CONSERVATION

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U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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Report No. TE4265-20-80

IMPACT ON ENERGY CONSERVATION OF
AUTOMATIC CONTROL SYSTEMS UTILIZATION
IN THE U.S. PULP AND PAPER INDUSTRY

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Prepared for
U.S. Department of Energy
Office of Industrial Programs
Washington, D.C.

Under Contract No. DEAC02-78CS-40150
Formerly Contract No. EM78-C-02-4611

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ACKNOWLEDGEMENTS

This report is the result of a joint effort on the part of Resource Planning Associates, J.E. Sirrine Co., and CENTEC Corp. Thermo Electron directed the study with S. Fam as program manager. The major participants were H. Hagler, R. Buta, and M. Chen of RPA; the late R. Majors, R. Tysinger, B. Pearson, M. Cherry, and D. Wilson of J.E. Sirrine; C. Rowan, Dr. E. Nichols, and R. Ilevia of CENTEC; and Dr. S. Nydick of Thermo Electron.

The author wishes to thank Fisher Instruments, Industrial Nucleonics, Measurex, MoDo-Chemetics, Nokia Electronics, and Sentrol Systems for their kind cooperation, and Messrs. T. Bustard and J. Rossmeissl of the Department of Energy for their guidance.

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ABSTRACT

This study is concerned with the energy and other resource benefits resulting from the computerized automation of processes in the U.S. pulp and paper industry. The primary objectives were to characterize the state of the art of computer controls in the industry and to pinpoint the problem areas that limit their further use. The study lasted approximately 4 months. An exhaustive survey of all the possible technologies in use, or under development, was not possible.

The main conclusions are that the pulping and recovery operations offer the greatest potential for reducing energy use by computer control, and that effective hierarchical control at the plant level requires the integration of these operations into one or more control loops. No control system has been found that provides reliable, fully automated control of recovery boilers for an extended period of time. The total technical potential for fuel savings was estimated at 0.2 quadrillion Btu's a year, or the equivalent of 94,000 barrels of oil per day.

1. EXECUTIVE SUMMARY

1.1 CONCLUSIONS

1.1.1 Energy Benefits of Hierarchical Computer Controls

There is enough evidence to suggest that the consumption of fuels and raw materials in the pulp and paper industry can be substantially reduced through the use of advanced computer process control. Our estimate of the total technical potential for fuel savings is 0.2 quadrillion Btu's per year, or the equivalent of 94,000 barrels of oil per day. This amounts to approximately 17 percent of the industry's consumption of purchased fuels and electricity in 1978. Between 60 and 90 percent of these savings would occur at the first two levels of unit process and multiple process - or regulatory - control where several unit processes are integrated in a control loop (Figure 1.1). The extent to which the use of energy can be reduced at these control levels depends on the sophistication of the installed system and the manner in which it is used. The computer control of an entire mill, or of a number of mills, is not expected to yield large savings in fuel consumption beyond what can be accomplished at the multiple process level of control.

1.1.2 Economics of Computer Control Systems

Existing technology is widely accepted for the control of papermaking machines. Reported paybacks for these systems lie between 6 months and 2 years. We estimate that the market for machine control is essentially at economic saturation. However, the market for the control of pulping operations (digesting and bleaching) is generally marked by lower perceived returns on investment and has only just begun to be penetrated (about 80 percent of U.S. capacity is not computerized).

1.1.3 Development Areas of Greatest Interest to Fuel Conservation

In our judgment, the greatest potential for energy savings by computerized automation in the U.S. pulp and paper industry now lies in the increased use of computer controls in digesters and bleach plants and in

Figure 1.1 Relative Energy & Resource Benefits of Hierarchical Computer Controls

developing control systems for the recovery operations. Both these areas require advancements in sampling techniques and sensor technology, as well as in supporting software. To our knowledge, no viable control system has yet been devised, in the U.S. or elsewhere, to fully automate the operation of lime kilns or recovery boilers.

For recovery boilers, it is necessary to develop sensors or sensor systems and their associated software that can accomplish the following functions:

- Liquor combustion stabilization
- Detection of smelt bed condition
- Real-time measurement of liquor
 - calorific value
 - viscosity
 - surface tension
- Better real-time measurement of percent solids

The computer control of pulping operations (digesting and bleaching) appears to be hampered mainly by somewhat unattractive economics and the lack of available techniques for the extraction of pulp samples from directly steamed digesters. It is also desirable, in our view, to develop a new measure of pulp quality that would be suited to direct real-time measurement. The sensor areas of greatest interest are in:

- Direct real-time measurement of pulp quality
- Bulk density measurement
- Improved chip moisture measurement
- Improved active alkali measurement

We believe that the pulping operations, recovery boiler and evaporator should ultimately be integrated in a control loop to derive the maximum energy benefits at the regulatory control level. This is likely to require a considerable amount of software which will vary from mill to mill.

1.1.4 Barriers to the Increased Use of Computer Controls

We found that there are definite barriers to the more widespread use of computer controls. These barriers fall into three categories: technical, economic, and institutional.

a. Technical Barriers

The technical barriers are chiefly centered on sensor technology and the need for reliable instruments that give consistent, repeatable readings and require minimum servicing and recalibration. There is also a need to improve upon the communication between vendors and users to better attune each other to their respective needs and concerns. Finally, the lack of standardized hardware and software among vendors tends to hamper whole-mill integration.

b. Economic Barriers

A realistic assessment of investment priorities must recognize that the industry's primary interest has to reside in its product, its competitive position, and in the profitability of its operations. Energy benefits may contribute in part to the ROI on product-related investments, but not always. Furthermore, because of low variable costs and the fact that there is a seller's market for pulp and paper products, the marginal return on an increase in production is now generally very high while paybacks for brand new (or "greenfield") mills now run in the order of 15 years, so the increase in production at a given site enjoys the highest priority. Hence, energy saving ventures having additional product-related benefits stand a much greater chance of being implemented than those which offer energy savings alone.

The industry recognizes that it will find itself constrained by the capacity of its recovery and pulping operations as it moves to expand its facilities in the 1980's, and it will likely opt for the computerized automation of its recovery and pulping operations if it is shown to yield increases in product capacity.

We found in our interviews with vendors that many companies which are interested in computer controls are adopting a wait-and-see attitude because of confused interpretations of the investment tax credits provided for in the Energy Tax Act of 1978. It is uncertain whether computers used in the mill for conservation would qualify for the 10-percent tax credit, particularly if they are also used for other purposes, such as improving quality control or increasing production.

c. Institutional Barriers

Perhaps the most visible institutional barrier is the paper industry's general lack of expertise in process control technology. Many firms still contract for maintenance services from the vendors, but the cost is high and continuing, and tends to make the investment difficult to justify. Since most mills would prefer the security of having their own people trained and responsible for key equipment, they attempt to hire from the outside but find that a shortage exists for qualified technicians. A spokesman for one company asserted that the shift supervisor would need to have a degree in electrical engineering to bridge the gap between the process control people and the operators. Higher levels of control will especially increase the mill's sensitivity to poor instrumentation.

There is another barrier to the acquisition of expertise in computer control: fear of antitrust action. This fear hampers the flow of information among process control specialists from different pulp and paper firms, even in the presumably open environment of professional meetings and symposia. Because of the number of antitrust lawsuits the government is filing, technical interaction among firms has declined drastically. The market penetration of computer control depends partly on whether pulp and paper firms can be persuaded that they work. Published reports about installed systems often come from the vendors and are, therefore, perceived to lack credibility. Plant managers want to see other mills and talk with their peers before getting involved. To the extent that open discussion among firms is reduced, the acceptance of computer controls will suffer.

Finally, middle and upper levels of management are usually not oriented toward computer applications and are not easily convinced of the need for computer control. In addition, it appears that some managers don't want to relinquish their decision-making authority to a computer while others don't want to exercise undue control over a decentralized structure which higher levels of control would enable them to do.

1.1.5 Possible Government Actions to Help Accelerate the Development and Use of Computer Controls

We mentioned above, that, in our view, the most substantial energy benefits to be gained by computer control at this time lie in the pulping and recovery operations and that these operations should be integrated into a loop at the second or regulatory level of control. To accomplish this goal, we propose a two component strategy aimed at (1) accelerating market penetration of computer control of pulping operations using current technology to derive the maximum benefit in the near term, and (2) developing sensor technology for later use. The first component includes the development of techniques for the extraction of pulp samples from directly steamed digesters and economic incentives. The type and magnitude of the economic incentives necessary to fuel a greater market penetration need to be ascertained. From our limited industry sample, it appears that the 10-percent energy tax credit may not be enough and that cost-sharing demonstration projects, funded by government and industry, would be more attractive. The second component includes sensor and software development in the areas mentioned in paragraph 1.1.3 above. However, direct federal assistance to R&D projects would have to be carefully designed to be accepted by vendors, because sensors and software are the tools by which they compete, and accepting federal assistance that requires public disclosure of all R&D results could be perceived as a threat to their competitive advantage.

Hierarchical controls at the plant or corporate levels appear to exist in several mills in Finland. It would be useful to determine the extent of

the Finnish experience and the benefits that were derived. The Office of Industrial Programs (OIP) could also explore opportunities for cooperative projects with Finland and Sweden under the International Energy Agency implementing agreement for the pulp and paper industry, or on a bilateral basis.

To counteract the fear within the industry of federal antitrust suits, OIP could provide the mechanics for the exchange of technical information, both within the industry and between vendors and users, by sponsoring technical seminars and workshops on process control, for example.

1.2 STATE OF THE ART OF COMPUTER CONTROL SYSTEMS

1.2.1 Control Systems Currently in Existence

Most of the systems in existence are used to control the operation of papermaking machines. The exact extent of the market penetration is unknown but it is estimated that computer controls are being applied in one form or another in approximately 30 percent of the machines in the U.S. Some place the estimate at between 50 and 80 percent of U.S. capacity, depending on the extent of control considered in the sample. Finland appears to be the most heavily instrumented (Table 1.1), followed by Canada, the U.S., and Japan. We were unable to obtain a figure for the Scandinavian countries during the short time allocated to this study.

The major suppliers to the U.S. are Industrial Nucleonics, Measurex, and Sentrol Systems of Canada (Table 1.2). It appears that further market penetration is restricted by low returns on investment in small machines having a capacity of less than 30,000 to 50,000 tons per year and that the principal activities lie in second generation or specialty sensors. Thus, for papermaking machines, computer control systems, as such, have essentially reached economic saturation at the current states of machine and control technology. The principal uses of these control systems are in production and quality control and in reducing production costs, the energy benefits arising as a byproduct of reduced drying, reduced rejects, and reduced production downtime.

TABLE 1.1

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PAPER MACHINES UNDER COMPUTER CONTROL

	TOTAL NUMBER OF MACHINES	NUMBER OF MACHINES WITH CC	PERCENT
U.S.	1545	464	30
CANADA	297	119	40
FINLAND	139	78	56
JAPAN	1300	70	5
WORLD	9813	1129	12

TABLE 1.2

**MAJOR SUPPLIERS TO THE U.S. OF COMPUTER CONTROL
SYSTEMS FOR PAPER MACHINES**

- **INDUSTRIAL NUCLEONICS CORPORATION**
Columbus, Ohio
- **MEASUREX CORPORATION**
Cupertino, California
- **SENTROL SYSTEMS, LTD.**
Ontario, Canada

Estimated Combined Market Share: over 90 percent

The situation is quite different in the "backyard" of integrated mills where the control of pulping operations is in a relative state of infancy, having reached only about 15 percent of the number of units in the U.S., or about 20 percent of pulping capacity. Here, there is better agreement on the extent to which the market has been penetrated. Around the world, Finland appears, again, to be the most heavily instrumented (Table 1.3), followed by Canada and the U.S. As in the paper-making area, the major suppliers to the U.S. are few (Table 1.4): Industrial Nucleonics, Measurex, MoDo-Chemetics of Canada, and Nokia of Finland. It appears that further market penetration is hampered principally by a few technical problems and by poor economics resulting from the high cost of equipment relative to the savings in chemicals and energy use.

