a right angle gear system connecting the motor and the rotor. A 1500 psi feeder bank requires seven motors with matching speed increasers.

Stage	HP
5	550
6	800
7	1350

The <u>bearing and seal cooling and lubricating systems</u> supply the oil to the hydrostatic bearing, the gear drive, and the roller bearings and seals.

The <u>seal pressurizing system</u> supplies CO_2 to the bearing cavity at a pressure slightly elevated with respect to the stage pressure. This accomplishes two important functions: The pressure differential across the internal seal is low, which enhances the life of the "hard-to-maintain" seal, and the leakage will be into the vessel, which precludes product gas leakage out of the vessel.

The <u>rotor cooling system</u> is a water-ethylene glycol closed loop coupled to an atmospheric water cooling tower via a heat exchanger.

The <u>high pressure storage bin</u> is sized to contain 33 tons of coal at an average density of 30 lb/ft^3. It is 55 feet long and has a diameter of 22 ft. It is equipped with a 70 degree included angle cone to facilitate unloading.

The <u>high pressure metering system</u> consists of a variable speed drive motor, a mechanical screw, a coal/steam pickup Venturi section, a steam flow indicator, and a mass flow meter with a data feedback loop which monitors and controls the screw drive motor. The steam/coal transport line to the reactor is a high pressure steel pipe. A piston operated shutoff valve is placed in this line.

b. Feeder Operation

Pulverized coal is metered from the atmospheric coal bin to the pneumatic transport line and deposited to the input of the first stage pump of the feeder. To maintain constant volumetric loading as the coal proceeds through the stages, gas must be added to compensate for the increase in pressure across a given stage. The fluidized coal proceeds through the seventh stage and is stored in the high pressure storage bin at coal partial density of 35 lb/ft^3.

The coal is metered through the high pressure metering system and inducted into the steam/O_2 transport and injected into the reactor. An amount of gas representing the difference between the gas contained in the coal arriving in the high pressure bin and that contained in the coal (leaving the high pressure bin) can be taken from the high pressure bin. This residual gas is processed through a cyclone separator and filter and introduced to the recirculating manifold for recirculation within the feeder. This reduces the amount of make-up gas required.

c. Cost Estimates

The estimated costs of the 1500 psi fluid dynamic lock with throughput of 625 TPH are given in Table A-12. The system includes six staged feeders (two feeders for each three gasifiers).

Table A-12. Fluid Dynamic Lock System Costs

MAJOR EQUIPMENT	
Feeder rotor assemblies	$2,229,500
Rotor cooling system	1,030,538
Seal pressurization system	99,808
Bearings/seal lube & coolant systems	400,900
Controls & Console	113,750
Tanks, Support Structure & Foundation	2,095,193
Valves, gages, pipe, fittings, etc.	317,685
Coal metering system, low pressure	51,651
Coal metering system, high pressure	81,900
Atmospheric storage bin	38,893
Cyclone separator	22,750
Rotor drive systems	3,649,095
TOTAL MAJOR EQUIPMENT (3 trains/gasifier)	$10,131,667
Other Equipment & Installation	15,369,741
ERECTED COST OF FEEDER	$25,501,408
Feeder Cost/Throughput	$40,802/TPH

Table A-12. Fluid Dynamic Lock System Costs (Continuation 1)

OPERATING COSTS/YEAR	
Labor	$ 522,000
kWh 0.25/kWh	6,925,648
MAINTENANCE & OVERHAUL	
Labor	$ 229,512
Material & Equipment	2,320,627
TOTAL DIRECT COST	$9,997,787
INDIRECT COSTS	
Annual Cost of Capital (12% of erected cost)	$3,060,170
TOTAL ANNUAL COST	$9,021,895

d. Coal Type, Size, and Preparation Limitations

The fluid dynamic lock is limited to dry, fine coal.

e. Development Considerations

Inherent problems of the fluid dynamic lock are

(1) It is limited to a 2:1 pressure ratio and therefore requires many stages to attain 1500 psi.

(2) Parasitic skin drag on rotating disk for commercial scale flow rate and pressure (1500 psi) is a major drive power drain that could only be reduced through the use of special gas mixtures in the pressurized receiver.

Critical design areas which require further development are

(1) Rotating face and bearing seals.

