S&A FY03 ANNUAL REVIEW MEETING

Assessment Study: Sensors and Automation in the Industries of the Future

Subareas: Automation, Industrial Control, Information Processing, and Robotics

Area Leads:

Mark Boddy, *Adventium Labs*

Frank Doyle, *University of California, Santa Barbara*

Mo Jamshidi, *University of New Mexico*

Tunde Ogunnaike, *University of Delaware*

Agenda

- **Project Introduction**
  - Deliverables
  - Context
  - Plan
- **Specific Technical Areas**
  - Automation
  - Industrial Controls
  - Information Processing
  - Robotics
- **Discussion/Q&A**

Project Deliverables

For each of the four technical sub-areas:

- **Identify opportunities for DOE/OIT research funding within the DOE/OIT "Industries Of the Future" (IOF), prioritized by energy savings and energy efficiency.**
- **Develop 2-3 case studies, constituting *Grand Challenge Problems***
- **Identify key funding agencies and major contractors**

Grand Challenge Problems

Case studies detailing an opportunity for significant energy savings and/or increased energy efficiency

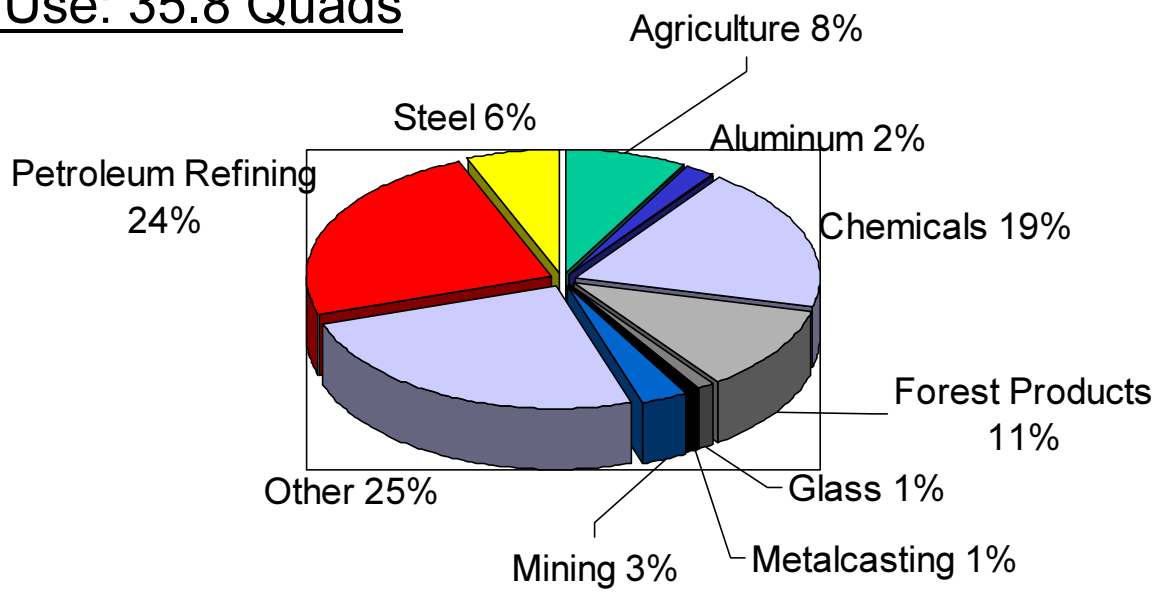
- **Large impact on energy use**
- **High-risk, high-return R&D**
- **Encourage public-private partnerships**
- **Integrate and coordinate smaller projects**
- **New solutions to complex technical problems**
- **Defined goals, to be achieved in a specified timeframe with measurable benefits**

Context: Source Material

- **National Academy of Engineering, Proc. National Academy Press, 2000.**
- **U.S. Department of Energy, Office of Industrial Technologies, Congressional Briefing by Denise Swink, Deputy Assistant Secretary, April 2, 2001.**
- **U.S. Department of Energy (report prepared by Energetics, Inc.), *Energy and Environmental Profile of the U.S. Chemical Industry*, May 2000.**