As for the computer control of recovery boilers, it appears to be largely in the experimental stages. The systems currently in existence do not provide reliable, fully automatic control although significant benefits can be derived from these systems.

1.2.2 Current Development Trends

The development of reliable sensors (giving reproducible readings without extensive recalibration, maintenance, or other attention), is particularly important to the increased use of computer controls in the pulp and paper industry. The problem is one of applications engineering and of survival in hostile environments. Because vendors cannot expediently or economically resolve these difficult problems on their own, they are inclined to branch out into other, more immediately profitable, areas, such as software or energy systems. Some progressive companies have been willing to experiment but access to an operating facility for experimental work is generally very limited. This situation may change in the future as the importance of backyard operations gains more recognition.

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TABLE 1.3

PERCENT PULPING OPERATIONS UNDER COMPUTER CONTROL

	BATCH DIGESTERS	CONTINUOUS DIGESTERS	BLEACH PLANTS
U.S.	20%	30%	15%
CANADA	25%	23%	20%
FINLAND	65%	90%	70%
JAPAN	NA	NA	NA
SCANDINAVIA	NA	20%	NA
WORLD	25%	25%	18%

NA = Not Available

TABLE 1.4

**MAJOR SUPPLIERS TO THE U.S. OF COMPUTER CONTROL
SYSTEMS FOR DIGESTERS AND BLEACH PLANTS**

- **INDUSTRIAL NUCLEONICS CORPORATION**
Columbus, Ohio
- **MEASUREX CORPORATION**
Cupertino, California
- **MoDo-CHEMETICS, LTD.**
Vancouver, B.C., Canada
- **NOKIA ELECTRONICS, INC.**
Atlanta, Georgia

Estimated Combined Market Share: over 90 percent

2. INTRODUCTION

The Department of Energy's Office of Industrial Programs (OIP) is evaluating a variety of approaches to energy management and process technology which would increase the efficiency with which energy is used in U.S. industry. One approach to energy management which is being evaluated is the automatic control of industrial processes. Automatic control systems (ACS) offer a method of reducing the amount of energy used by one or more processes in excess of the minimum required by the particular technologies employed in those processes. This is achieved in a number of ways, such as a tightening of the tolerances on product quality, or a better scheduling and distribution of energy among the individual unit processes.

2.1 PROGRAM SCOPE AND OBJECTIVES

The primary objectives of this study were: determine how automatic control systems are currently being used in the pulp and paper industry and estimate the reduction in energy use attributable to this practice; characterize the state of the art of sensor technology and estimate the additional reduction in energy use if ACS were more widely used; identify the areas where RD&D efforts would be most productive in increasing energy efficiency; conduct an economic ROI analysis; identify the major impediments to the application of ACS; and evaluate the effects of government actions on the increased use of ACS.

In identifying the areas of difficulty, it is necessary to consider not only the particular requirements of the paper industry itself, but also the problems faced by the instrumentation industry in its efforts to provide the proper sensors, and the problems of the computer control industry in supplying the necessary software.

2.2 THE SYSTEMS NATURE OF PROCESS CONTROL

It is important to recognize that the problem of optimization is a systems problem since it involves interactions between a number of

processes. Thus, improvements made in one process could be aided, or mitigated, by changes in another process along the chain. Causal relationships are generally impossible to establish in an unambiguous manner. Also, the total benefit resulting from the use of several control loops is not necessarily equal to the sum of the benefits derived from each control loop taken one at a time; the whole may be less than, or exceed, the sum of its component parts. For this reason, a mill's estimate of the benefits it derived from ACS may differ from that of another mill.

For the purposes of this study, we examined digital computer control systems and not the analog types of systems. One reason why digital systems are preferred to analog systems is that digital systems can perform feed-forward control with software whereas analog systems do so with hardware. (In theory, feed-forward control offers the possibility of achieving perfect control because it manipulates process parameters before any harm is done.) Another reason is that digital systems using computers can accomplish faster and more sophisticated control functions than can analog systems. A third reason is that the logging, reporting, and management information system functions can be accomplished in a much simpler fashion with digital systems.

This was a 4-month study. Its purpose was not to conduct an exhaustive survey of all the sensors and computer control equipment in existence or under development, but rather to ascertain the prevalent practice and to pinpoint the main areas of difficulty.

2.3 TECHNICAL APPROACH

To study the particular requirements of the three principal industrial sectors, Thermo Electron retained the services of: Resource Planning Associates of Washington, DC; CENTEC Corporation of Fort Lauderdale, Florida and Reston, Virginia; and J.E. Sirrine Company of Raleigh, North Carolina (see Figure 2.1). Consultants were used, as necessary, from the pulp and paper industry, suppliers of computer control equipment, and

Figure 2.1 Participants

sensor manufacturers. In this study, we considered the prime energy-using processes in integrated pulp and paper mills. These mills account for approximately 75 percent of U.S. capacity. The particular processes we examined are shown in Table 2.1.

In Chapter 3 we treat the state of the art of computer process control at the different hierarchical levels. Although we considered the energy systems for which there is a strong demand, we did not treat their associated control systems in detail because they are not specific to the pulp and paper industry. Chapter 4 deals with the computer control industry. The development areas that now appear to be of greatest interest to energy conservation and their associated potentials for energy savings are treated in Chapters 5 and 6. The impediments to the increased use of ACS are discussed in Chapter 7, and the possible actions that the government might pursue to overcome these barriers are outlined in Chapter 8.

TABLE 2.1

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PRIME ENERGY USERS IN INTEGRATED PULP & PAPER MILLS

Process	Energy Used	
	MMBtu/adt	Avg. % Total Energy
<u>Pulping</u>		
Batch Digester (80% digester capacity)	4 - 5	14
Continuous Digester (20% capacity)	1.2 - 1.5	
Refining	0.6 - 2	6
Bleaching	4 - 5	14
<u>Recovery</u>		
Recovery Boiler	1.4 - 1.8	5
Evaporator	2.5 - 3.5	10
Lime Kiln	2 - 2.5	7
<u>Papermaking</u>		
Drying	4 - 10	32
Total	19.7 - 31.3	88

Gross Energy Used (First Half 1978): 31.4×10^6 Btu/adt

3. STATE OF THE ART OF PROCESS COMPUTER CONTROL

3.1 EVAPORATOR AND RECOVERY BOILERS

There are currently only about 15 computer control systems in operation or on order for the control of evaporators and recovery boilers. Instrumentation has been a constraining and critical factor in delaying control of the recovery operations. The difficult problems in measurement include: online measurement of emissions, black liquor analysis, furnace temperature, char bed shape and height, and black liquor spray patterns.

The primary functions of the recovery area computer control systems are to: (1) maintain constant black liquor concentration and compensate for variations in black liquor properties, (2) control boiler fouling, (3) accommodate load changes and variations in boiler operation, and (4) most importantly, optimize chemical reduction and steam production.

3.1.1 Control Systems Currently in Existence

Computer control systems are presently being marketed worldwide by three companies, two are American (Measurex and Fisher Controls) and one is Finnish (Nokia Electronics).

a. The Fisher dc/Provox System

The Fisher system is shown schematically in Figure 3.1. The system consists of both a primary digital control package (a dc process computer and Provox software) and an analog backup. The analog backup system is used when the digital system is down. When the outcomes of the two control strategies differ, direct digital control is implemented through computer auto-manual stations.

The controlled variables include: total, primary and secondary air flow, black liquor flow, primary and secondary liquor temperature, furnace draft, steam pressure, drum level and oil pressure. Input measurements include duplicate O₂ analyses, heavy liquor refractometers,

Figure 3.1 Coordinated Control of Liquor and Air is Provided by Fisher Computer Control System

primary windbox pressure, smelt bed weight (with strain gauges placed on char bed supporting beams) and smelt bed sodium light intensity.

Oxygen concentration in the flue gas is regulated to optimize thermal efficiency. Control also includes maintenance of the proper black liquor solids content from the evaporator and concentrator. Boiler air distribution between primary and secondary air flows is a preprogrammed function of the desired production rate. Secondary adjustments are made on the basis of a measurement of the smelt bed sodium light intensity in order to effect minimum dust loading.* If the proper boiler air distribution is maintained, the height of the smelt bed becomes primarily dependent on the liquor droplet size distribution. The optimum bed height is maintained by measuring bed weight by means of strain gauges placed on the bed supporting structure and utilizing this measurement as an input to the automatic regulation of liquor temperature which, in turn, controls droplet size distribution.

The control system can operate with black liquor and fuel oil input. System control is maintained by plant personnel at a console where they can interact with the computer using everyday language. Process visibility is provided by means of CRT displays. The computer control system also incorporates documentation functions for different levels of management.

b. Measurex 2001

The Measurex recovery boiler control system shown schematically in Figure 3.2 consists of a modular control package for multiple effect evaporators, including whole black liquor and solid black liquor oxidation, direct contact evaporation, liquor firing, combustion, air pollution, smelt dissolving tanks, production rate optimization and thermal efficiency optimization.

*Dust loadings and percent smelt reduction are correlated against bed sodium light intensity.

3-4

Figure 3.2 The Measurex Recovery Boiler Control System

The Measurex control strategy is similar to Fisher's except for three important areas. The Measurex system relies on the dry solids rate and the liquor temperature (for droplet size control) to maintain a constant bed, whereas Fisher utilizes strain gauge bed measurement in addition to these quantities. Secondly, total air requirements are calculated and controlled by the computer based on the dry solid flow rate in a feed-forward loop, utilizing an infrared spectroscopic measurement of CO for trim control in a feedback loop. Finally, the primary air is usually controlled manually, with the secondary and tertiary air controlled by the computer in a fixed ratio, depending on dry solids rate and total air requirements.

Dust and total reduced sulfur* are also functions of primary air control. Increasing the percent of primary air increases dust but decreases the sulfur in the flue gases and vice versa. Lastly, the Measurex system also controls soot blowing via feedforward and feedback loops in order to maximize steam generation.

c. Nokia Auto Recovery System

The Nokia auto recovery system is the result of a cooperative research project from 1970-1973 by users, manufacturers of equipment and academics in Finland. Based on this sponsored research, Nokia Electronics developed the system in cooperation with a user, Emeo-Gutzeit Oy and the University of Oulu. The system shown schematically in Figure 3.3 incorporates some of the same control features as the Fisher and Measurex systems, namely black liquor, total air, and partial air distribution, and soot blowing. In addition, the Nokia system controls the char bed by monitoring the temperatures and pressures at the furnace walls detecting major differences between the oxidation and reduction zones. This information is utilized in a feedback loop as an input into the black liquor control to change the liquor spray patterns and to obtain air symmetry in the furnace by controlling the air distribution. Prior to these feedback loops, a

*Reduced sulfur ends up as a stock emittant.

Figure 3.3 Main Functions of the Nokia Recovery Boiler Control System

feedforward loop incorporating the black liquor control system decides upon the initial spray pattern from the measured black liquor flow rate and dry solids content. The total air flow requirements are also first obtained in a feedforward loop from the black liquor flow and corrected in a feedback loop based on O_2 and SO_2 measurements and the furnace temperature and pressure measurements previously mentioned.

All three of the control systems described above have their particular advantages and disadvantages. To our knowledge, none has been shown to reliably provide fully automated control of the recovery boiler over an extended period of time.

