EVALUATION OF ERDA-SPONSORED COAL FEED SYSTEM DEVEL)PMENT

R. L. Phen

W. K. Luckow

L. Mattson

D. Otth

P. Tsou

Jet Propulsion Laboratory
Pasadena, California

N78-13252

ABSTRACT

In March of 1977 the Jet Propulsion Laboratory began to provide staff support to the ERDA coal feeder development program. An initial task in that support effort was the evaluation of the coal feeders under development by ERDA. The objective of the evaluation was to recommend to ERDA those coal feed systems which should continue to receive development support as the program progressed into the pilot-scale phase, and to recommend the development actions to be undertaken for the selected feeders. The evaluation was based upon criteria such as technical feasibility, performance (i.e. ability to meet process requirements), projected life cycle costs and projected development cost. An evaluation methodology was developed which incorporated the evaluation criteria. Using this methodology, an initial set of feeders were selected based on the feeders' cost savings potential compared with baseline lockhopper systems. Additional feeders were considered for selection based on: 1) increasing the probability of successful feeder development, 2) application to specific processes and 3) technical merit. This paper presents the results of the evaluation, lists the feeders recommended for continued development and outlines a coal feeder development program.

INTRODUCTION

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. (IRR), 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 concepts are now being evaluated and tested by the contractors in preparation for a pilot-scale system demonstration effort which will begin about October 1977.

The objective of the JPL 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-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 which includes the development contractor; a brief description of the feeders, their characteristics and development status.

EVALUATION APPROACH

The criteria for the evaluation included:

- Technical feasibility
- Performance, i.e., ability to meet process requirements
- Projected life cycle costs
- Projected development risk and costs

Table 1. Coal Feed Systems

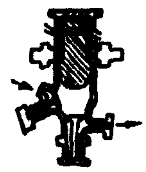
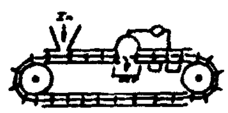
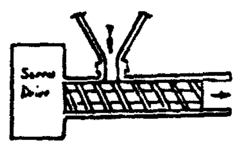
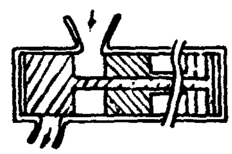
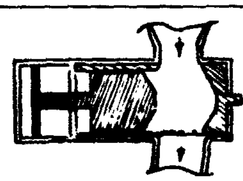
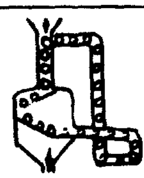
System	Developer	Schematic Drawing	Description	Pressure Limitations
• Positive Displacement	Foster-Miller		Cycled cavity piston fluidized coal feeder	1500 psi
• Centrifugal Feeder	Foster-Miller		Rotating centrifugal fluidized coal pump	1500 psi
• Linear Pocket Feeder	Foster-Miller		Tubular conveyor with coal conveyed to high pressure by a chain of interconnected pistons	1500 psi
• Screw Feeder	Ingersol-Rand		Type of auger which conveys coal axially down its length as the screw is rotated	1500 psi
• Single Acting Piston Feeder	Ingersol-Rand		Two coaxial delivery pistons operate in a common cylinder housing	1500 psi
• Rotary Valve Piston Feeder	Ingersol-Rand		Coal is transferred to high pressure by a poston sleeve rotation	1500 psi
• Kinetic Extruder Feeder	Lockheed		Rotating centrifugal fluidized coal pump	1000 psi (single stage) 1500 psi (two stages)
• Standpipe-Ball Conveyor Feeder	Lockheed		Standpipe filled with metal balls which conveys coal in the spaces between the balls	300 psi

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Table 1. Coal Feed Systems (Continuation 1)

System	Coal Type, Size and Preparation Requirements	Development Status	Development Uncertainties
• Positive Displacement	• Any type • Size - fine/medium	Prototype in test	• Purging gas requirements may become large in large factors • Valve sequencing and sizing • Materials selection for seals and valve seats
• Centrifugal Feeder	• 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	• 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	• 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	• 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
• Rotary Valve Piston Feeder	• Any type • Size - fine to coarse	Concept only	• Same as single acting piston feeder
• Kinetic Extruder Feeder	• Any type • Size - fine	Prototype in test	• Same as centrifugal feeder
• Standpipe-Ball Conveyor Feeder	• Any type • Size - fine to coarse	Bench tests	• Control of ball spacing and feeding mechanism • Purging gas out of CO_2 feed line