Context: Current IOF Energy Use

Total 1997 End Use: 35.8 Quads



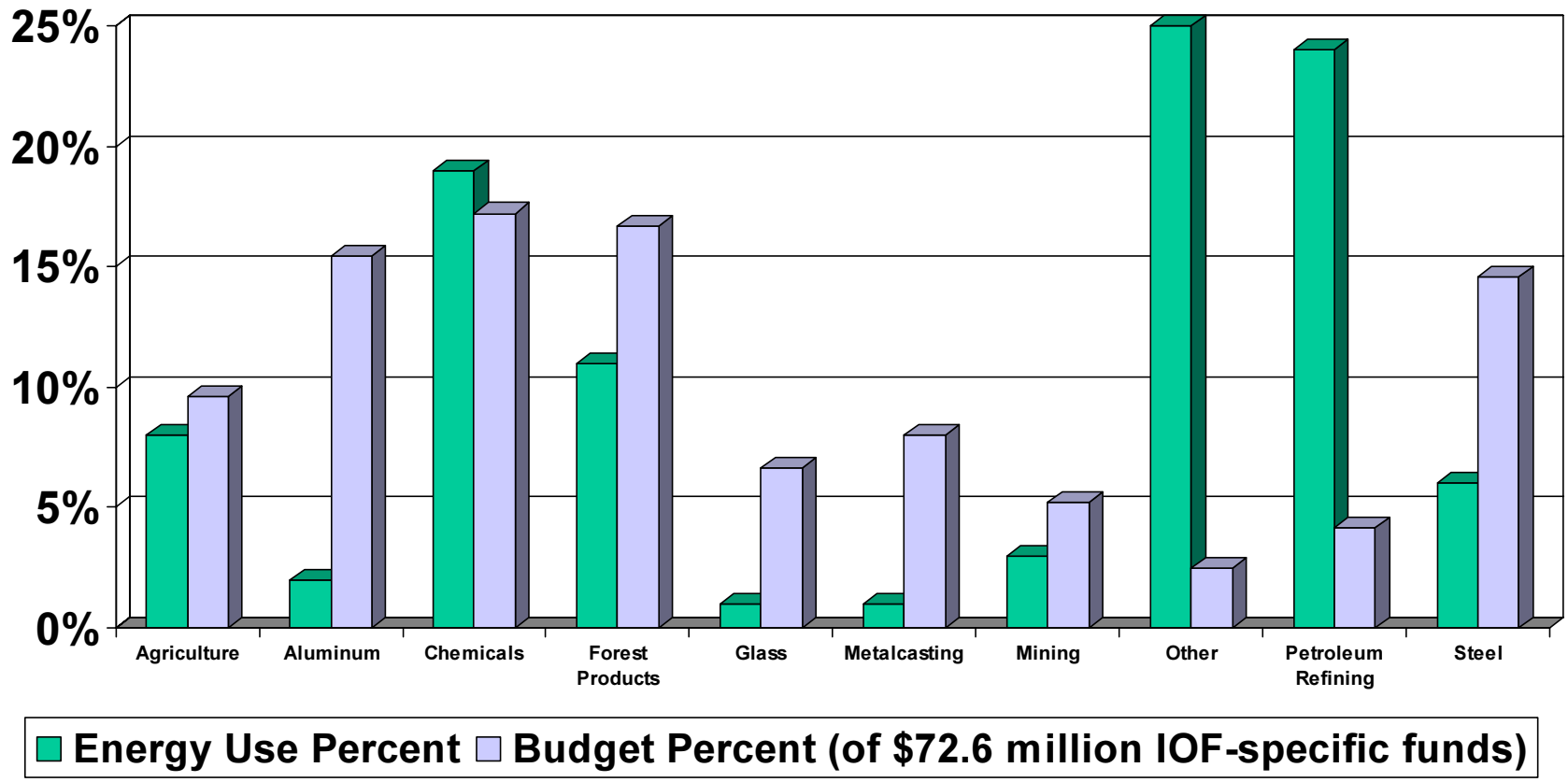
Petroleum Refining not considered.

Food and Cement will be added.

Largest consumers (after Petroleum):
Chemicals (19%) and Forest Products (11%)

Source: U.S. Department of Energy, Office of Industrial Technologies, Congressional Briefing by Denise Swink, Deputy Assistant Secretary, April 2, 2001. http://www.nemw.org/Swink_OIT_Apr2001.pdf

Context: DOE Investments (2001)



Source: U.S. Department of Energy, Office of Industrial Technologies, Congressional Briefing by Denise Swink, Deputy Assistant Secretary, April 2, 2001. http://www.nemw.org/Swink_OIT_Apr2001.pdf

Context: NAE Study

Energy Research at DOE: Was It Worth It, NAE Press, 2000.

DOE:

- Founded 1977
- $91.5B funding for energy research, 1977- 2000.

Energy Efficiency Programs

- Reduce life-cycle costs of energy consuming goods.
- Reduce pollutant emissions.
- Reduce risk of oil supply interruptions.
- Increase stability and reliability of power grid.

Context: NAE Study Conclusions

DOE R&D programs (1978 – 2000) have produced significant benefits:

Economic Benefits. Benefits of the R&D programs were judged to be well in excess of the DOE investment.