3.1.2 Energy and Resource Benefits

The primary functions of a computer control system for a recovery boiler, as a unit process, are: (1) to increase the output of steam, (2) to reduce the amount of fuel used in supplementary firing, (3) to increase liquor reduction, (4) safety, and (5) to reduce polluting emissions.

Steam production, and thus thermal efficiency, are improved primarily by operating with the optimum amount of excess air (based on either CO or O_2 measurements), smelt bed control, and soot blower control. Nokia has reported thermal efficiency improvements from 57 to 62 percent. Measurex reports a 69-percent decrease in the use of supplementary oil and a 68-percent reduction in boiler degradation due to tube fouling. Measurex and Nokia report a 2.5 to 4 percent and a 5 percent increase, respectively, in capacity to burn black liquor. The occurrence of black-outs with computer control was almost eliminated in one installation. Nokia estimates the payback time for their system to be from 8 to 16 months. At the Enos-Gutzeit Oy mill annual energy and chemical savings at Finnish prices (in U.S. dollars) were \$190,000 and \$50,000, respectively.

3.1.3 Current Development Trends

The energy savings potential of computer control applied to recovery boilers is just being recognized by the paper and pulp industry. The

additional benefits of computer control in increasing the recovery capacity of existing boilers will also become more apparent in the future when expansion of pulp production in many mills becomes limited by recovery boiler capacity. The application of computer control to recovery boilers should increase rapidly in the future.

The primary differences between currently available computer control systems for recovery boilers are in the means of measuring excess air and the measurement and use of char bed characteristics.

In all likelihood there will continue to be differences of opinion and preferred methods of control with regard to the use of O_2 , CO, or both, as a means of controlling excess air. The O_2 advocates claim that CO measurements are not sufficiently sensitive or accurate in the 0-500 ppm range of interest. On the other hand, CO proponents argue that new developments make measurements in this range possible, that CO measurements, unlike O_2 , can be averaged across the flue gas stream by spectroscopic techniques rather than made at discrete sampling points. They also point out that the presence (or absence) of CO is a direct consequence of combustion quality and, therefore, unlike O_2 , the amount of CO is almost insensitive to air infiltration. It can be argued that both CO and O_2 measurements are required to assess the integrity of the burner as well as the amount of excess air.

The means of characterizing the smelt bed are also in dispute. Fisher uses a stain gauge bed weight measurement and a bed sodium brightness measurement as control inputs for spray droplet and air distribution control in order to maintain bed integrity. Measurex has a software package which depends primarily on dry solids rate and total air requirements. Nokia employs a complex arrangement of measuring furnace temperatures for bed and air control. It is likely that, because of the smelt bed's complex shape and behavior, there will be a continuing

difference of opinion in the industry about the usefulness and meaning of bed weight and sodium brightness measurement sensors.

Of primary importance to improving the control of recovery boilers is the development of sensors for better characterization of the black liquor input. In addition to flow rate and percent dry solids, the measurement of the fraction of organic and inorganic compounds, and hence the heating value of the liquor, would allow the development of software for the computation of combustion characteristics and the requirements for saltcake additions. Table 3.1 summarizes our view of the importance of recovery boiler control and the development areas of greatest interest.

3.2 LIME KILNS

Lime kilns are major energy users and contribute significantly to environmental pollution, particularly when they are used to incinerate plant waste gases. In addition to the energy and environmental benefits, computer control of lime kilns permits a more stable maintenance of white liquor causticity which improves and stabilizes the operation of digesters and decreases the load on washers and evaporators.

Some computer control systems are reportedly in operation in Finland at the Kemi Co. where the payback is estimated at one year if the capacity of the mill is 700 tons of pulp per day or more.

An extensive amount of effort has been spent developing models for lime kilns at the University of Oulu in Finland, at Boeing in the U.S., and elsewhere. The purpose of developing these models and simulation techniques is to determine the instrumentation and software strategies that are most appropriate to a particular installation. After completing a preliminary feasibility study, Boeing installed a computer system in April 1979 at one of Crown-Zellerbach's mills. No fundamental instrumentation problems were found. The system is now undergoing minor modifications but has registered an 8-percent decrease in fuel costs. Payback periods on the basis of fuel savings alone are also estimated at one year for pulp mills

TABLE 3.1
SUMMARY OF RESULTS
RECOVERY BOILER CONTROL

- FULLY AUTOMATED CONTROL SYSTEM IS VITAL FOR PLANT LEVEL HIERARCHICAL CONTROL
- NO FULLY AUTOMATED CONTROL SYSTEM EXISTS
- LACK OF TECHNOLOGY MAIN OBSTACLE
- SENSOR DEVELOPMENT AREAS:
 - Liquor Combustion Stabilization
 - Smelt Bed Condition
 - Real-Time Measurements of Liquor
 - Calorific Value
 - Viscosity
 - Surface Tension
 - Better Real-Time Measurement of Percent Solids
- SOFTWARE DEVELOPMENT ESSENTIAL
- INDUSTRY LIKELY TO BECOME INCREASINGLY LIMITED BY RECOVERY BOILER CAPACITY

having a capacity of 600 tons per day or more. The only other known system in the U.S. is currently in the engineering phase.

The computer control of lime kilns also offers other benefits. By exercising tight control on fuel use and temperatures at the firing end it is possible to increase somewhat the production of lime and reduce refractory damage. If the systems in the above two plants succeed and reach their estimated return on investment, it is likely that they will be rapidly adopted by the industry. The effort should then be extended to include the causticizers and washers.

3.3 DIGESTERS AND BLEACH PLANTS

Digestion and bleaching together comprise the pulping operation. About 69 percent of the wood pulp in the U.S. is made by the Kraft, or sulphate, process (Table 3.2). Two types of digesters are currently in use: continuous digesters and batch digesters. Batch digesters, which account for about 80 percent of U.S. capacity, can be subdivided into directly steamed units where steam is injected into the tank, and indirectly steamed units. Directly steamed units are in the majority, but some mills are converting some of their digesters to the indirect type of steamed unit.

Computer controls have penetrated an estimated 20 percent of the total U.S. sulphate and soda pulping capacity.

3.3.1 Control Systems Currently in Existence

The primary control objectives are:

- Consistently produce a pulp of uniform quality* in any desired grade
- Minimize or eliminate rejects
- Maximize the yield or the amount of pulp that can be obtained from a given load

*Pulp quality is measured in terms of wood delignification.

TABLE 3.2
WOOD PULP CAPACITY (1979)

	PERCENT TOTAL CAPACITY
SULPHATE AND SODA	68.54
MECHANICAL (EXCLUDING TMP)	14.70
SEMI-CHEMICAL	8.40
SULPHITE	4.11
DISSOLVING AND SPECIAL ALPHA	2.73
THERMO MECHANICAL (TMP)	1.40
SCREENING	<u>0.12</u>
TOTAL	100.00

TOTAL FORECAST WOOD PULP CAPACITY: 57,130,000 TONS

SOURCE: AMERICAN PAPER INSTITUTE "STATISTICS OF PAPER AND
PAPERBOARD 1978," (FORECAST).

- Minimize steam consumption
- Minimize the amount of chemicals used for bleaching

The most popular measure of pulp quality is the Kappa number (see Table 3.3). However, this method generally involves taking pulp samples downstream of the digester, after the actual cook, corrections then being made to the following cooks. There are, however, some measurements which can be made by which it is possible, in principle, to infer the Kappa number. Some of these measurements can be made online, or at least with sufficiently short sampling times (in the order of a few minutes) to be usefully predictive in controlling the cooking sequence. The computation of the Kappa number necessarily involves the use of some assumptions regarding the nature and the state of the incoming chips (species and moisture), the uniformity of their loading, the composition of the liquor, the temperature of the mix, etc. Any, or all, of these conditions are subject to change.

A typical batch digester control system utilizes Kappa number feedback. Depending on the type of pulp desired, the computer determines the desired alkali-to-wood ratio, Kappa target, over-pressure target, and "H" factor target from a grade code file. Chip loading and liquor flow are controlled by the computer. Constant chip moisture is assumed by the computer. In the working phase, the computer calculates the H factor every 30 seconds from temperature measurements. The desired cooking time for a given digester is controlled by the computer, based upon production requirements. The computer then calculates the digester time/temperature relationship required for a given H factor and supplies the required steam to satisfy this relationship. The time/temperature cooking characteristics are checked every 30 seconds and corrections are automatically made to obtain the desired H factor. Cooking is stopped when the H factor target is obtained. Pulp samples are analyzed for Kappa number and the liquor is examined for residual alkali content in the laboratory. Adjustments are then made in the H factor grade code file.

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TABLE 3.3
PULP TEST METHODS

DIRECT METHODS

- Permanganate Number
- Kappa Number
- Nu Number
- Permittivity Measurement
- Optical Reflectance
- Spectrophotometry

INDIRECT METHODS (Applied to Liquor)

- Conductivity Methods
 - Direct Conductivity Measurement
 - Conductimetric Titration
 - Differential Conductivity
- Ion Selective Electrodes
- Refractometry
- Calorimetry

The system can be used to schedule the operation of digesters to smooth out steam demand. The sequence of chip and white liquor loading is also controlled allowing optimum packing densities and more production from a given cook. One constraining difficulty is the extraction of pulp samples from directly steamed digesters.

The same basic system can be applied to continuous digesters where the residual alkali content in the liquor is measured continuously. Kappa feedback control, and feedforward control of liquor/wood, alkali/wood ratios, and reaction zone temperature are used. One problem area appears to be in the measurement of dry wood input loading. Chipmeters are based upon volumetric displacement and any change in chip density or moisture seriously affects the ability of the computer to control the Kappa number accurately. An alkali concentration measurement is usually performed offline and fed to the computer. The flow of white liquor is used to control the amount of effective alkali.

Table 3.4 gives a summary of the parameters involved in the various control functions, a description of the most prevalent types of computer systems and their capital and operation and maintenance costs, and the resulting energy and other resource benefits. Table 3.5 describes the most prevalent sensors and their principle of operation.

3.3.2 Energy and Resource Benefits

Figure 3.4 illustrates the manner in which the different controls yield economic, energy, and other resource benefits. In this study we did not take a net energy point of view but considered only those energy benefits that occur at the mill and contribute to its ROI. Thus, the reduction in the amount of chemicals is not represented as having a component of reduced energy use. The figure also illustrates the system's nature of process control. A reduction in specific fuel consumption may be traced, for example, to reduced rejects or to a reduction, or smoothing-out, of steam demand. In turn, these effects may be caused by more than

TABLE 3.4
EXISTING COMPUTER CONTROL SYSTEMS IN
DIGESTERS AND BLEACH PLANTS

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Unit Process	Energy Used		CCS Package	Operating Parameters	Benefits of Controls			Cost of Controls		Market Penetration (% Total Capacity)
	MMBtu/a.d.t.*	Average** Percent Total Energy			Energy Savings		Other	Capital	O&M	
					Percent	MMBtu/a.d.t.				
Digesting Batch (80% installed capacity)	4-5	14	<ul style="list-style-type: none">• Computer• Printer/plotter• Control functions (software)• M. I. S.• Alkali sensors for 2 digesters• Startup & installation	Chip Feed Chip filling Liquor filling Temperature Chemical/wood ratio Liquor/wood ratio Washing Blowing	7-10	0.5	Yield increase: 1-2% Reduced wood use: 3-4% Chemical savings: 7-10% Steam levelling Reduced steam blowdown	\$350,000-400,000	\$2000-4000 per month	25
Continuous (20% installed capacity)	1.2-1.5	3.5	<ul style="list-style-type: none">• Computer• Printer/plotter• Control functions (software)• M. I. S.• Alkali sensors -Upper heater-Extraction stage• Startup & installation		Negligible	Negligible	Yield increase: 1.5-2% Reduced wood use: 3-4% Chemical savings: 7-10%	\$350,000-400,000	\$2000-4000 per month	20
Bleaching	4.2-4.6	14	<ul style="list-style-type: none">• Computer• Printer/plotter• Control functions• M. I. S.• Chlorination sensor• Hypo sensor(s)• Dioxide sensor(s)• Startup & installation	Chemical flows Temperatures pH	8-12	0.45	Production increase: 2-5% Chemical savings: 8-10%	\$350,000-400,000	\$2000-4000 per month	25

*Millions of Btu per air-dried ton of finished product.