Table 1. Coal Feed Systems (Continuation 2)

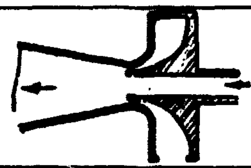
System	Developer	Schematic Drawing	Description	Pressure Limitations
• Fluid Dynamic *	Lockheed		Rotating bladeless turbine	2:1 pressure ratio per stage
• Gas-Solids Injector, Feeder	Lockheed		Gas-solids injector pump	2:1 pressure ratio per stage

Table 1. Coal Feed Systems (Continuation 3)

System	Coal Type, Size and Preparation Requirements	Development Status	Development Uncertainties
• Fluid Dynamic Lock Feeder	• 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	• Any type • Size - fine/medium	Prototype tests	• Wear in nozzle throat • Compressor seals and bearings

Factors contributing to each feeders' relative capabilities in the above categories is shown in the methodology flow diagram given in Figure 1. The approach illustrated 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 lock-hopper system.

(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.

(6) Consider recommending an expanded set of feeders as a means of increasing the probability of feed system commercialization.

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

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

DATA ACQUISITION

Data to accomplish the evaluation was obtained from the three feeder contractors and additional subcontractors as listed in Table 2. All data were analyzed by JPL for use in the evaluation.

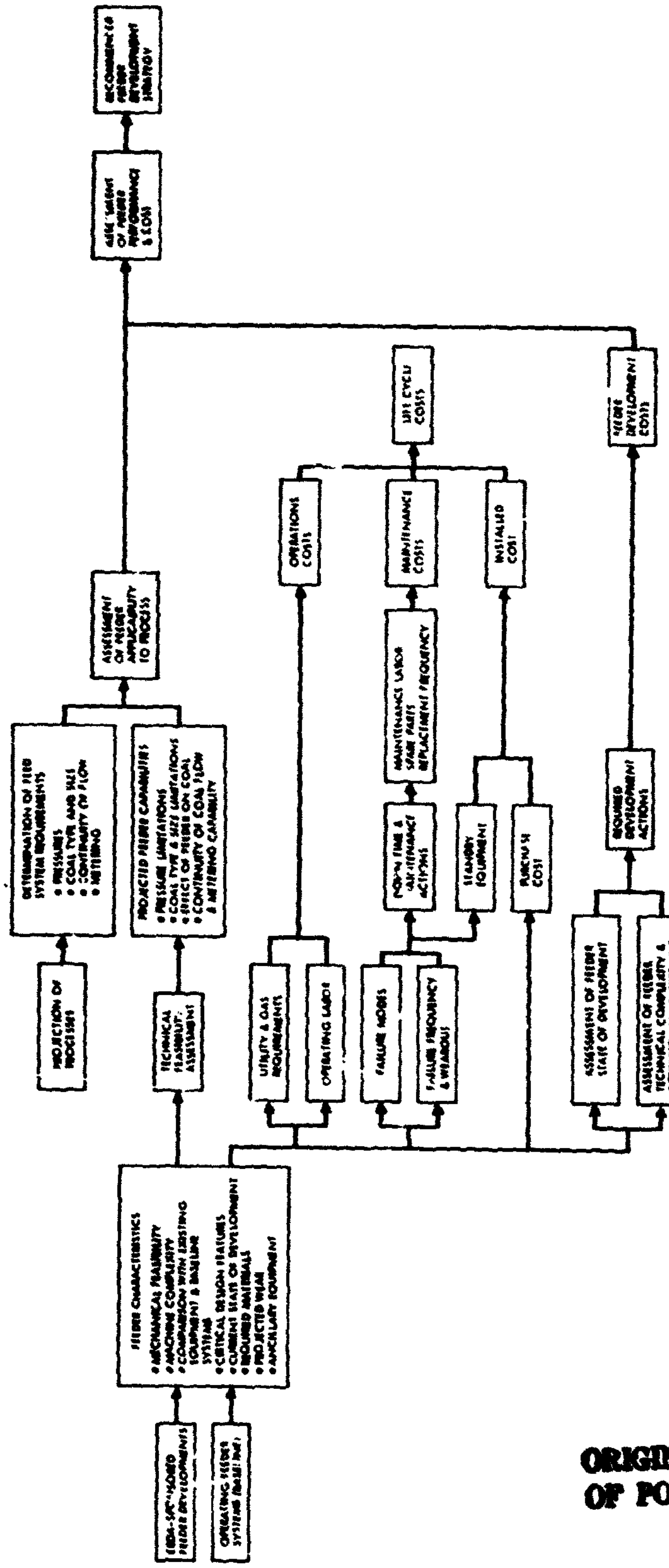


Figure 1. Coal Feed System Evaluation Methodology

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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 the following:

- pressure - 150 to 1500 psi
- 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
- continuous flow should be provided
- coal metering capabilities are required
- lifetime - 20 years

The above requirements were developed by analysis of the conversion processes which were anticipated to achieve future commercialization. Further review of these processes enables 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 matched against the generic requirements of the processes to establish the compatibility of the candidate feeders and the various conversion processes. Generic process conditions were determined by analysis of processes characteristics and are shown in Table 3. Application of the candidate feeders to the generic process conditions is shown in Table 4.

DEVELOPMENT UNCERTAINTY RANKING AND RELIABILITY

The development status and development problem areas have been used to estimate the commercialization potential for each feeder. The following

DATA	SOURCE [1]
TECHNICAL ASSESSMENT	
• TECHNICAL DESCRIPTIONS	CONTRACTORS