Environmental Benefits. Substantial reductions in pollution resulted. $64 - $90 billion savings as a result of reduced cleanup and reconstruction.

National Security Benefits. Improvements in oil recovery technology increased oil production in the U.S., reducing our dependence on foreign oil.

Knowledge Benefits. DOE funded research adds to our knowledge base.

Source: NAE, Proc. NA Press, 2000.

Context: Chemical Industry Survey Data

U.S. Department of Energy, *Energy and Environmental Profile of the U.S. Chemical Industry*, May 2000, p. 48, summarizes the Top Chemicals Ranked as Targets of Opportunity for Improved Energy and Materials Efficiency:

- **Nitrogen/Oxygen**
- **Sulfuric Acid**
- **Ethylene**
- **Lime**
- **Propylene**
- **Ammonia**
- **Chlorine/Sodium Hydroxide**
- **Sodium Carbonate (Soda Ash)**
- **Ethylene Dichloride**
- **Phosphoric Acid**
- **MTBE**
- **Vinyl Chloride**
- **BXT (Benzene-toulene-xylene)**

Project Plan

- **Identify current energy efficiency of IOF segments at a meaningful level of aggregation (similar processes). Compare with global competitors in each segment.**
- **Identify industries and their major operations in which automation in one of the four technical areas may play a *major* role in advancing the state of the prevailing technology.**
- **Identify industries and associated operations in which incremental improvements in automation are insufficient to realize significant energy savings.**

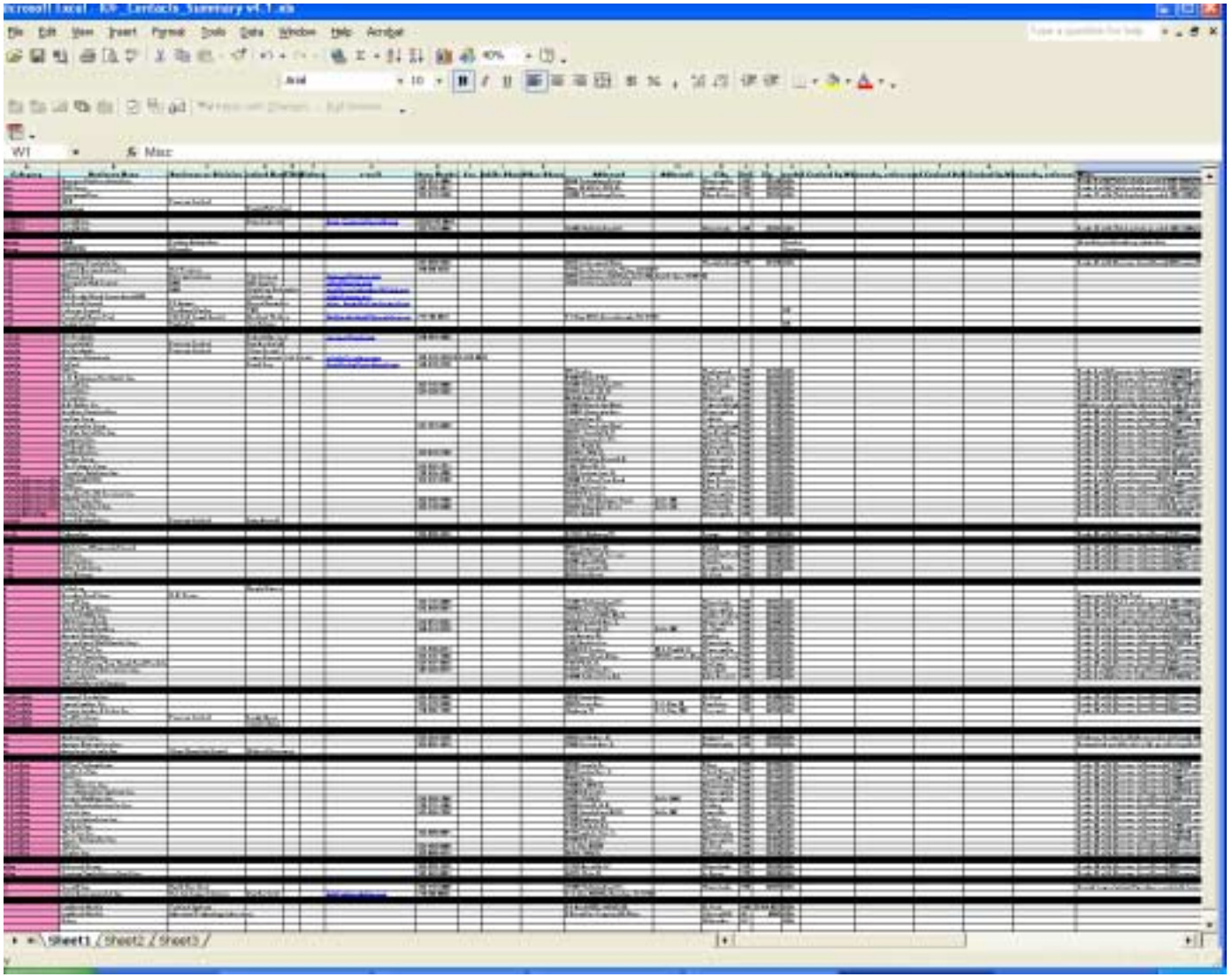
Project Plan (cont'd)