**Total energy used (first half of 1978): 31.4 MMBtu/a.d.t.

TABLE 3.5

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PREVALENT SENSORS USED FOR COMPUTER CONTROL OF DIGESTERS

MEASUREMENT VARIABLE	SENSOR TYPE	PRINCIPLE OF OPERATION	OPERATING RECORD	DRAWBACKS
CHIP MOISTURE	Capacitance/ Conductivity	The Dielectric Constant and Conductivity of Wood Varies with Moisture.	● Good (New Instrument)	
CHIP WEIGHT / VOLUME	Rotating Vane	Supplies Chips at Constant Volume Rate.	● Poor	● Requires Constant Calibration
EFFECTIVE ALKALI CONCENTRATION	Conductimetric Titration	Conductivity of Black Liquor Depends Primarily on "Effective Alkali" Constituents (NaOH, Na ₂ S). Measures Volume of Sulfuric Acid beyond which Conductivity is Constant. "Q-Factor" Control Approach.	● Very Good	● Too Expensive ● Requires Highly Skilled Personnel ● Probes Require Frequent Cleaning
	Conductivity	Probeless Conductivity Measurement and Monitoring as Function of Time. "H-Factor" Control Approach.	● Good	
	Differential Conductivity	Black Liquor Conductivity Changes with Addition of CO ₂ . Measures Amount of CO ₂ for Complete Titration. "H-Factor" Control Approach.	● Good	

Other Sensors Used to Measure Cooking Temperature and Time, Steam Pressure and Flow Rate, Vessel Pressure.

Note: Refractometers and Gamma Ray Densitometers are used in addition with continuous (Kamyr) digesters.

Figure 3.4 Main Computer Controls in Digesters

control function, therefore it is generally not possible to attribute a benefit to a single-control function in an unambiguous manner if more than one control function is involved, which is generally the case because of the high capital cost of computer control equipment.

Another aspect of the systems nature of process control is the fact that a benefit in one process could turnup as either a benefit or a loss in another. One example of this aspect is the increase in efficiency of the recovery and/or power boilers when steam demand is levelled. Power production in the turbogenerators could increase also. Another example is pulp yield improvement which has the effect of reducing the quantity of liquor required to produce a given amount of pulp. This, in turn, results in a decrease in the amount of steam generated in the recovery boiler which, all else being constant, must be compensated by an increase in fuel consumption at the power boilers. If, however, the increase in yield is accompanied by a decrease in steam demand, then the plant could equilibrate with no net change in fuel consumption. The energy benefit would then be in the reduced volume of chemicals.

3.3.3 Current Development Trends

Current efforts appear to be directed at developing chip moisture sensors that compensate for frozen chips, and improving the evaluation of effective alkali concentration from which pulp quality and the extent of the cook are inferred from supporting software. No direct inline measurement exists to determine pulp quality in a manner that would correlate with the standard Kappa test. This test is time consuming and after the fact. For real time evaluation of pulp quality it will be necessary to devise a new and simpler measure of the extent of wood delignification.

Other problem areas being addressed are the difficulty of extracting samples from pressurized, directly steamed digesters and the generally high capital cost of the equipment. One vendor whose equipment had a reportedly excellent record of success in the industry is not pursuing the U.S. market because of the relatively poor return on investment.

From the standpoints of hierarchical control and energy benefits, it is important that the pulping operations be integrated with the recovery operations into one or more control loops. As shown in Figure 3.5, there is an intimate connection between these operations. Changes in one process can affect not only the operation of the other processes, as noted above, but also the operation of the entire plant. Our assesement of the state of the art and the development requirements of interest is summarized in Table 3.6.

3.4 REFINERS

Chemical pulp refiners are reported to use 30 to 40 percent of the electric power at paper mills. Consequently, the potential for energy savings is substantial.

Several control methods are in existence. They include adjusting the refiner load based on drainage, porosity, or temperature difference between input and output mass flow, or controlling the total refining power.

One recently developed computer control system exploits the fact that, in addition to the load, the refiner power loss is approximately proportional to the third power of the speed of rotation. The addition of this variable also permits a more accurate control over the desired paper properties and the use of less expensive pulp grades. In this system, speed control is currently accomplished through the use of thyristor-driven continuously regulated dc motors. From measurements of speed, mass flow and consistency, the software package computes the specific refining energy and the specific edge load for a given refiner geometry. These values are then compared with their respective set points previously obtained from laboratory tests of tensile strength and tear resistance. The system is claimed to have achieved a 40 to 50 percent decrease in specific power consumption.

3.5 PAPER MACHINES

The earliest computer control systems reportedly appeared around 1958-1960. By 1978, between 50 and 80 percent of U.S. capacity incorporated

Figure 3.5 Schematic of Pulp and Liquor Recovery Operations

TABLE 3.6
SUMMARY OF RESULTS
DIGESTER CONTROL

- SUBSTANTIAL MARKET REMAINS
- MAIN TECHNICAL IMPEDIMENT IS SAMPLE EXTRACTION IN DIRECTLY STEAMED UNITS
- SENSOR DEVELOPMENT AREAS
 - Real-Time Measurement of "Pulp Quality"
 - Bulk Density Measurement
 - Improved Chip Moisture Measurement
 - Improved Active Alkali Measurement
- SOFTWARE DEVELOPMENT NECESSARY
- NEW MEASURE OF "PULP QUALITY" ESSENTIAL FOR REAL-TIME CONTROL
- DIGESTER CONTROL WOULD BENEFIT FROM TIE-IN WITH RECOVERY BOILER AND EVAPORATOR

these systems to some extent. The market appears to be near economic saturation, its further penetration being limited by unattractive economics in small machines. The principal uses of control systems in papermaking machinery are in production and quality control and in reducing production costs.

3.5.1 Control Systems Currently in Existence

Moisture and basis weight control are the most prevalent elements in machines equipped with computer controls (see Table 3.7) followed by caliper, ash, efflux ratio, dry stock and headbox, and speed control. The need for opacity control has somewhat diminished in recent years because of the lower paper standards and the lower cost of titanium slurries. Table 3.7 gives a summary of the parameters involved in the various control functions, a description of the most prevalent types of computer systems and their capital and operation and maintenance costs, and the resulting energy and other resource benefits. Table 3.8 describes the most prevalent sensors and their principles of operation.

3.5.2 Energy and Resource Benefits

Figure 3.6 illustrates the manner in which the more popular types of controls yield economic, energy, and other resource benefits. In this study we did not take a net energy point of view but considered only those energy benefits that occurred at the mill and contribute to its ROI. These energy benefits, however, may not be directly visible. For example, moisture control provides a more tightly controlled, uniform moisture profile which obviates the need to overdry some areas in order to ensure that that final product is of acceptable quality. The paper emerges from the dryer with a slightly higher moisture content. This results in a reduction of rejects and downtime and a reduced drying requirement at constant machine speed. Common practice, however, is not to reduce the steam and hot air to the dryer but, rather, to speedup the machine at constant dryer load to obtain an increase in production, the final result being a reduction, not in total fuel consumption, but in fuel consumption per unit

TABLE 3.7
EXISTING COMPUTER CONTROL SYSTEMS IN PAPERMAKING

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Variable or Component Controlled	CCS Package	Operating Parameters	Benefits of Controls			Cost of Controls		Market Penetration (% Total Capacity)
			Energy Savings		Other	Capital	O&M	
			Percent	MMBtu/a. d. t.				
Moisture Control	<ul style="list-style-type: none">ComputerScanning basis weight and moisture sensors at reelControl functions (software)M. I. S.Startup & installation xxxxxxxxxxxxxxxx	Steam drying pressures or speed	3-6% (drying)	0.1-0.6	Increased production: 3-6% Reduced downtime Reduced rejects	\$200,000 - \$225,000 xxxxxx	\$8,000 - \$10,000/mo. xxxxxxxx	50
Basis Weight Control		Fixed stock flow into fan pump	1-2% (drying)	0.04-0.2	Reduced fiber consumption: 1-2% Reduced rejects Reduced drying Increased production 1-2%			
Caliper Control		Air shower nozzles in calendar	0-2% (drying)	0-0.2	Reduced downtime Reduced rejects Reduced drying Permits greater moisture 0-2%			
Ash Control (in area grades which are 60% of total)		Mineral flow into fan pump	0	0	Reduced material cost by substitution of fillers (e.g., clay) for fiber			
Opacity Control (for coated papers)		Titanium flow into fan pump Mid-range control in blending	0	0	Reduced chemical (Titanium dioxide) consumption			
Efflux Ratio Control (jet-to-wire ratio)		Fan pump speed Stream flow valve Bypass valve & mid-range on stream flow valve	0	0	Improved quality Throughput maximization Grade change control			
Dry Stock Control (commonly with basis weight)		Consistency Adjust thick stock flow	0	0	Reduced rejects Used mostly with basis weight			

Also, a general benefit of computer control is reduced-grade change time (from an average of 15 - 30 min to 2 - 5 min), which results in increased production, energy savings, and fewer rejects.

TABLE 3.8

PREVALENT SENSORS USED FOR COMPUTER CONTROL IN PAPER MACHINES

MEASUREMENT VARIABLE	SENSOR TYPE	PRINCIPLE OF OPERATION	OPERATING RECORD	DRAWBACKS
Caliper (Thickness)	Contacting Magnetic Reluctance	Reluctance of an Oscillator Circuit, Magnetically Coupled Across Paper, Changes with Paper Thickness Thereby Inducing Changes in Oscillator Frequency.	Good	<ul style="list-style-type: none"> ● Cannot be used on Wet Coated Paper ● Mechanical Scanning Mechanism Requires Maintenance
Ash (Used with Basis Weight and Moisture Sensors)	X-Ray Transmission (with Air-Gap Temperature Compensation)	Absorption of X-Rays of Given Energy Differs with Paper Material and Thickness.	Good	<ul style="list-style-type: none"> ● Heavily Dependent on Software ● Mechanical Scanning Mechanism Requires Maintenance
Opacity (For Writing Paper)	Visible Light Transmission	Absorption of Visible Light Depends on Paper Thickness and Coating.	Good	<ul style="list-style-type: none"> ● Mechanical Scanning Mechanism Requires Maintenance

TABLE 3.8 (Cont'd)
PREVALENT SENSORS USED FOR COMPUTER CONTROL IN PAPER MACHINES

MEASUREMENT VARIABLE	SENSOR TYPE	PRINCIPLE OF OPERATION	OPERATING RECORD	DRAWBACKS
Moisture	Multi-Pass Infrared Transmission with Wavelength Ratioing 0-25% Moisture <500 gsm (Generally with Carbon "Corrector")	Intensity of Light Transmitted in Non Water-Absorbing Wavelength Relative to Intensity of Light Transmitted in Water-Absorbing Wavelength Increases with Water Content Multi-Pass Provides Decoupling from Basis Weight	Good	Mechanical Scanning Mechanism Requires Maintenance
	Infrared Reflectance with Wavelength Ratioing 0-75% Moisture Tissue to Heavy Eoard Corrector for <150 gsm	Same as Above	Good	Same as Above
Basis Weight	Transmission Type Beta Ray Gauge (Generally with Housing Temperature Control and Working Air Gap Temperature Compensation)	Number of Electrons Transmitted Decreases with Basis Weight	Good	Same as Above

Figure 3.6 Main Computer Controls in Papermaking Machines

of product output. This practice is rooted in the fact that the marginal return on an increase in production is much higher than the marginal return in decreasing fuel consumption at current fuel prices.