• STATE OF DEVELOPMENT	CONTRACTORS
• DEVELOPMENT PROBLEM AREAS	CONTRACTORS
• RELIABILITY	KAMAN SCIENCES
PROJECTED PERFORMANCE	
• PRESSURE	CONTRACTORS
• COAL TYPE & SIZE LIMITATIONS	CONTRACTORS
• EFFECT OF FEEDER ON COAL	CONTRACTORS
PROCESS APPLICABILITY	JPL
PROCESS IMPACT	INTERNATIONAL SCIENCE AND TECHNOLOGY
PROJECTED COSTS	
• INSTALLED	CONTRACTORS, ICARUS[2]
• OPERATING	CONTRACTORS, JPL
• MAINTENANCE	CONTRACTORS, JPL[2]
• DEVELOPMENT	JPL
PROBABILITY OF SUCCESSFUL DEVELOPMENT	JPL

(1) IN ALL CASES DATA WAS ASSESSED BY JPL
(2) RELIABILITY DATA FROM KAMAN SCIENCES WAS USED TO DETERMINE STANDBY EQUIPMENT, SPARES, DOWNTIME, ETC.

Table 2. Data Sources

Table 3. 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 4. 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	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 due to feeder's inability to provide required coal size consist

P - Incompatible feeder/process combinations due to feeder's inability to feed to required pressure.

are the estimates of 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

Reliability analysis of the feeders were conducted by Kaman Sciences, Corp. The results of this analysis are summarized in Table 5. The table shows pertinent failure rate and availability data, and the number of redundant systems required per gasifier to achieve 95% availability. Note that the IRR screw feeder has the best reliability and that the FMA positive displacement pump has severe projected reliability problems due to its complexity and the large number of feeders required for a plant. It is important to note that the most significant contributors to most of the feed systems' unreliability were ancillary equipment. Therefore, feed system considerations should receive greater attention in the future development program.

Table 5. Summary of Feed-System Reliability Considerations(1)

Feed System	Failures in 10^6 Hours	Availability per Feeder or Train	Availability per Gasifier	Feeders or Trains per Gasifier	Required Backup Feeders or Trains per Gasifier for 95% Availability
Screw Feeder					
Unheated	1,290	0.96	0.85	4	1
Heated	1,490	0.96	0.85	4	1
Gas-Solids Injector	3,060	0.93	0.93	1	1
Ball Conveyor Feeder	3,710	0.92	0.85	2	1
Centrifugal Feeder	3,890	0.91	0.91	1	1
Kinetic Extruder Feeder	4,230	0.91	0.83	2	1
Single Acting Piston Feeder	4,800	0.90	0.66	4	2
Rotary Piston Feeder	4,850	0.89	0.63	4	2
Linear Pocket Feeder	7,530	0.85	0.61	3	2
Fluid Dynamic Lock Feeder	10,180	0 80	0.64	2	2
Positive Displacement Feeder	39,540	0.51	0.13	3	3 (2)
Lockhopper	5,120	0.89	0.79	2	2
Slurry Pump	2,430	0.95	0.90	2	1

(1) Data provided by Karran Sciences, Corp.