- **Identify process improvements and technology innovation enabled by advances in the four technical areas promising dramatic improvements in energy efficiency.**
- **Coordinate with DOE-OIT's *vision* and *roadmap* for the IOFs for 2010, 2020.**
- **Conduct a survey of research funding (major sources, key areas, major contractors) relevant to energy savings and energy efficiency in the IOF.**

Interview Methodology

- **State of the Art: Manufacturing Operations**
  - Assess current energy efficiency
  - Determine currently deployed technologies
  - Ascertain perceived needs (plant managers are painfully aware of their energy costs)
- **Emerging Technology: Vendors**
  - Identify emerging technologies in the product pipeline
  - Evaluate applicability to identified needs
- **Research: Academics/Research Labs**
  - Perform gap analysis for maturing technologies vis-à-vis customer needs

Industrial Contacts – Preliminary List



Stretch Goals

Quantifying energy benefits

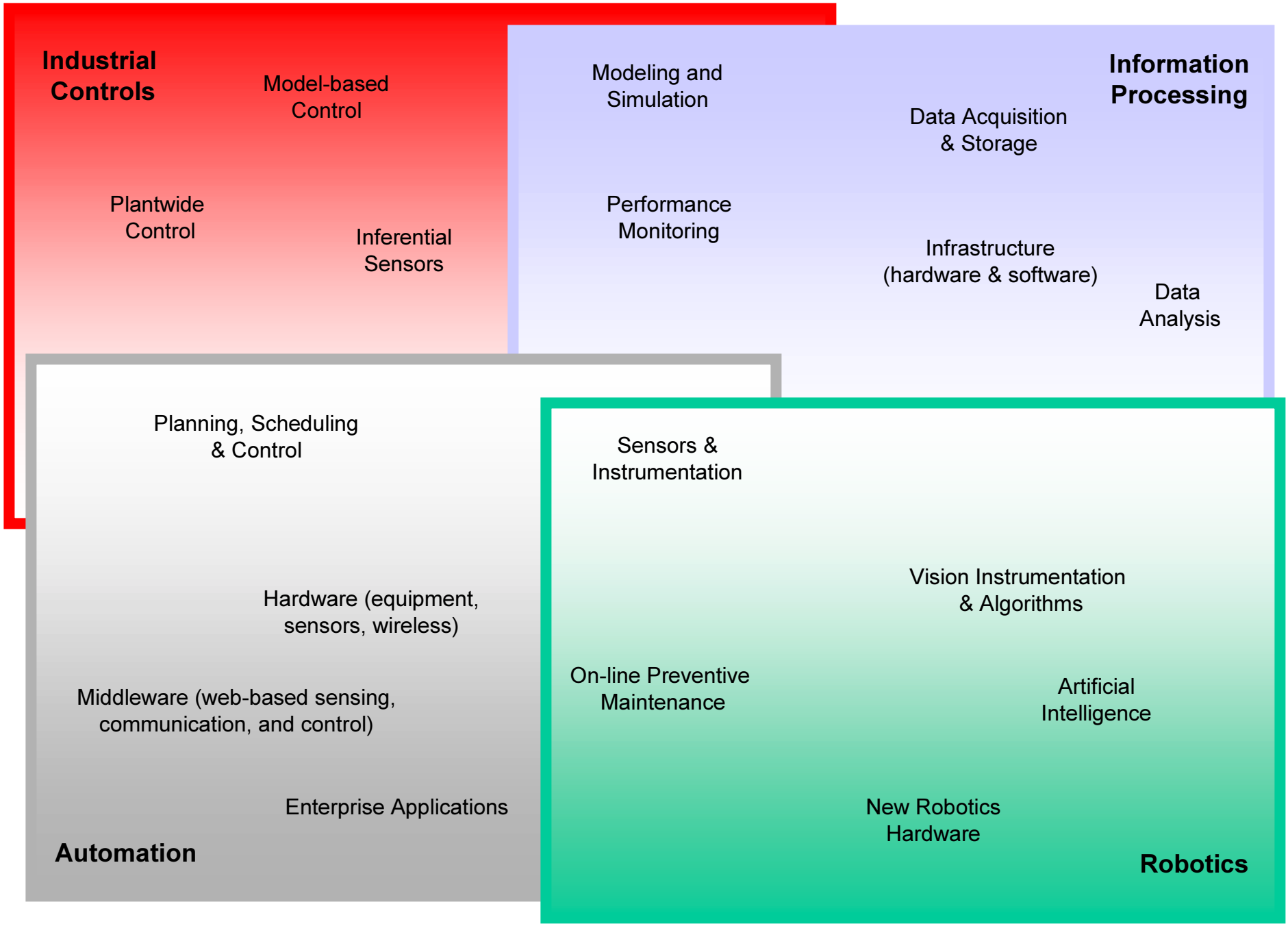
- Time permitting, analytical models will be made to study the impacts of robotic technologies in applicable members of the IOFs.
- Employ energy supply and demand data to generate Dynamic Leontief Models to forecast energy use, compared with current trends and practices.
- Above analytical approaches can be modified to account for environmental benefits and constraints.