Figure 3.6 also illustrates the coupling that exists between the different control functions and the benefits derived from them which, as previously pointed out (Section 3.3), does not generally permit an unambiguous disaggregation and attribution of the benefits to specific control functions. As a result, there is a certain amount of subjectivity to the evaluation of benefits. The benefit values given in the figure are average representative ranges of vendor claims and industry experience as related to us or as documented in the literature.

3.5.3 Current Development Trends

Some efforts are being directed at extending headbox controls, developing dryer controls and improving moisture and caliper controls. There is also a demand for sheet property measurements, e.g., strength, and for press section and finishing controls. Difficult online measurements of freeness and consistency are being pursued as are better scanning mechanisms to reduce maintenance, or stationary scanning systems that would greatly reduce maintenance. Table 3.9 is a summary assessment of the state of the art of control systems as applied to paper machines and the sensor development areas of current interest.

3.6 ENERGY SYSTEMS

Energy systems are basically concerned with the management and control of industrial boilers and power-generating plants. As such, they are not specific to the pulp and paper industry and, consequently, were not studied in detail. However, they have gained considerable interest in recent years, particularly after Measurex's centerpiece system was installed at Union Camp's mill in Franklin, Va. Since that time, demand has soared, attracting companies such as GE, IBM, Honeywell, Foxboro, Leeds and Northrup, and Westinghouse in addition to Industrial Nucleonics and Measurex.

TABLE 3.9
SUMMARY OF RESULTS
PAPER MACHINE CONTROL

- MARKET FOR INTEGRATED COMPUTER SYSTEMS NEAR ECONOMIC SATURATION
- CONTROL OF SMALL MACHINES LIMITED BY ROI
- MARKET PREDOMINANTLY IN SECOND GENERATION SENSORS
- SENSOR DEVELOPMENT AREAS:
 - Dryer Control
 - Real-Time Freeness Measurement
 - Consistency Measurement
 - Stationary Scanning Systems
 - Sheet Property Measurements
 - Press Section and Finishing Controls
 - Specialty Sensors

The chief attraction of energy systems lies in their ability to trim the costs of generating steam and electrical power. In power and recovery boilers fuel consumption can be considerably reduced by decreasing the amount of excess air or oxygen. Power boilers typically burn two fuels. One is a swing fuel, such as oil, which provides fast response to changes in steam demand. The other is the base fuel, such as bark or hogged wood, which is much less expensive but provides a slower response to load changes and has different polluting emissions. The heart of the power boiler steam loading control is the "allocator" which directs increases in steam demand to the least costly boiler and decreases in steam demand to the most costly boiler, subject to federal and local environmental constraints. Individual boilers are also optimized with respect to efficiency (by reducing excess air) and emissions. This is accomplished by a combination of stack monitors measuring opacity, CO or O₂, and supporting software to compute the required fuel/air ratios for a given steam production target.

Perhaps the single most important feature of interest to the pulp and paper industry is the ability to shift fuels from the mostly imported residual oil (around \$3.50 per million Btu's) to locally plentiful wood (around \$0.55 to \$0.60 per million Btu's).

Another source of savings is in electrical power generation where the system essentially chooses, through its software, whether it is more economical to generate additional electricity at the plant or to purchase it from the local utility. This "teline" control generally depends on the utility's rate structure and the plant's instantaneous steam and power demands. For example, as process steam requirements decrease, the amount of power purchased is increased instead of condenser flow.

3.7 HIERARCHICAL CONTROL LEVELS AND THEIR RELATIVE BENEFITS

In general, computer control systems can be described as occurring at one of four levels of ascending hierarchy:

- Level 1 – Unit process controls for individual operations, such as digesting or bleaching.
- Level 2 – Integration of Level 1 controls; or integrated control of two or more processes, such as digesting and bleaching or digesting, bleaching, and recovery boiler.
- Level 3 – Total integration of all Level 2 controls. Whole-mill control, from raw material to finished product.
- Level 4 – Control of two or more mills.

No controls at Level 3 or Level 4 currently exist in the U.S. pulp and paper industry.

It is generally recognized that the major (about 60 to 90 percent), portion of the energy and resource conservation benefits that can be attributed to computer control (Figure 3.7) occur at the two lowest levels of control: the unit process level and the "regulatory" or multi-process level where several unit processes are integrated in a control loop. All recent installations that have been documented tend to include the second level of control where possible. This practice is based largely on two considerations: (1) The inherent systems nature of the problem of controlling unit processes that interact with each other and (2) the cost of installing computer controls. The logging of selected data, obtainable from current digital control systems, is another function that is useful in troubleshooting and documentation. With the proper software, second level computer control can now be used to some extent for production scheduling and grade changing within the mill. This software, however, generally depends upon the type of equipment available in a particular mill and the way it is linked together.

We were not able to obtain cost figures for such "custom-designed" software from the primary vendors. Our estimate is that it could contribute as much as 50 to 75 percent to the total cost. In fact, one of the industry's suppliers of computer controls specializes in software and purchases the

Figure 3:7 Relative Energy & Resource Benefits of Hierarchical Computer Controls

computer hardware of the control package it offers to the industry from independent vendors.

The common practice today is to install computer controls at the two lowest levels, generally utilizing two or more minicomputers which may have data linkages for reporting and manual process coordination. An operator station is generally provided for manual process control in case the computer controls fail. Additions to the system are then gradually made as greater confidence is gained in the operation and reliability of computer controls. It is possible, by this "modular" approach, to end up with a de facto third level, albeit not fully automated, control system. The common policy, however, is that each additional step taken to expand the system must "stand on its own two feet", i.e., the return on investment of each expansion must be sufficiently attractive. This criterion becomes increasingly difficult to satisfy as one progresses to the higher levels of hierarchical control.

The third level of computer control is where all the mill processes are fully controlled as a system. Full compensations are automatically made to any process in the mill for actions taken in any other process. At that level, it is possible, in principle, to schedule production in a manner that will automatically optimize the operation of the entire mill relative to virtually any self-consistent set of criteria; (the second level scheduling function mentioned above usually requires the intervention of a skilled operator or mill manager). We estimate the incremental benefits of third level controls over second level controls to be in the 5 to 15 percent range, depending on the particular process looping arrangements and the degree of sophistication with which second level controls are implemented in a given mill.

The fourth and highest level of hierarchical control deals with the operation of a number of mills. Some (2 to 5 percent) incremental energy and resource conservation benefits can be gained at that level by optimizing the operation of a set of mills around a given production allocation and

scheduling. However, the primary function of "corporate" control is management information and documentation. The value of this function is subjective, to a large extent, so that the economic justification for that level of control will depend entirely on corporate perceptions and policies.

An additional factor in the adoption of hierarchical controls is the large body of software involved, which may need to be modified as the occasion arises. Higher levels of control will also increase the mill's sensitivity to proper maintenance of the instrumentation.

4. THE COMPUTER CONTROL INDUSTRY

4.1 TRENDS IN MANUFACTURING AND APPLICATIONS

Over the past eighteen years, the number of computers used in process control applications has increased at a rate of 67 percent per year (1). During this period the price/performance ratio for computer hardware has improved by a factor of 20,000 (2). Both of these trends are expected to continue unabated into the 1980's. This section briefly reviews the progress to date in computer applications to process control and discusses the impact of large scale integration (LSI) and microelectronic devices on the present and future of the process control industry.

The earliest applications of computer technology to process control began in 1958. Large-scale mainframe computers were incorporated into plant control schemes along with extensive conventional analog backup systems. The computer control system architecture was typically centralized for two reasons: first, the expense of a single Central Processing Unit (CPU) was too great (over \$50,000) to justify the purchase of more than one; second, the centralized approach was the most natural from the standpoint of the then prevalent control schemes and the state of the art of computer network design. Hence the first digital controllers, typically present in large complex manufacturing processes, employed a centralized architecture in which one processor was multiplexed among several control loops, and cost in the order of hundreds of thousands of dollars.

The development of the transistor and integrated circuit technology in the early 1960's spawned a new generation of digital computers. The ability to incorporate greater numbers of functional elements into less space, coupled with tremendously reduced power requirements, allowed computer manufacturers to produce machines of comparable power and functionality to the earlier mainframes in a smaller package, for a lower price, and with greatly increased reliability and maintainability. The increasing degree of miniaturization of electronic components reduced the price of computational

power to such an extent that computer manufacturers began to adopt the attitude that selling peripheral hardware, such as printers and disk memory systems, was more profitable than selling the computers themselves. This outlook resulted in more emphasis upon integrated systems development. However, business applications received most of the attention, while the process industry received little attention from the minicomputer and large-scale mainframe manufacturers. Despite this fact, estimates in the literature claim that 20 percent of all computers and 40 percent of all minicomputers are used in control applications (1). Unfortunately, this widespread utilization of minicomputers in process applications is not well documented since there is little incentive for industrial manufacturers to publish performance statistics and economic analyses of their proprietary systems.

4.2 THE IMPACT OF MICROELECTRONICS ON THE PROCESS CONTROL EQUIPMENT INDUSTRY

The discovery of the transistor and subsequent development of the semiconductor integrated circuit was primarily motivated by size, weight, and power constraints inherent in the complex electronic systems of various aerospace and military systems. Once the compatibility of microelectronics and the computer was discovered a chain reaction began that is revolutionizing the process control industry. Miniaturization of electrical computer components led to the production of low cost high-performance processors based upon fully solid-state circuitry. A new manufacturing segment of the computer industry grew up around the design and development of minicomputers. The main-frame manufacturers that had dominated the computer hardware industry were forced to compete with a completely new product in a wide-open, new market.

Concurrently, a new industry based upon semiconductor technology was established to provide the variety of microelectronic components for the computer and other industries. Four of the top ten semiconductor companies were formed after 1955. Annual utilization of electronic functions

(transistors, logic gates, and bits of memory), worldwide, has increased 2000 times since 1960, and utilization is expected to continue increasing by another factor of 100 in the next 10 years (3).

This particularly rapid growth of the microelectronics industry has caused unit prices of components to drop dramatically. Between 1963 and 1972, the average price per unit decreased from about \$20 per unit to less than \$0.70 per unit (3). The result is that speculative new markets and technologies related to process control abound for entrepreneurs with a research and/or marketing background and a willingness to gamble. Small companies, with specialized process knowledge and experience, have emerged to integrate the generalized components produced by the semiconductor and computer industries.

In summary, the main-frame manufacturers that dominated the process control computer industry of the early 1960's have been supplanted by three new industrial segments: minicomputer manufacturers; semiconductor manufacturers; and Original Equipment Manufacturers (OEM's). The last segment includes not only the small, specialty companies, but also has an increasingly strong contingent of analog process control equipment manufacturers.

The types of products offered by the new manufacturing segments mentioned above vary from completely integrated distributed control systems down to a single microprocessor encased in the same package with a sensor or final control element (to impart "intelligence" to it). The companies with extensive experience in analog controls tend to manufacture digital controllers that closely parallel, both in appearance and function, their analog precursors. The minicomputer manufacturers tend to make freer use of alphanumeric and graphical display devices with the result that their control systems appear more like the business systems with which they have more experience. Both approaches have merit, and there is a distinct movement, currently, to utilize the best of what both offer. The semiconductor companies continue to expend tremendous research and development resources on new, smaller, more powerful microelectronic devices. Very Large Scale Integration (VLSI)

techniques have produced a new generation of microprocessors that operate on sixteen-bit words (as opposed to the eight-bit words used by the earlier LSI components) and pack enough power to out-perform much higher priced midrange minicomputers.