(2) Adding three additional feeder banks/gasifier would only increase the availability to 52%. Additional feeders required to achieve 95% availability were not determined.

Table 6. Technical Assessment Ranking

Development Uncertainty Ranking	Ability to Meet Requirements	Reliability Ranking	Overall Ranking
1. Screw	1. Single Acting and Rotary Piston	1. Screw	1. Screw
2. Gas-Solids Ejector	2. Screw	2. Gas-Solids Ejector	2. Single Acting Piston
3. Positive Displacement	3. Positive Displacement Piston	3. Ball Conveyor	2. Rotary Piston
3. Linear Pocket	3. Centrifugal/Kinetic Extruder	3. Centrifugal	3. Centrifugal
4. Single Acting Piston	3. Linear Pocket	3. Kinetic Extruder	3. Kinetic Extruder
4. Rotary Valve Piston	4. Gas-Solids Ejector	4. Single Acting Piston	3. Linear Pocket
5. Centrifugal	4. Fluid Dynamic Lock	4. Rotary Valve Piston	3. Positive Displacement
5. Kinetic Extruder	5. Ball Conveyor	5. Linear Pocket	3. Gas-Solids Ejector
5. Fluid Dynamic Lock		6. Fluid Dynamic Lock	4. Fluid Dynamic Lock
		7. Positive Displacement	5. Ball Conveyor

EVALUATION RESULTS

The feed systems were ranked preliminarily based upon the technical factors:

- development uncertainty
- ability to meet requirements
- reliability

The ranking is shown in Table 6. The technical data, which was used to rank the feeders was also incorporated in the cost analysis. The technical ranking was used to check the results of the cost analysis to assure that feeders selected on a cost basis included those with high technical ranking.

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. These costs are shown in Tables 7-10 for various reactor pressures.

Development costs were determined by assessment of the feeder development status. The assessment is summarized in Table 11 and the costs are summarized in Table 12.

Using the capital, installation, operating and maintenance costs given in Tables 7-10, life cycle costs were calculated for each feed system. Cost savings, ΔC, for individual feeders and for feeder sets compared with the

Table 7. 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	Mat'l				
Foster Miller										
Positive Displacement		5,740	240	75	14.4	250	9	70	14*	126*
Linear Pocket		2,151	250	240	15	150	9	70	1	9
Centrifugal		1,971	160	138	15	36	3	210	1	3
Ingersol 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	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

*Number of cylinders per bank and feeder.

Table 8. 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	Utility	Labor	Mat'l				
Foster Miller										
Positive Displacement		6,820	240	240	17	340	9	70	14*	126*
Linear Pocket		2,150	250	833	15	150	9	70	1	9
Centrifugal		2,358	160	405	15	40	3	210	1	3
Ingersol 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 Extender		6,043	240	456	49	556	6	104	1	6
Sandpipe 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	5	104	1	6

*Number of cylinders per bank and feeder.

Table 9. 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	Mat'l				
Foster Miller										
Positive Displacement		8,140	240	851	17	343	9	70	14*	126*
Linear Pocket										
Centrifugal		3,355	150	788	15	178	3	210	1	3
Ingersol 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	240	848	61,895	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	11[illegible]	6	104	1	6

*Number of cylinders per bank and feeder.

Table 10. 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	Mat'l				
Foster Miller										
Positive Displacement		8,140	240	851	17	343	9	70	14*	126*
Linear Pocket										
Centrifugal		3,355	160	788	15	178	3	210	1	3
Ingersol 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	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	8,923	209	139	6	104	1	6

*Number of cylinders per bank and feeder.

Table 11. Coal Feeder Development Assessment

Feeder	Development Status	Scale-ability	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
Ejector	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
Rotary Piston	Paper Concept	Good	A	Low

*S - Simple
A - Average
C - Complex

baseline lockhopper systems were determined. The following three parameters were then used to select the most promising feeders.