Research Topic Introductions

- **Automation**
- **Industrial Controls**
- **Information Processing**
- **Robotics**

Four Collaborative Study Teams

- **Automation**
  - Bonnie Bennett & Mark Boddy, Adventium Labs
  - Tariq Samad, Honeywell
- **Industrial Controls**
  - Frank Doyle (UCSB)
  - Tunde Ogunnaike, U. Delaware
  - Tariq Samad, Honeywell
- **Information Processing**
  - Tunde Ogunnaike, U. Delaware
  - A. Ganesh Vaidyanathan (DuPont)
- **Robotics**
  - George Bekey, USC
  - Clarence de Silva, UBC
  - Jeanne Dietsch, CEO, ActivMedia Robotics
  - Joseph Engelberger, Founding CEO Emeritus, Unimation, Inc. (USA's first robotic company) and HelpMate Robotics, Inc.
  - Mo Jamshidi, UNM
  - DOE Liaison: Francois Pin, ORNL


Industrial Controls
Model-based Control
Plantwide Control
Inferential Sensors
Modeling and Simulation
Information Processing
Data Acquisition & Storage
Performance Monitoring
Infrastructure (hardware & software)
Data Analysis
Planning, Scheduling & Control
Hardware (equipment, sensors, wireless)
Middleware (web-based sensing, communication, and control)
Enterprise Applications
Automation
Sensors & Instrumentation
Vision Instrumentation & Algorithms
On-line Preventive Maintenance
Artificial Intelligence
New Robotics Hardware
Robotics

Definition of Automation

"Automation" refers to systems that assist or replace human efforts in the sense-infer-act loop that is common from low-level control problems all the way up to long-range planning for an entire enterprise.

Automation: Topics

- **Hardware, e.g. advances in plant equipment, new sensor technologies, and wireless solutions and standards.**
- **Middleware, e.g. web-based sensing, communication, and control, client-server and peer-to-peer application middleware.**
- **Online applications, e.g. integrated control and on-line scheduling, and preventive maintenance.**
- **Enterprise applications, e.g. integration of process and business systems, knowledge management, autonomous systems (e.g., software agents).**

Automation: Benchmark Problem Examples

- **Integration of planning, scheduling, and control to reduce energy costs due to changeovers (e.g., factory-wide operations optimized to minimize use of fuel, or chemical plant changeover optimization to minimizing fouling in polymerization reactors).**

- **Process instrumentation and integration of scheduling and control to reduce energy costs due to individual plan steps (e.g., heat-treating of metals, carbon/carbon composite drying).**

Industrial Controls

- **Coverage**
  - Low-level feedback control design, implementation, monitoring
  - Advanced process control (APC)
  - Simulation for design and training

- **Related studies**
  - Vision 2020 Workshop on Process Measurement and Control [sponsored by NIST & NSF, 1998]
  - Control in an Information Rich World – *Report of the Panel on Future Directions in Control, Dynamics, and Systems* [2002]