In an environment such as this, where prices drop by as much as 25 percent per year, the incentive for research and development is quite high. A one-year lead in introducing a new product can give a company a significant advantage over its competitors. Conversely, any lag can result in tremendous losses in market penetration. Thus, the process control computer equipment industry is heavily committed to extensive R&D programs.

For the semiconductor manufacturers these programs are directed at increasing miniaturization, reducing power requirements, and improving production yields. For the minicomputer manufacturers the R&D programs address both hardware and software process control requirements. In this respect, the minicomputer manufacturers are more directly addressing the specific needs of the process control industry, since the software packages are often directed toward satisfying process control functions that have broad applicability, and hence acceptably wide marketability. From all appearances, semiconductor devices aimed at specific process control requirements are conspicuously absent from current and anticipated product lines. The basic operational philosophy shared by several of the semiconductor component manufacturers is that it is not cost effective to develop a specialized component that would sell for \$100-\$200 each when there are several standard components available in the \$2-\$5 range that can be configured (programmed, etc.) to perform the same task. Despite some controversy over this posture, the semiconductor manufacturers seem disinclined to change. In contrast, the OEM's are actively specializing and developing digital controllers designed to solve specific problems. Since many of these companies are small and undercapitalized, they can lack stability. However, as the specialized control applications market matures, it is precisely these companies that will fill the gap that currently separates

the generalized equipment/component manufacturers and the process control user community.

4.3 THE IMPACT OF MICROELECTRONICS ON THE METHODOLOGY OF PROCESS CONTROL

The vast majority of currently installed control systems utilize one of a small set of standard control strategies, e.g., on-off and proportional-integral-derivative (PID) control. The reason for this is that there is a very limited collection of control strategies that are implemented by commercially available analog controllers. The process control industry, for very practical reasons, has selected a set of widely applicable control strategies for incorporation in the equipment it manufactures. A major impact of microelectronic applications to process control is the unlimited flexibility that users will have in the selection and implementation of specialized control algorithms. The developmental effort to implement process-specific, optimal-control strategies, once they have been formulated, is minimal for programmable process controllers, in contrast with that for analog or hard-wired systems. The reconfiguration of a programmable controller to implement a different control algorithm often is comprised of minor software alterations in comparison to the hardware changes required to accomplish the same task in an analog controller.

The increased flexibility in selection of control strategies for implementation on even small control problems has generated new interest in applying the sophisticated and powerful analytical techniques of mathematical control theory. These techniques usually require some mathematical characterization of the system to be controlled in terms of its workload and its associated response to the workload. To obtain such a detailed understanding of a target process, computers have been, and will increasingly be, utilized as monitors that continuously record the state of a system and its environment in machine readable form. Techniques for data storage, retrieval, reduction, and analysis have been an active area of research with fruitful results. The analytical techniques for converting empirically observed system data

into either analytical or probabilistic models are available and have been implemented in many forms on digital computers. All of these facts imply that for even small and/or highly specialized control problems, research formerly confined to scholarly journals and university laboratories can be utilized widely in industrial applications through custom software and firmware that drives standard hardware.

The potential broad applicability of microelectronic controllers, due to their low cost, reliability, and inherent flexibility through software, has caused the process control equipment manufacturers to focus on software as an essential factor in the development of effective controllers. Two approaches to the issue of software development for programmable controllers predominate: development and implementation of customized, preprogrammed systems that utilize proprietary software or firmware; and development and implementation of software tools for utilization by the customer to build his own software.

The current trend in process control equipment manufacturing is for the hardware manufacturers to develop software tools, while the larger manufacturers also provide separate consulting services to assist the purchaser in building the software necessary to install the system at his site. The software tools provided by the manufacturers are typically language compilers and interpreters. Some of the more sophisticated packages incorporate multitasking, real-time operating systems with communications drivers designed to support multiple-loop/multiple-CPU hierarchical control configurations. Either the computer vendor or a specialized OEM is required to install the more complex controller systems. The manufacturers of less expensive and/or complex programmable controllers often build a specialized language interpreter into firmware (read only memory). The purchaser is responsible for the integration of the device into his own control scheme. The language interpreters often utilize forms to fill in or relay ladder diagrams to minimize the learning curve required prior to program development.

4.4 PROBLEMS FACED BY THE COMPUTER CONTROL INDUSTRY

There are at least four major industries involved in the production and implementation of microelectronic based controllers: the semiconductor industry, educators/researchers, the computer systems hardware/software manufacturers, and the industry with the process to be controlled. Each of these sectors has its own view as to its role and responsibilities toward bringing about the application of microelectronics to industrial control problems. A lack of balanced perspective is probably the major force in retarding the widespread proliferation of microelectronic controllers.

Semiconductor manufacturers have adopted the role of developing general purpose devices that require extensive expertise to configure to the specialized requirements of industrial control. Universities either train students for gate and circuit level design or abstract mathematical techniques in systems control theory. The computer industry neglects process control applications in its seminars and literature, and has pre-occupied itself with going after the business and scientific applications markets, almost to the exclusion of all else. Industrial control engineers have been reluctant to learn about programming and computer systems development. The result is that hardly anyone is filling the essential role of Systems Integrator. There are indications that OEM's and consulting firms are beginning to assume this role, but the need is much greater than the available assistance.

Lack of published information is another significant impediment to a more widespread proliferation of microelectric control instrumentation. It is difficult for potential users to perform feasibility studies and cost/benefit analyses prior to making the commitment to computerized control. Technical reports that present the experience of other users are rare because there is little incentive for private corporations to share their hard-earned secrets.

Another problem facing the widespread proliferation of microelectronic based industrial control is economic. Many processes that can realize significant benefits from "intelligent" controllers occur in industrial sectors

that are unequipped to bear the initial cost of development of such systems. While the hardware investment is small, qualified personnel are scarce and expensive to hire either as consultants or as full-time staff.

Lack of standardization is another problem that affects the development of microelectronic industrial controllers. Each microcomputer process control systems manufacturer develops a unique set of functional modules that communicate over unique data paths with different signal conventions and protocols. Almost certainly, the development of a microelectronic based controller will require the interfacing of sensors from one manufacturer with actuators from another, a central processing unit with input/output interfaces from yet another, and a control panel for the operator from possibly a fourth vendor. The only way to accomplish this is with multidisciplinary expertise. Much of this problem can be alleviated through standardization of component interfaces. Software standardization has been the object of much effort in the computer industry without much success. The process control industry has reason to attempt better progress because the scope of its problems is somewhat narrower.

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5. DEVELOPMENT AREAS OF GREATEST INTEREST TO ENERGY CONSERVATION

The state of the art survey of Chapter 3 has shown that paper machines in the U.S. are close to being economically saturated with computer controls and that the market lies principally in second generation or specialty sensors. Although this situation will change as new and/or faster machines are introduced, it is not likely to occur in the near term. Computer control of the pulping area, on the other hand, it still in its infancy, having penetrated only about 20 percent of the market. The energy benefits of available ACS in this area have been documented in a number of cases and can be substantial.

The main technical problem appears to be the extraction of samples from directly steamed batch digesters operating at steam pressure. The main economic problem is the high cost of the equipment relative to the savings in energy and chemicals. Other technical problems have been pointed out by some users in the industry's trade journals while other users have found the same equipment satisfactory. Perceptions of need and performance under the same operating conditions sometimes differ significantly among users and/or suppliers. We believe that a greater market penetration of second level computer controls on batch digesters and bleach plants would result in significant energy benefits.

The other area that offers the greatest potential for energy savings is the recovery boiler, for which no control system exists. Here, too, perceptions of benefits differ. For example, some mills use residual fuel oil continuously in the recovery boilers while others use it primarily for start-up. We believe that the pulping operations, recovery boiler, and evaporator should ultimately be integrated in a control loop to derive the maximum energy benefits.

For the pulping operations, the sensor areas of greatest interest appear to be in:

- Direct real-time measurement of pulp quality
- Bulk density measurement

- Improved chip moisture treatment
- Improved active alkali measurement

For recovery boilers, it is necessary to develop sensors or sensor systems, and their associated software, which can accomplish the following functions:

- Liquor combustion stabilization
- Detection of smelt bed condition
- Real-time measurement of liquor
 - calorific value
 - viscosity
 - surface tension
- Better real-time measurement of percent solids

6. POTENTIAL FOR ENERGY SAVINGS

6.1 INTRODUCTION

To learn about industry's attitudes toward automatic process controls, we conducted in-depth interviews with management personnel at selected pulp and paper firms and with manufacturers of process controls. (Appendix A describes our interviewing method.) By agreement with OIP, we focused our interviews on 600-tn/day integrated pulp and paper mills located in the southern region of the United States, for the following reasons:

- The average-size integrated mill produces about 600 tons of product a day.
- About 75 percent of pulp and paper is produced by integrated mills.
- About two-thirds of pulping capacity and half of papermaking capacity is located in the South.

We regard our conclusions as preliminary for several reasons. First, we were limited in the number of pulp and paper companies we could interview, and in the amount of time we could spend interviewing them and visiting their facilities. Second, ACS is a fledgling technology which has not yet permeated the thinking of the pulp and paper industry, an industry which generally views new technologies from a highly conservative perspective. Moreover, a good deal of controversy surrounds process control technologies, particularly in the pulping and recovery areas. Finally, because vendors and users perceive ACS needs and performance so differently, it is difficult to define the benefits and limits of existing and advanced technologies.

Nevertheless, we believe that this preliminary effort reveals a significant opportunity for energy conservation through use of ACS in the pulp and paper industry, enough so to warrant a programmatic effort by OIP to overcome the barriers identified as currently limiting achievement of ACS potential.

6.2 ENERGY SAVINGS USING AUTOMATIC CONTROL SYSTEMS

Over 80 percent of the energy used in pulp and papermaking is used in the digesting, refining, bleaching, and papermaking processes, and by the evaporators and lime kilns. Because of this, these areas offer the best opportunities for energy conservation. In addition, improved control of the recovery boiler will reduce the amount of fuel required by the mill powerplant. Typical distribution of energy consumption within a mill is shown in Figure 6.1.

To assess the energy savings that ACS could provide at level 1, we asked the companies we interviewed to comment on the probable market penetration and relative energy savings associated with both existing and advanced automatic control systems. Potential energy savings using existing controls for three of the most energy-intensive processes (digesting, bleaching, and papermaking) are detailed in Figure 6.2. This figure does not cover potential energy savings in the recovery area (evaporator, recovery boiler, lime kiln), for which few controls have been developed. As shown in Figure 6.2, ACS market penetration is relatively high for papermaking, however, ACS is generally used not for energy conservation but to control quality and production. Bleaching and digesting, for which potential savings are also high, show low ACS market penetration suggesting that there are barriers to its acceptance (see Chapter 7).

Advanced level 1 control systems and the energy benefits they are likely to produce are described in Figure 6.3. We summarized the control technology needs for the most energy-intensive processes, including those in the recovery area. There was general agreement among people we interviewed that the evaporators, recovery boiler, and lime kiln offered the best energy-saving opportunities for ACS, even using conservative estimates of benefits.