$\Sigma\Delta C$ - The life cycle cost difference between the candidate feeder and the baseline (lockhopper) feeder summed over the process applications. A maximum value of this parameter represents the objective of the plant developer who seeks to minimize costs.

Table 12. Estimate Feed Systen Development Costs

Feed Svstem	Relative Development Costs (Million $)		
	Phase III	Phase IV	Total(1)
Positive Displacement Feeder	1.3	3.3	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
(2) Staged systems

L - Cost leverage = $\Sigma\Delta C$/development costs. A maximum value of this parameter represents the goals of ERDA which seeks the maximum return for its development funding.*

R - Realizability. The probability of successful commercialization.

Figure 2 shows how these three parameters change with increased development funding, and with different selection of feeder sets. All combinations

*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 feeder/gasifier systems.

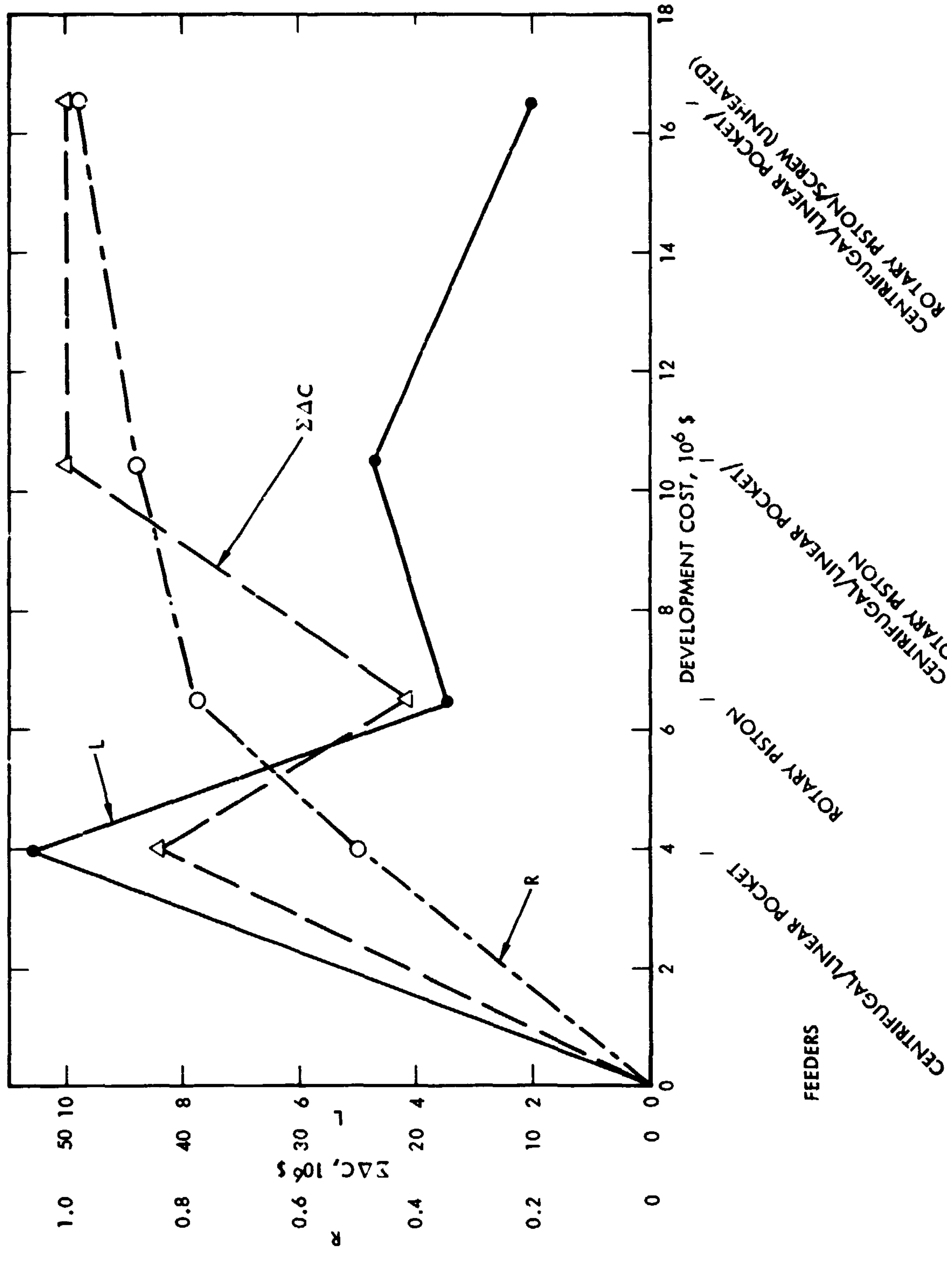

Figure 2. Feed System Selection Parameters

of feeder sets which could meet all process conditions were examined. Figure 2 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:

(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 the set of 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 was 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 shown in the figure, because development costs are increasing faster than corresponding increases in cost savings, $\Sigma\Delta C$. By combining the centrifugal/linear pocket and rotary piston feeders, increased realizability is achieved; but 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. Additionally, none of the other feeders was determined to have advantages for specific applications or redeeming technical features which would recommend its selection.

RECOMMENDED SYSTEMS

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

FMA centrifugal feeder or LMSC kinetic extruder

FMA linear pocket feeder

IRR rotary valve piston feeder

IRR unheated screw feeder

The recommended actions for each feeder and the bases for these recommendations are summarized in Table 13 and detailed in the Coal Feed System Development Plan, JPL Report 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 12. 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 problem
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.	• Very complex • High cost compared to baseline systems. • 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 results.
(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.

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

The process impact study conducted in conjunction with International Science and Technology 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.

FUTURE FEED SYSTEM DEVELOPMENT

The coal feed system development program has the objective to provide the coal conversion process plant designer several feeder options which could result in technical advantages and cost savings over conventional lockhopper and slurry pump systems. Basic to the feeder development are the program elements of strategy which include:

(1) Maintaining open options - by continuing with parallel feeder development programs to increase the probability of successful development, and providing for the development of new concepts if they have advantages over other systems being developed.

(2) Involve decision makers - such as architect/engineering firms, utilities, and process developers in the pilot and demonstration phases, to assure that the feeders are tested against real process requirements and that the results will be rapidly disseminated throughout the industry.

(3) Component testing and resolution of common problems - by centralized testing to avoid duplication of effort.

(4) Utilization of process pilot plants for testing to demonstrate process compatibility. The schedule of Figure 3 reveals that some of the pilot plant processes will have completed process demonstration and be available for component tests at the time pilot scale feeders become available for test.

(5) Centralized demonstration test facility is suggested for duration testing of demonstration scale feeders. Plant designers will require such testing before they will commit to the incorporation of the feeders in demonstration or commercial plants.

(6) Feeder integration into process demonstration plants is required as a commercialization step, yet their development schedule is lagging the demonstration plant schedule as shown in Figure 3. Late introduction of feeders into the demonstration plants, or introduction into second generation plants, should be considered.

(7) Cost sharing by the contractors during the demonstration phase is recommended to stimulate contractor interest and introduce marketing considerations into the program.

The feed system evaluation and the strategic elements provided the basis for the plan which is summarized in the schedule of Figure 4. Shown in the figure are schedules for the specific feeder developments and related support tasks. Key features of the program illustrated by the schedule are the following:

- Component development of the centrifugal and kinetic extruder feeders is shown continuing in parallel until a better understanding of the concept is obtained. Then a single pilot plant-scale effort is recommended.