Industrial Controls: Topics

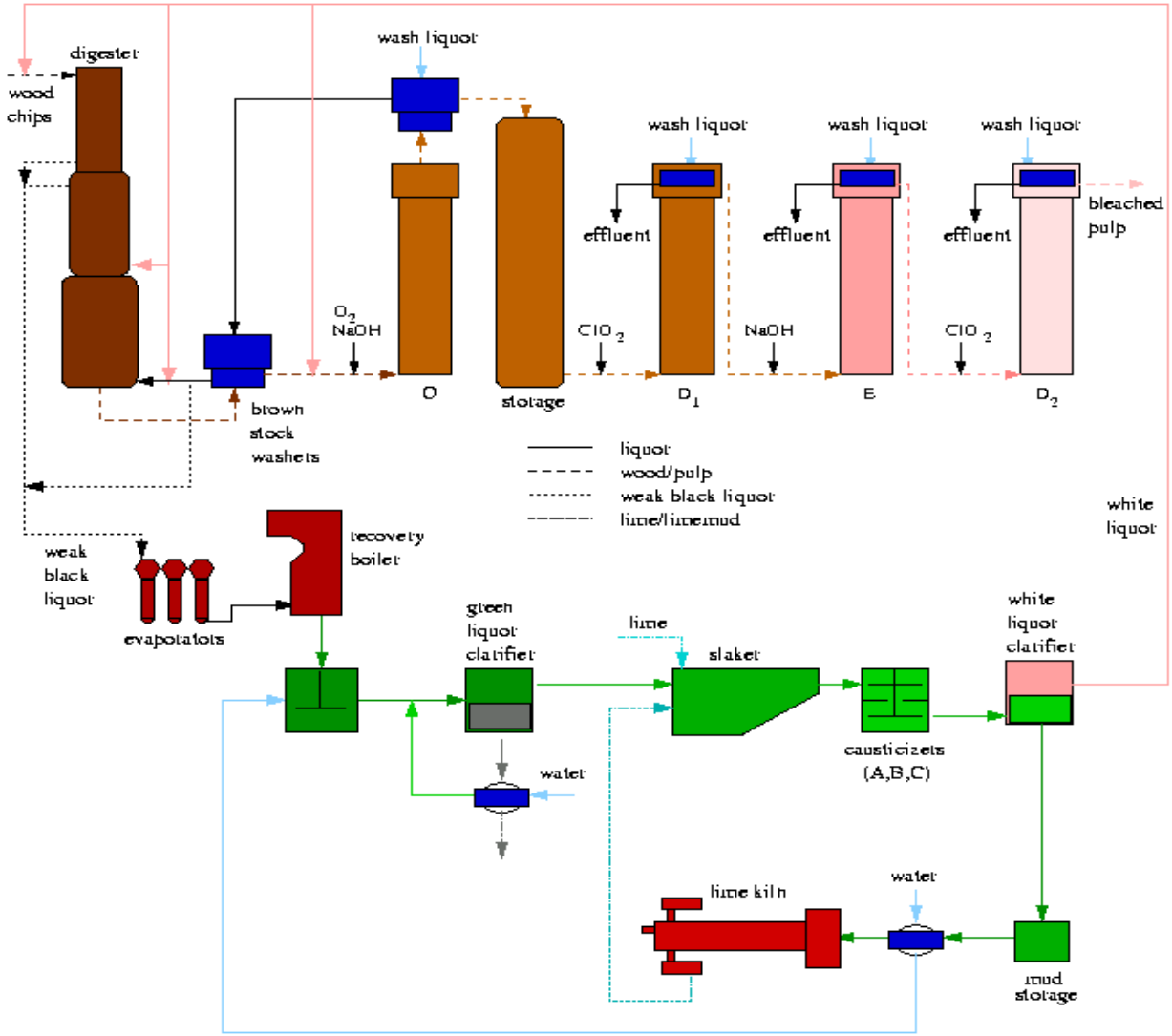
- **Linear and Nonlinear Model Predictive Control**
- **Adaptive and gain-scheduled control**
- **Plant-wide optimization and control (links to both information processing and automation)**
- **Sensor technology needs for process control**
- **Control simulation, including operator training simulation**
- **Controller performance monitoring**
- **Inferential sensors, such as neural network “soft sensors”**

Industrial Control Challenge Problem:

Integrated Plant-wide Control

- **Sector Overlap**
  - Specific example from forest products
  - Approach has relevance to all sectors
- **Technology Overlap**
  - Industrial controls
  - Information processing
  - Automation
- **Opportunities**
  - Tighter control of unit interactions
  - Minimize propagation of variability
  - More effective transitions (rate, specie)
  - Integration with higher-level decision-making