(2) Modeling and designing the transition phase of coal feeding and delivery to obtain efficient methods of transferring the descending coal to radial flow.

Critical wear components which must be replaced every 8000 hours are

(1) Bearings.

(2) Seals.

(3) Disks.

11. LOCKHEED GAS-SOLIDS INJECTOR CONCEPT

a. Description

In this concept, a staged injector pump transfers pulverized coal from atmospheric pressure to the high system pressure. The system shown in Figures A-21 and A-22 uses a compressor to drive the injector. The particle-free recirculating gas jet entrains the solid particles. The solids are taken from one pressure level to the next by jet entrainment. The recirculating gas is cooled prior to compression and particle separators are used to de-entrain the solid particles. Although this concept requires no valves and no moving parts in the coal cycle, the pressure ratio for each stage is limited to a 2:1 ratio and therefore seven stages are needed to obtain 1500 psi.

A schematic diagram of a feeder bank, delivering coal at 208 TPH for a 1500 psi system, is shown in Figure A-23. For a plant delivering 625 TPH, three feeder banks are required. Assuming three gasifiers are installed per plant, one feeder bank is assigned to each gasifier.

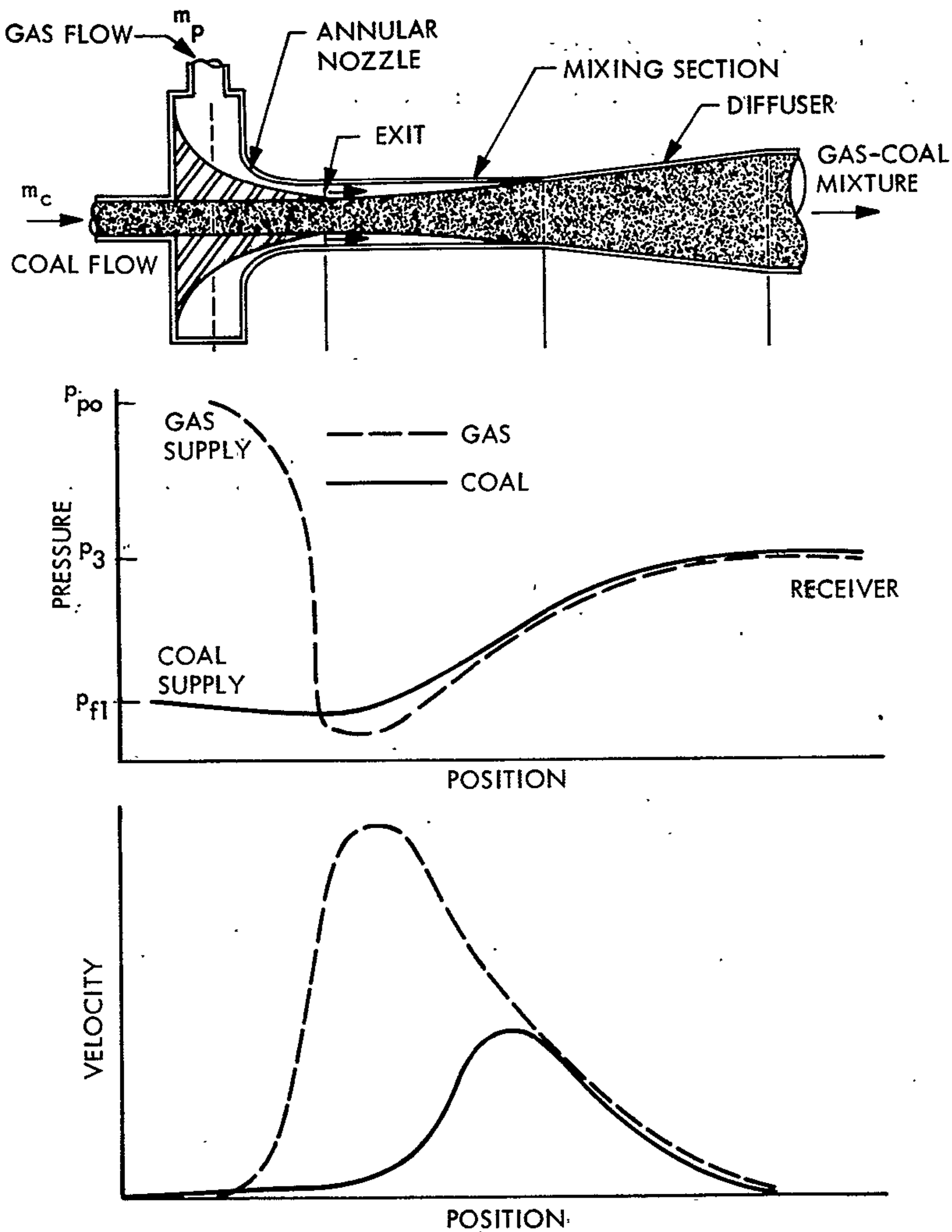

Figure A-21. Ejector Schematic

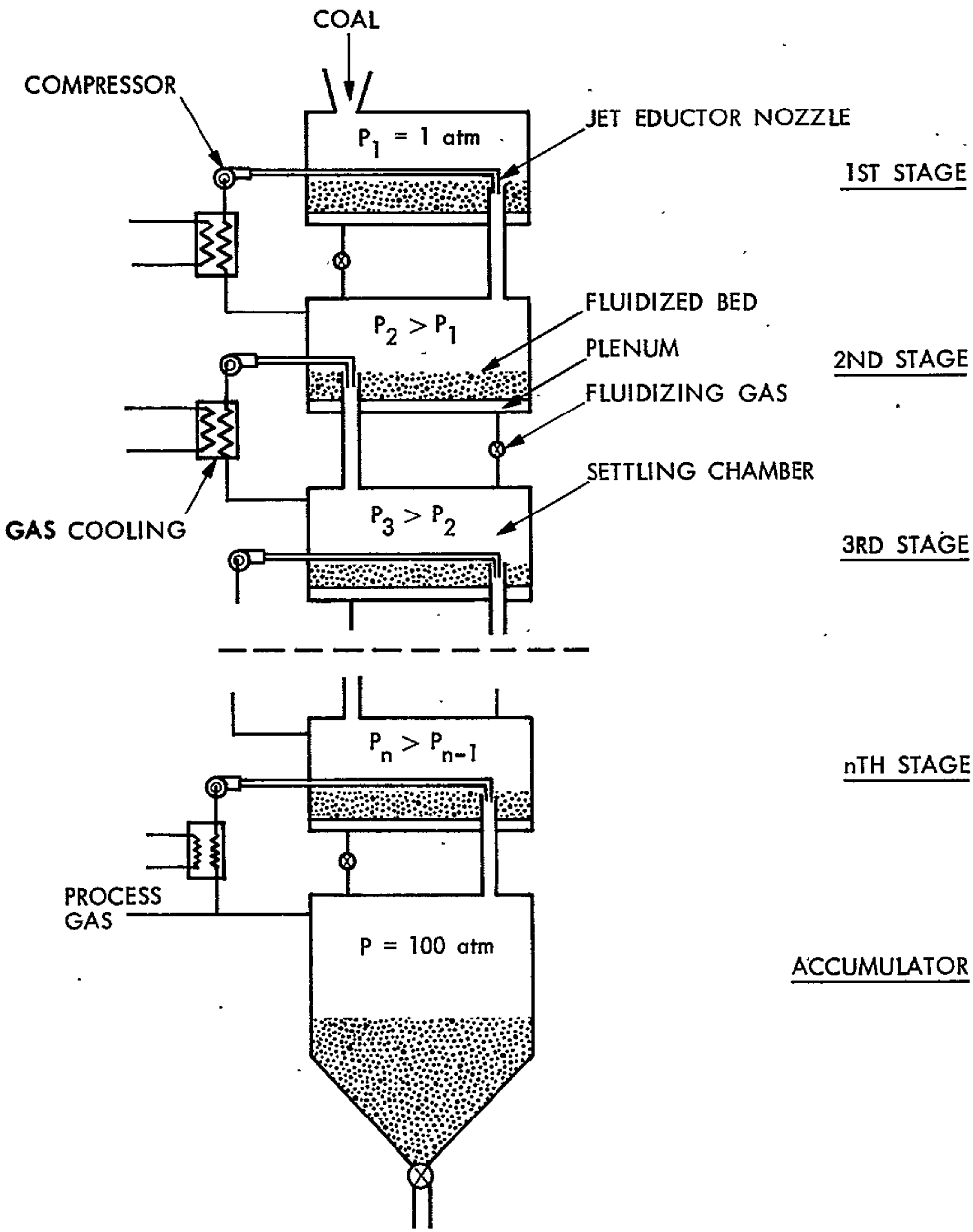

Figure A-22. Gas-Solids Injector Concept

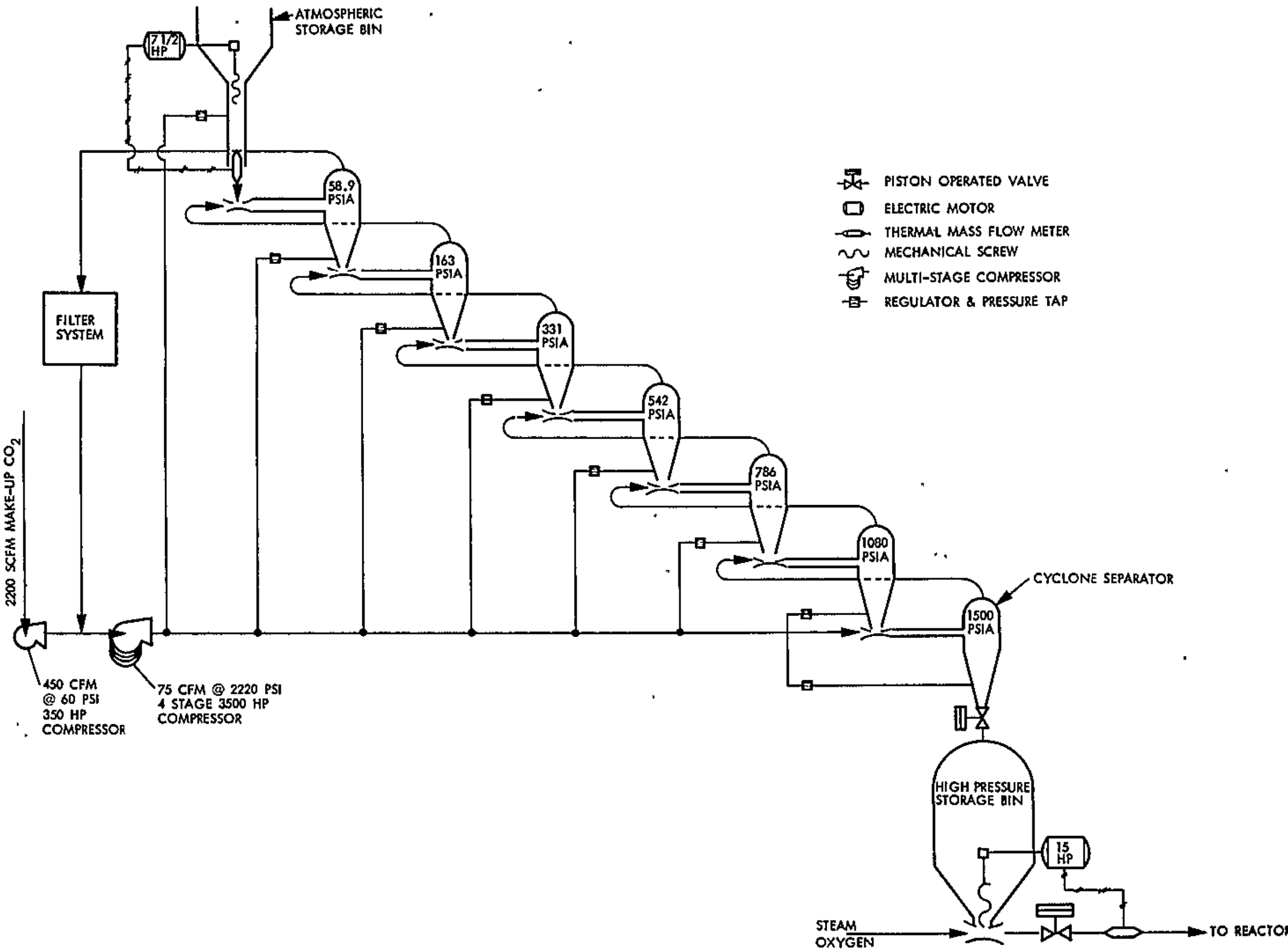

Figure A-23. Injector System

Each feeder bank consists of the following major equipment:

(1) Atmospheric storage.