Companies we interviewed sometimes disagreed about which variables it would be useful to measure. For example, opinions varied on the usefulness of measuring the viscosity and the heating value of the liquor in the

Figure 6.1 Energy Flow in a Pulp and Paper Mill

Unit Process	Average Energy Use		Benefits with Controls			Cost of Controls		Market Penetration
	Million Btu/Ton*	Percent of Total Energy**	Energy Savings		Other	Capital	O&M	
			Percent	Million Btu/Ton*		(\$1000)	(\$1000/Month)	
Batch digesting†	4.4	14.0	15-25	0.66 - 1.10	Increased yield: 1-2% Reduced wood use: 3-4% Chemical savings: 7-10% Steam leveling Reduced steam blowdown	350-400	2-4	Low (10-25%)††
Continuous digesting†	1.8	3.5	Negligible	Negligible	Increased yield: 1.5-2% Reduced wood use: 3-4% Chemical savings: 7-10%	350-400	2-4	Low (15-25%)
Bleaching	4.4	14.0	5-12	0.22 - 0.53	Increased production: 2-5% Chemical savings: 8-10%	350-400	2-4	Low (5-10%)
Papermaking	11.3	36.0	3-6 (Using moisture control)	0.34 - 0.68	Increased production: 3-6% Reduced downtime Fewer rejects§	300-500 depending on degree of control	8-10	High (75-85%)
			1-2 (Using basic weight control)	0.11 - 0.23	Increased production: 1-2% Reduced fiber consumption: 1-2% Fewer rejects Reduced drying time	300-500 depending on degree of control	8-10	High (75-85%)

SOURCE: Resource Planning Associates, Inc., based on data provided by Thermo Electron Corp. and companies interviewed.

- * Air-dried ton of finished product.
- ** Average percent of total energy required for paper production (31.4 million Btu/ton for first half of 1978)
- † Batch digesting represents 80% of installed pulping capacity; continuous digesting, 20%
- †† Percent figures derived from company interviews; based on total capacity.
- § Another benefit of computer controls is reduced grade change time (from an average of 15-30 minutes without controls to an average of 2-5 minutes with controls), which results in increased production and energy savings, and fewer rejects.

Figure 6.2 Potential Energy Savings with Existing Automatic Control Systems

Unit Process	Technology Needs	Average Energy Use		Probable Control Benefits		
		Million Btu/ton*	Percent of Total Energy**	Energy Savings Million Btu/ton ⁺	Other	Comments
Batch Digesting	Reliable measurement of chip moisture under all conditions, including freezing	4.4	14	0.06 (reduced steam requirement for adequate cook)	More uniform kappa number, resulting in higher production	Paper companies agreed that these needs should be addressed. One vendor said the energy benefits would come primarily from steam leveling, not reduced steam use.
	Reliable measurement of active alkali			0.06 (reduced steam requirement for adequate cook)		
	Reliable on-line measurement of kappa number during cook			0.12 (reduced steam requirement for adequate cook). This capability would alleviate need to measure other cooking variables (chip moisture, active alkali, etc.)		Two companies agreed it would be useful, but did not believe it could be measured; one vendor said substitute measurements will produce the same results.
Brown Stock Washing	Reliable measurement of sodium content of pulp from the washers	0.94	3	0.14 (reduced steam to evaporators)	Reduction in bleach plant chemicals; reduction in make-up salt cake requirements	A reliable sensor is already available; companies interviewed disagreed on whether significant energy savings were possible.
Refining (Stock Preparation)	Reliable on-line measurement of freeness	3.1	10	0.11 (reduced refiner horsepower and moisture content of sheet to dryers)	More uniform sheet formation and increased production	Important area for control although one paper company said freeness doesn't indicate anything; more important is a measure for refining.
Papermaking	Reliable on-line measurement of sheet properties, i.e., machine and cross-machine direction strength, stiffness, and tear	11.3	36	0.12 (reduced steam requirement to dry off-grade paper)	Fewer off-grade products	The sheet properties mentioned are all destructive in nature and difficult to measure on-line.

Figure 6.3 Potential Energy Savings with Advanced Level 1 Automatic Control Systems

Unit Process	Technology Needs	Average Energy Use		Probable Control Benefits		Comments
		Million Btu/ton*	Percent of Total Energy**	Energy Savings Million Btu/ton†	Other	
Evaporators	Need computer model for most efficient time for boil-out of evaporators	2.83	9	0.19 (reduced steam requirement)		Important area for control. Estimate of savings conservative.
Recovery Boiler	Reliable measurement of black liquor as to: viscosity, surface tension; and heat value	—	—	1.42 (eliminates starting burner oil) 0.08 (reduced steam required to heat excess air)	Allows more stable operation of boiler due to uniform particle size and distribution at spray nozzles	Opinions varied as to the usefulness of measuring viscosity and surface tension; two companies would focus on measuring liquor composition (organic/inorganic ratio) and bed height.
	Reliable measurement of steam to determine adequacy of blow-down	—	—	0.12 (reduced steam use in continuous blowdown)	Reduced need for pollution treatment	One company would not want to restrict the amount to blow-down, to ensure safe operations.
	Soot blowing					Two companies emphasize the need for controls that measure when to blow soot from the boiler tubes.
Lime Kiln	Reliable measurement of temperature gradient in kiln, and of sodium in lime mud.	2.2	7	0.09 (reduced fuel use)	Better slaking control resulting in more uniform liquor composition to digester	General agreement that this is a conservative estimate of savings. One company said burning coal in the lime kiln would be a lot cheaper, but mills are reluctant to do so, because they don't know the effect carbon ash has on the calcining of lime.
	Reliable measurement of flame qualities	2.2	7	0.09 (reduced fuel use)		

SOURCE: Resource Planning Associates, Inc., based on estimates provided by J.E. Sirrine Company, and reactions from companies interviewed by RPA.

* Air-dried ton of finished product.

** Average percent of total energy required for paper production (31.4 million Btu/ton for the first half of 1978).

† Unit energy savings were based on a 600-ton-a-day integrated pulp and paper mill.

Figure 6.3 (Cont'd) Potential Energy Savings with Advanced Level 1 Automatic Control Systems

recovery boiler; one vendor thought it made more sense to focus on the height of the bed and the composition of the black liquor. Reducing the amount of boiler blowdown was also considered useful by some companies, but one plant said this might give rise to unsafe operating conditions.

We estimate that the pulp and paper industry could save approximately 0.09 quads a year using existing ACS and another 0.15 quads a year using advanced ACS.* A breakdown of potential energy savings is presented in Figure 6.4.

So far we have focused on level 1 controls. It was difficult on the basis of our research findings to estimate the incremental benefits associated with the higher levels of control. People we interviewed generally agreed in attributing 60 to 90 percent of total potential energy savings to level 1 and 2 controls, with the fewest energy benefits linked to level 4 controls. Several sources were of the opinion that between 5 and 15 percent of overall energy savings would result from installation of level 3 mill controls. Despite diminishing returns, some of the more innovative companies felt that the potential financial benefits warranted further research into the higher levels of control. These firms have taken one of two approaches: either developing process controls now with the intention of eventually fitting them into an integrated hierarchical structure; or establishing the foundation for multilevel controls by setting up a management information system to facilitate the flow of information between the mills and corporate headquarters.

We discuss these points further in the next chapter, which deals with barriers to the increased use of ACS.

* These calculations are based on the assumption that energy savings for the various processes are mutually exclusive. We also assumed that the R&D costs associated with new sensors will not make their prices unacceptable to the industry.

Unit Process	Average Energy Use		Existing ACS			Advanced ACS		
	Million Btu/ton	Percent of Total	Market Opportunity (Percent) ^{††}	Potential Energy Savings (Million Btu/ton) [†]	Total Potential Energy Savings (10 ¹² Btu/year) ^{††}	Market Opportunity (Percent)	Potential Energy Savings (Million Btu/ton) [†]	Total Potential Energy Savings (10 ¹² Btu/year) ^{††}
Batch Digesting	4.4	14.0	82.5	1.10	54.0	100.0	0.24	14.3
Washing	0.94	3.0				100.0	0.14	8.3
Refining (Stock Preparation)	3.1	10.0				100.0	0.11	6.5
Bleaching	4.4	14.0	92.5	0.53	29.2			
Papermaking	1.3	36.0	20.0	0.91	10.8	100.0	0.12	7.1
Evaporators	2.83	9.0				100.0	0.19	11.3
Lime Kiln	2.2	7.0				100.0	0.18	10.7
Recovery Boiler						100.0	1.62	96.4
Total		93.0			94.0 (0.09 quads/yr)			154.6 (0.15 quads/yr)

SOURCE: Resource Planning Associates, Inc., based on data provided by Thermo Electron Corp. and J.E. Serrine Company

* Maximum energy savings using level 1 Automatic Control Systems (ACS) for individual unit processes.

†† ACS market saturation of 100% less average ACS market penetration to date. 100% market saturation assumes no time constraints, and that the older mills will eventually be replaced by new.

† Unit energy savings calculated for a 500-ton-per-day integrated pulp and paper mill.

†† Total energy savings based on total paper and paperboard production for 1976 (59,523,151 tons/year) according to *Post's 1978 Pulp and Paper Directory*.

Figure 5.4 Potential Energy Savings*

7. BARRIERS TO THE INCREASED USE OF COMPUTER CONTROLS

Although ACS offers substantial potential for energy conservation, there are definite barriers to its widespread acceptance. We have grouped these barriers into three categories: technical, economic, and institutional.

7.1 TECHNICAL BARRIERS

To achieve predicted energy savings using advanced ACS will require not only improving existing sensors but also developing new types of sensors to measure process variables that are now measured either directly, using human judgments, or indirectly, by measuring other critical variables. Some sensors, particularly those for digesting and the recovery area, are either unavailable or unreliable. New sensors are needed, for example, to measure chip moisture at freezing conditions, the kappa number, the bed condition in the recovery boiler, and the composition of the liquor that feeds the boiler. Paper companies need sensors that give consistent readings at given conditions and require minimum servicing and recalibration. Until adequate sensors are developed, few companies will even consider looking beyond level 1 controls to higher levels of control.

Information about ACS needs and capabilities is often difficult to come by. There is a need to improve the flow of information between process control vendors and the pulp and paper industry process control staffs. Information is either inadequate, out of date, or conflicting. It is difficult for those companies which are highly dependent on ACS vendors for information, design concepts, and R&D to evaluate competing systems objectively. Furthermore, paper companies tend to typecast vendors according to specialties they are aware of, and fail to explore the vendors' full capabilities. A process control manager at one paper company remarked that it would be helpful if different types of computers could communicate with each other within a mill; vendors indicated that this capability already exists.

Poor communication between vendors and users sometimes puts them at cross purposes. For example, one vendor seems to be emphasizing ACS control of the digesting process, although the paper companies are apparently more interested in controls for the recovery boiler. One vendor believes that firms considering multilevel controls are worried most about potential lost sales while the mills are shut down for retrofit operations; however, a process control manager at a paper company said that their chief concern is the uncertain economic benefits of the higher levels of control.

Finally, the lack of standardized hardware and software among vendors hampers whole-mill system integration. There is a particular need to develop algorithms for the higher levels of control.

7.2 ECONOMIC BARRIERS

It is unlikely that pulp and paper mills will adopt ACS for energy conservation while the costs of energy remain relatively low. With energy costs amounting to from 5 to 10 percent of the cost of production, energy-related capital investments are assigned a low priority. Energy conservation projects have to compete with other projects (e.g., improved production or pollution abatement) for limited discretionary funds, and in terms of costs and benefits they may compete at a disadvantage. One company in our sample has had a poor history of achieving predicted energy savings for energy conservation projects.

Even if saving energy reduces manufacturing costs, mills are unlikely to adopt any energy conservation projects that would reduce production. Production is foremost in the minds of mill managers. There is a seller's market for pulp and paper products, and with low variable costs, the marginal return on an incremental increase in production is generally very high. If an energy-saving investment reduces production, the lost profits may greatly exceed the energy savings.