Example: Pulp Mill Flowsheet



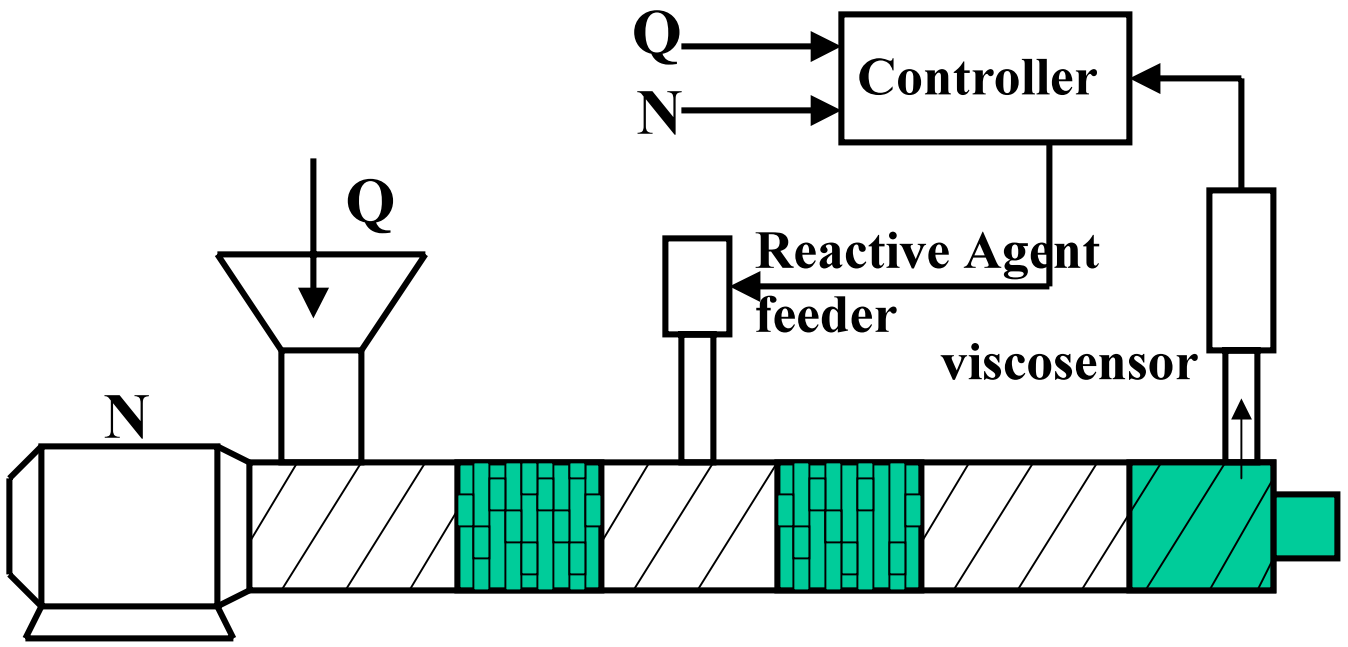
Information Processing:Topics

- **Data Acquisition and Storage**
  - On-line process data management, rectification, and reconciliation
  - Data compression and archiving
  - Data integration (e.g., Quality Control lab data)
- **Process Operations & Performance Monitoring**
  - Sensor and analyzer fault detection, identification and correction
  - Process performance analysis
- **Sensor System Design and Implementation**
  - Robust sensor system design
  - Sensor Fusion
  - Soft sensors

Information Processing: Topics

- **Data Analysis**
  - Multi-scale, high-, low-, and medium frequency data analysis
  - Continuous, discrete and categorical data analysis
  - Image processing and analysis
- **Empirical Process modeling with applications**
- **Infrastructure**
  - Software and hardware maintenance and support

Benchmark Problem: (Reactive) Extrusion



Benchmark Problem: Extrusion

- **Sector Overlap**
  - Specific example from Chemicals Industry (Extruded and Molded Plastics; Engineering Polymers; Packaging, etc)
  - Direct relevance to Aluminum (carbon electrodes production) and metal casting (injection molding);
- **Technology Overlap**
  - Industrial controls
  - Information processing
  - Automation

Benchmark Problem: Requirements

- **Produce compounded materials that meet customer quality performance requirements at much higher yield rate**
  - Reduce energy consumption
  - Minimize end-use rejection rate;
  - Reduce material waste
  - All items influence energy usage.
- **Flexible and efficient manufacturing process**
  - Short lead times
  - Effective control system

Key Problem Areas

- **Data Acquisition and Processing;**
  - Process monitoring (for fault detection and mitigation)
  - “Signal Decomposition” (pre-processing for control strategy implementation)
  - “Missing variable” inference
  - Correlation of measurable process variables to End-Use product characteristics
- **Integrative Modeling;**
  - Mixed binary/continuous variables across the system
- **Advanced Control System Design and Implementation**