(2) Atmospheric metering system.

(3) Injectors.

(4) Main compressor.

(5) Filter system.

(6) CO_2 make-up compressor.

(7) Cyclone separators.

(8) High pressure storage system.

(9) High pressure metering system.

The atmospheric storage bin is designed to hold 48 tons of pulverized coal. It is fitted with a 70 degree included angle cone to allow gravity feed to the atmospheric metering screw.

The atmospheric metering system consists of a mechanical screw driven by a variable speed motor. A mass flow meter with a data feedback monitors and controls the screw drive motor.

The injectors are characterized by a constant-area mixing chamber in which the primary particle-free gas is decelerated by the entrained coal particles with a resulting increase in pressure.

The main compressor is a four-stage reciprocating type with interstage cooling.

The filter system consists of a cyclone separator, a pre-filter two-stage centrifugal type.

The stage cyclone separators are capable of withstanding full system pressure.

The high pressure storage bin is sized to contain coal at an average density of 30 lb/ft^3. It is equipped with 70 degree included angle cone to facilitate unloading.

The high pressure metering system consists of a variable speed drive motor, a mechanical screw, a coal/steam pickup Venturi section, a steam flow indicator, and a mass flow meter with a data feedback loop which monitors and controls the screw drive motor. The steam/coal transport line to the reactor is a high pressure steel pipe. A piston-operated shutoff valve is placed in this line.

b. Feeder Operation

During coal preparation, the coal is cleaned and dry pulverized coal enters the atmospheric coal bin. The piston-operated shutoff valve in the transport line to the reactor is closed. The compressors are started and system pressure increases. At a specified pressure level in the first stage cyclone, the atmospheric metering system is activated. Upon arrival of coal in the high pressure bin, the high pressure metering system and the steam-oxygen transport system start and the opening of the shutoff valve occurs. At the point in time when make-up gas can be drawn from the high BTU plants, the startup gas system is turned off and make-up gas is recirculated through the plant and feeder.

c. Cost Estimates

Estimated costs of the three feeder bank, 1500 psi injector system for a 625 TPH plant are given in Table A-13.

d. Coal Type, Size, and Preparation Limitations

The injector is limited to dry, medium sized coal.

e. Development Considerations

The major inherent problem with the injector concept is its limitation to a 2:1 pressure ratio on each stage. It therefore requires many stages to obtain 1500 psi.

A critical design problem is the requirement for a conveniently removable nozzle or access design that minimizes replacement of throat "high wear" sections.

Critical wear components are

(1) Nozzle throat.

(2) Compressor seals and bearings.

Table A-13. Gas-Solids Injector System Costs

<u>Major Equipment</u>		
Atmospheric Storage Bins	$ 42,740	
Atmospheric Coal Metering System	56,760	
High Pressure Coal Metering System	90,000	
Tanks, Support Structure, and Foundation	530,000	
Valves, Gages, Pipe, Etc.	300,000	
Cyclones and Regulators	301,510	
CO_2 Compressors, Drives, and Switchgear	4,668,000	
Filter Systems	175,000	
Jet Pumps	1,330,000	
Controls and Consoles	228,750	
TOTAL MAJOR EQUIPMENT COSTS		$ 7,722,760
Other Equipment and Installation Costs	6,183,210	
ERECTED COST OF FEEDER		$13,905,970
Feeder Cost/Throughput	22,250/TPH	

Table A-13. Gas-Solids Injector System Costs (Continuation 1)

OPERATING COSTS/YEAR		
Labor	$ 522,000	
kWh (.025kWh)	4,096,000	
MAINTENANCE AND OVERHAUL		
Labor	5,006,149	
Material and Equipment	3,337,433	
TOTAL DIRECT COST	$12,961,580	
INDIRECT COST		
Annual Cost of Capital (12% of Erected Cost)	1,668,716	
TOTAL ANNUAL COST		$14,630,296