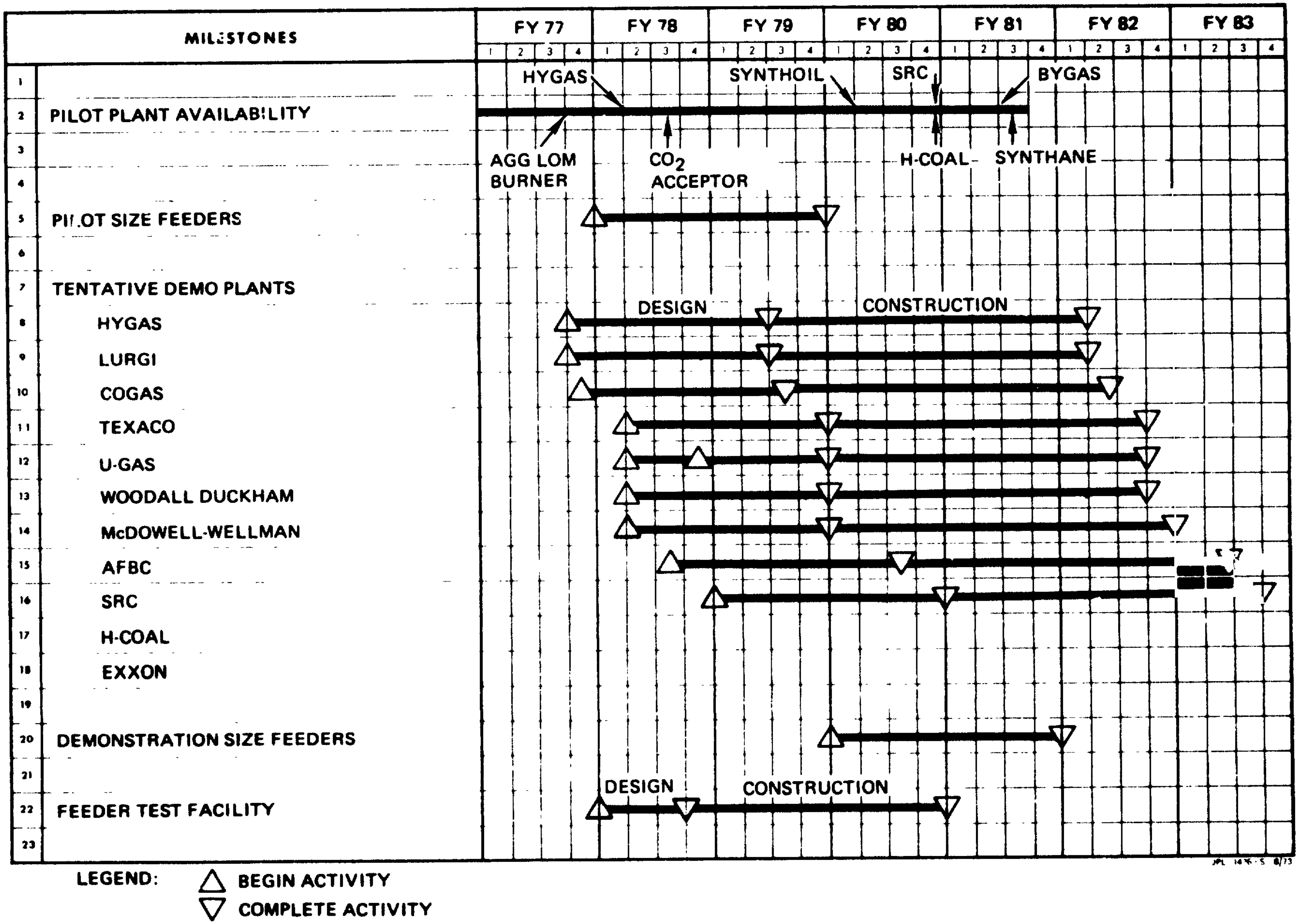

Figure 3. Overall Feeder/Process Schedule

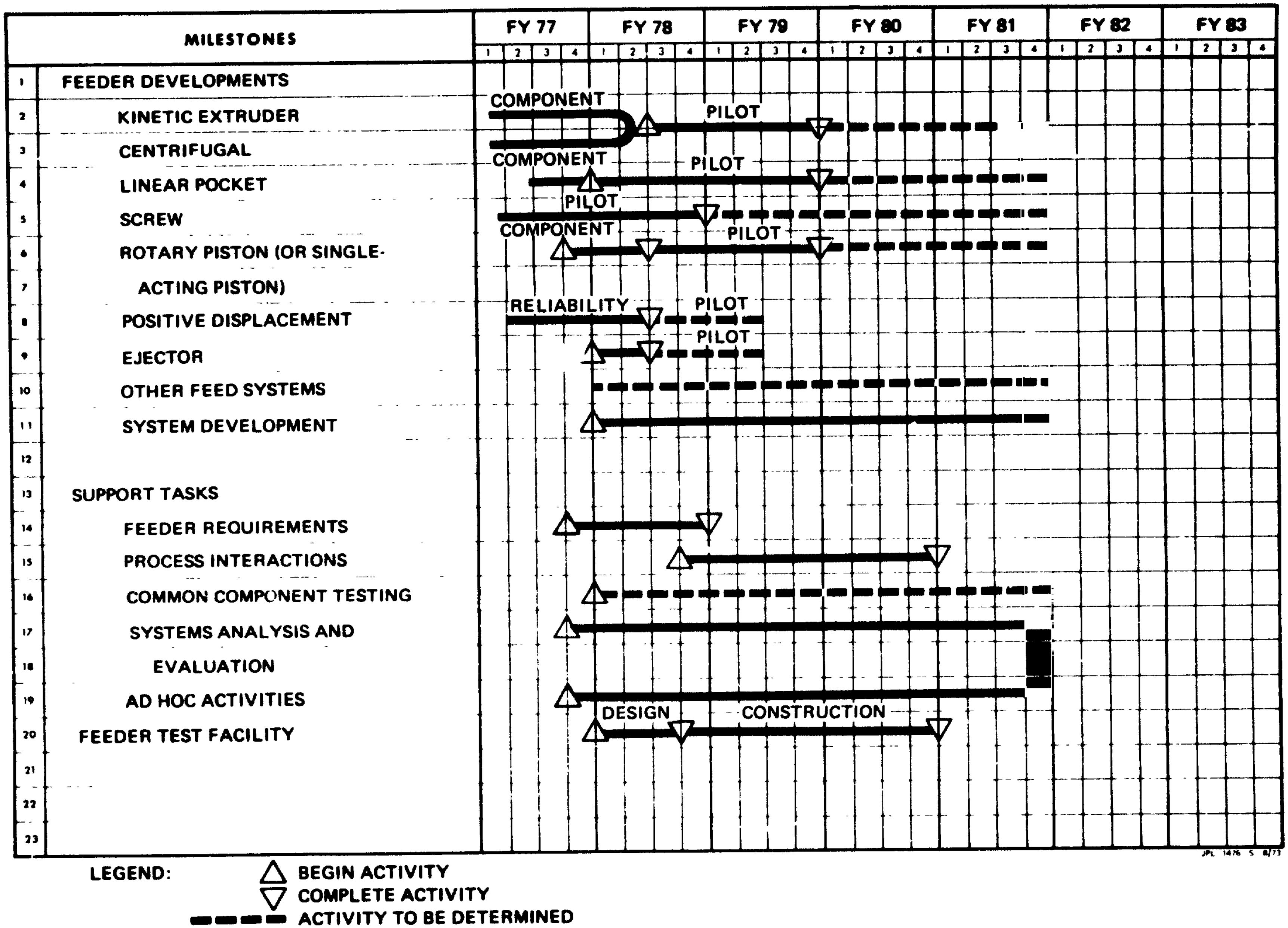

Figure 4. Coal Feed Development Schedule

- Pilot-scale development of the linear pocket feeder is recommended if prototype testing is successful. The development effort should concentrate on seal effectiveness and life, metering of coal to the pockets, seal tube life and the effectiveness of the water lock or gas-water transfer subsystem.
- Continued pilot scale testing of the screw feeder is recommended with emphasis on the unheated design.
- Accelerated component testing of the rotary piston feeder is recommended, followed immediately by pilot-scale development (if component testing is successful). This will permit completion of the pilot phase of the development on a schedule consistent with the other feed system developments.
- It is the intent to reduce the number of feeders under development to a minimum set upon completion of the pilot scale phase of the program. Therefore, demonstration efforts for each of the feed systems are shown "to be determined" after the pilot phase.
- The positive displacement feeder is shown undergoing continued testing to obtain a better understanding of the capabilities, projected costs and reliability. A decision to proceed into pilot scale development will be made when the capabilities of the centrifugal/kinetic extruder feeders are determined by the component tests. If the tests of these two feeders are successful, it will be recommended that the development of the positive displacement feeder, which is a backup system, be discontinued.
- The ejector is shown subject to applications analysis prior to pilot scale development. Pilot plant development will only be recommended if special applications are found.

- Other feed systems development will be undertaken when promising feeder concepts are identified.
- Feeder systems development is recommended to be conducted in conjunction with the specific feeder development efforts.
- Support tasks will be performed, as required, to guide the development efforts.
- The need for a demonstration-scale feeder test facility will be analyzed. If the facility is needed, design and construction will follow.