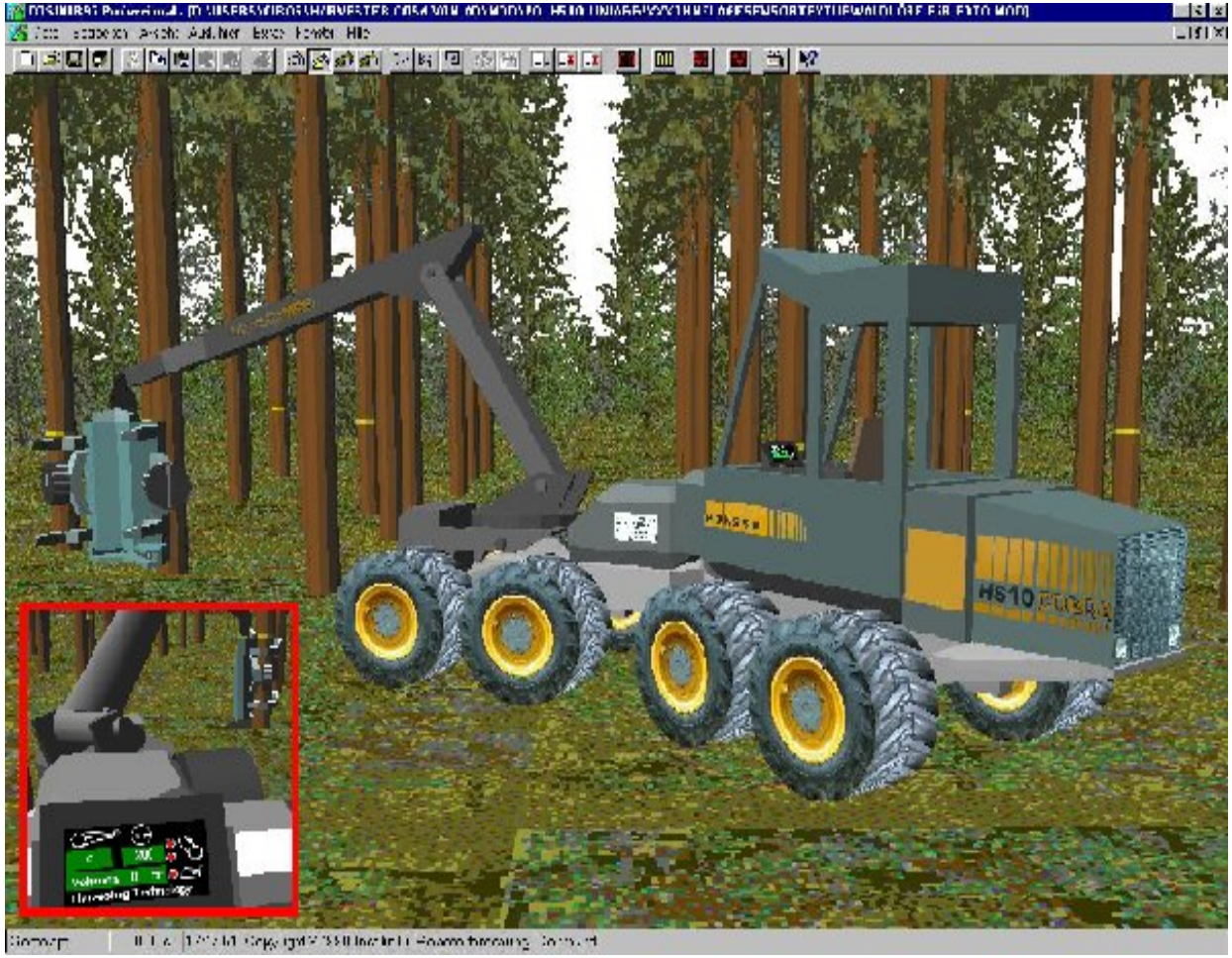
Robotics: Areas

- **New Sensors & Instrumentation**
- **On-line Preventive Maintenance**
- **Vision Instrumentation & Algorithms**
- **Artificial Intelligence – Soft Computing (Neural networks, evolutionary computing, Fuzzy Logic, etc.)**
- **New Robotics Hardware**
- **Automation**

Robots in Energy-Intensive Industries

- **Examples:**
  - Waste reduction through quality control
  - Early identification of inefficiency problems
  - Reduced need for human-friendly environment
- **Food processing:**
  - Robot handling, cleaning, packaging
- **Forest products: Robotic tree harvesting**
  - Not fully robotized, but could be

Simulation of Tree Harvesting



Robotics Benchmark Problem: Maverick

Robotic inspection system for bulk liquid storage tanks

- **Reduce costs**
- **Reduce waste**
- **Eliminate emptying & cleaning tanks**
- **$425,000 investment by DOE recovered in the first 3 uses of Maverick.**
- **Projected energy savings of close to 12 trillion BTUs by 2010.**
- **Partnership of DOE NICE3, Solex Environmental Systems, Inc., and Texas Natural Resources Conservation Commission**

Discussion/Q&A

- **Emphasis on segments:**
  - By energy use?
  - By current investments?
  - Spread evenly?

- **Suggestions for additional sources of information and expertise that should be included?**
  - Others at DOE
  - Other R&D players (academics, national labs)

- **??**