One vendor told us that many pulp and paper firms which are interested in ACS are adopting a wait-and-see attitude toward ACS

investments because of confused interpretations about the investment tax credits provided for in the Energy Tax Act of 1978. It is uncertain whether computers used in the mill for energy conservation would qualify for the additional 10-percent tax credit, particularly if they are also used for other purposes, such as improving quality control or increasing production.

One step toward improved energy management would be cost accounting systems in which energy is treated as a controllable cost. One company's long-term objective is to have the mill's information and cost-control system reflect energy costs so that operators and managers are held accountable for energy performance. However, other companies do not share this concern.

The process control manager at one paper company expressed the opinion that vendors are not developing the higher levels of control because it is difficult to transfer a system from mill to mill. Mills differ greatly in terms of plant capacity, raw materials used, product line, and age and type of equipment used. Each ACS application has to be custom-made; developing suitable control software requires a substantial investment, yet it is highly uncertain whether a given ACS will work in other mills. Not only does this increase costs considerably, but vendors prefer to develop units or systems that can be packaged and sold to more than one customer.

Finally, investments in ACS for the retrofit market must usually fit into the cycle for asset turnover or scheduled shutdowns, and the rate for replacing equipment is very low in the pulp and paper industry. If the market demands high-capacity utilization, installation of a major control system for energy savings will be delayed.

7.3 INSTITUTIONAL BARRIERS

Vendors of ACS systems supply important technical services and training to the industry. First, they frequently custom-design a system to match the capabilities of the customer, so that the system can be

modified or expanded to suit the user's needs. As part of the agreement they often train mill personnel in operations and maintenance. However, it is the exceptional mill that becomes self-sufficient at maintaining its process control systems, particularly the sensors, which are critical to the reliability of the system. A pulp and paper firm may contract for maintenance services from the ACS vendor, but the cost is high and continuing, and makes the ACS investment difficult to justify. In any case, most mills prefer the security of having their own people trained and responsible for maintaining key equipment, thereby minimizing their dependence on the ACS supplier. Customized technical assistance contracts, which tailor supplier involvement in the maintenance program to suit the capabilities of the mill, are increasingly common. However, some paper companies have complained that mill personnel are not well-enough trained to handle maintenance, and have chosen to increase their technical resources by hiring from the outside. Unfortunately, for both vendors and mills, there is a shortage of qualified people. A major source of skilled workers, former military personnel trained in various electronics systems, is no longer providing enough personnel to meet civilian industry needs. Moreover, the turnover of qualified ACS operators and maintenance personnel has made it difficult to maintain a constant work force.

As more sophisticated levels of control are adopted, operating and maintenance crews will need to acquire additional skills to handle them. A spokesman for one company indicated that the shift supervisor would need to be a college graduate with a degree in electrical engineering to bridge the gap between the process control people and the operators. Higher levels of controls will especially increase the mill's sensitivity to poor instrumentation. Accurate sensors and reliable controls must be serviced and calibrated on a regular basis. The extent to which electronics technicians, rather than electricians, are required and available for maintenance will be a factor in acceptance of the higher levels of control.

There is another barrier to acquisition of the expertise required for use of ACS: fear of antitrust action hampers the flow of information among process control specialists from different pulp and paper firms, even in the presumably open environment of professional meetings and symposia. Because of the number of antitrust lawsuits the government is filing, technical interaction among firms has declined drastically. Market penetration of ACS depends partly on whether pulp and paper firms can be persuaded that they work. Published reports about installed systems often come from ACS vendors themselves and therefore lack credibility. Plant managers want to see other mills and talk with their peers before getting involved. To the extent that open discussion among firms is reduced, acceptance of ACS will suffer.

Finally, there is a tendency in the industry to resist technological innovations, particularly those involving computers. There was considerable resistance when computerized process controls were first introduced to papermaking in the early 1960s, and most companies that experimented with computers ran into problems, including a lack of qualified technicians, management skepticism, inadequate standards for most control variables, and difficulty in quantifying process characteristics.

Many people in the industry regard papermaking as an art which requires judgments about the look and feel of pulp and paper that are difficult to measure, must less computerize. It took several years, but computerized controls have begun to be accepted. However, ACS has been used chiefly for market-oriented reasons to improve product quality and increase production; reducing energy costs has been a minor factor in most decisions to install ACS, although with rising fuel prices and uncertain supplies, plant managers are beginning to realize the importance of energy management and conservation.

In the companies we interviewed, energy managers or coordinators started to appear in the corporate structure about 2 years ago; and increased awareness of potential energy conservation is beginning to filter

from top management down to mill operators. However, this has been a slow process. Middle and upper levels of management are usually not oriented toward computer applications and are not easily convinced of the need for ACS. It appears that, on the one hand, some managers don't want to relinquish their decision-making authority to a computer, and on the other hand, some don't want to exercise undue control over a decentralized structure, which higher levels of control would enable them to do.

8. POTENTIAL GOVERNMENT ACTIONS

To a limited degree, market penetration of level 1 ACS will probably take place within the next few years with or without government encouragement or assistance, particularly for the energy-intensive processes.

The industry seems, on the whole, to have accepted the idea of automatic controls on the papermaking machinery. Full market penetration in this area may take from 5 to 10 years, depending on whether smaller plants can afford the investment and when older equipment is scheduled for replacement. Existing controls for the digesting and bleaching processes have low market penetration; it may take 3 to 5 years before the industry begins to accept controls on these pulpmaking processes. Few sensors or controls have been developed for the recovery area, and it is unlikely that significant advances will be made in the next 5 years, without outside encouragement. Furthermore, it is unlikely that higher levels of control will be achieved until controls are developed and adopted for the recovery area and other unit processes.

There are several ways in which the federal government could encourage the use of ACS for energy conservation.

In the short term, the market penetration rate for ACS in digesting and bleaching would probably increase if users were provided with a clear interpretation on whether, and under what circumstances, firms investing in energy-saving automatic control systems are entitled to an additional 10-percent investment tax credit, as provided by the Energy Tax Act of 1978, even if the control systems are also used for reasons other than energy conservation. As we indicated earlier, some companies are holding off on investments until DOE makes an unambiguous ruling.

We did not explore potential incentives such as accelerated depreciation allowances and loan guarantees. The process control manager at one paper company told us that any government incentive to push ACS would have to be out of the ordinary; investment tax credits might not offer

enough incentive, but cost-sharing projects seemed attractive. Pulp and paper companies might be interested in ACS demonstration projects jointly funded by the government. These would not only help participating firms financially, but would also give them a headstart on ACS technology. The manager commented that there was a lot to be learned, even if such a venture did not achieve its principal objectives. There is little chance currently of undertaking cooperative demonstration projects among firms within the industry because of antitrust concerns.

To counteract the fear within the industry of federal antitrust suits, OIP could provide the mechanism for an exchange of technical information, both with the industry, and between vendor and user. In conjunction with trade associations such as the Technical Association of the Pulp and Paper Industry (TAPPI) and the American Paper Institute (API), OIP could sponsor seminars and workshops for process control groups from within the pulp and paper industry, or workshops which representatives from other industries knowledgeable about ACS could attend.

Sponsoring intra-industry workshops would allow technical people to discuss freely the benefits and problems of existing ACS, and develop ideas for new unit process controls and higher-level controls. Proceedings of each workshop could be distributed throughout the industry and to vendors of process controls. By inviting only technical people and the government, and avoiding discussions of pricing or marketing, DOE might alleviate anti-trust complications.

An interindustry workshop would bring together the key specialists in process control from many industries and universities.* Bringing different

* A meeting was recently held by the Department of Commerce to determine how much interest there would be in establishing a cooperative technology center for the exchange of information about process control systems and instrumentation. Process control vendors and specialists from a number of industries attended. The concept is still in the planning stages, but DOE could help the Department of Commerce determine the feasibility and benefits of such a center.

perspectives to bear on the common problems of automatic process controls might produce unexpected benefits. For example, the cement industry's vast experience with kilns may be helpful in designing controls for the lime kiln used in the recovery area of a pulp and paper mill. Most of the firms we interviewed have brought in experienced personnel from outside the pulp and paper industry to direct efforts in process control and to design higher controls. The industry seems to realize that process control is not industry-specific, and that there are synergistic benefits to be gained from industrial cross-fertilization.

One subject that might be discussed at government sponsored workshops is the expanded use of third-party specialists, such as systems engineering companies, to analyze the needs of the pulp and paper mills and translate them into design applications for sensors and computer hardware and software. This would reduce some of the credibility problems inherent in having the vendor determine the needs of the customer.

Along the same lines OIP could foster a better technology exchange with the Scandinavian countries. The pulp and paper industry has long regarded Sweden and Finland as leaders in ACS, especially at the higher levels of control. One possibility is to send a U.S. study team composed of industry, academic, and government ACS specialists to evaluate these Scandinavian systems.

By detailing energy profiles and technology, assessing whether they can be transferred to the United States, and publishing the results, OIP would enhance the image of higher controls in the United States. OIP could also explore opportunities for cooperative projects with these two countries, either under the IEA implementing agreement for the pulp and paper industry, or on a bilateral basis. Opening up market opportunities in the United States for their special ACS product and design expertise might provide incentive enough for either country to cooperate with the United States. The benefits the United States might expect from such cooperative activities would have to be balanced against domestic economic interests in the process control industry.

DOE could also help to upgrade the skills of mill operators and maintenance crews by providing training grants at established organizations such as the Institute for Paper Chemistry, and at selected educational institutions with ongoing technical programs relevant to the pulp and paper industry. In addition, DOE could stimulate R&D into sensors and computer software. However, direct federal assistance to R&D projects would have to be carefully designed to be accepted by ACS vendors, because sensors and software are the tools by which they compete, and accepting federal assistance that requires public disclosure of all R&D results could be perceived as a threat to their competitive advantage. Initially, the government should probably focus on identifying R&D needs through industry surveys and workshops, and on communicating those needs to vendors and users.

Because of the need to standardize computer software, the government could subsidize the development of communications standards among different types of computers, a computer language for manufacturing processes, and algorithms for integrating process controls. Universities with strong research programs in process controls and systems analysis are good candidates for federally funded projects in these areas, with potential benefits to all process industries.

APPENDIX - FIELD INTERVIEWS

To study all possible uses of ACS and their respective costs and benefits would have required investigating a large part of the industry. Because of time and budgetary constraints, we limited our field interview sample to three paper companies and two process control manufacturers, although two additional paper and process control companies were interviewed by telephone. (Pulp and paper companies contacted were: Scott Paper, International Paper, Union Camp, and Westvaco; process control firms contacted were Industrial Nucleonics, Measurex, and Nokia, a Finnish firm.) However, since the pulp and paper industry is highly concentrated, our field interview sample actually represents about 20 percent of total pulp and papermaking capacity, and our sample of process control vendors represents about 90 percent of current computer process control business in the pulp and paper industry.

In the process control industry, we spoke with managers from engineering and finance, and product managers for the pulp and paper industry. In the paper industry, we spoke with managers from process control design research and development, engineering managers, and energy planning managers. We explored the paper industry's attitudes toward ACS, their impressions of existing and advanced ACS packages for each of the energy-intensive unit processes in the mill, and their views of what role the government could play in promoting ACS development and application. Our sample, while limited, covered a wide spectrum of attitudes toward ACS, from innovative to skeptical.

To assess potential energy savings with both existing and advanced automatic controls, we prepared two sets of descriptions, and asked the companies interviewed to comment on each process control described in terms of associated costs, potential energy savings, and probable market penetration. The composite responses from these questionnaires are presented in Chapter 6.

First we described the types of automatic controls currently available for several unit processes. The types of sensor varied depending on the process, but each control consisted of a computer mainframe, software programs, and reporting capabilities. Next we described advanced control technologies for several unit processes, requesting responses about associated energy savings and other benefits that would accrue if those needs were addressed.