Engineered Learning Systems for Engineering and Education

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OUTLINE:

- **Motivation - Simulation for Engineering and Education**
- **Features of Engineered Learning Systems**
- **Current R&D Directions for Learning Systems**
- **Application to Environmentally-Benign Semiconductor Manufacturing**
- **Conclusions**

Acknowledgements

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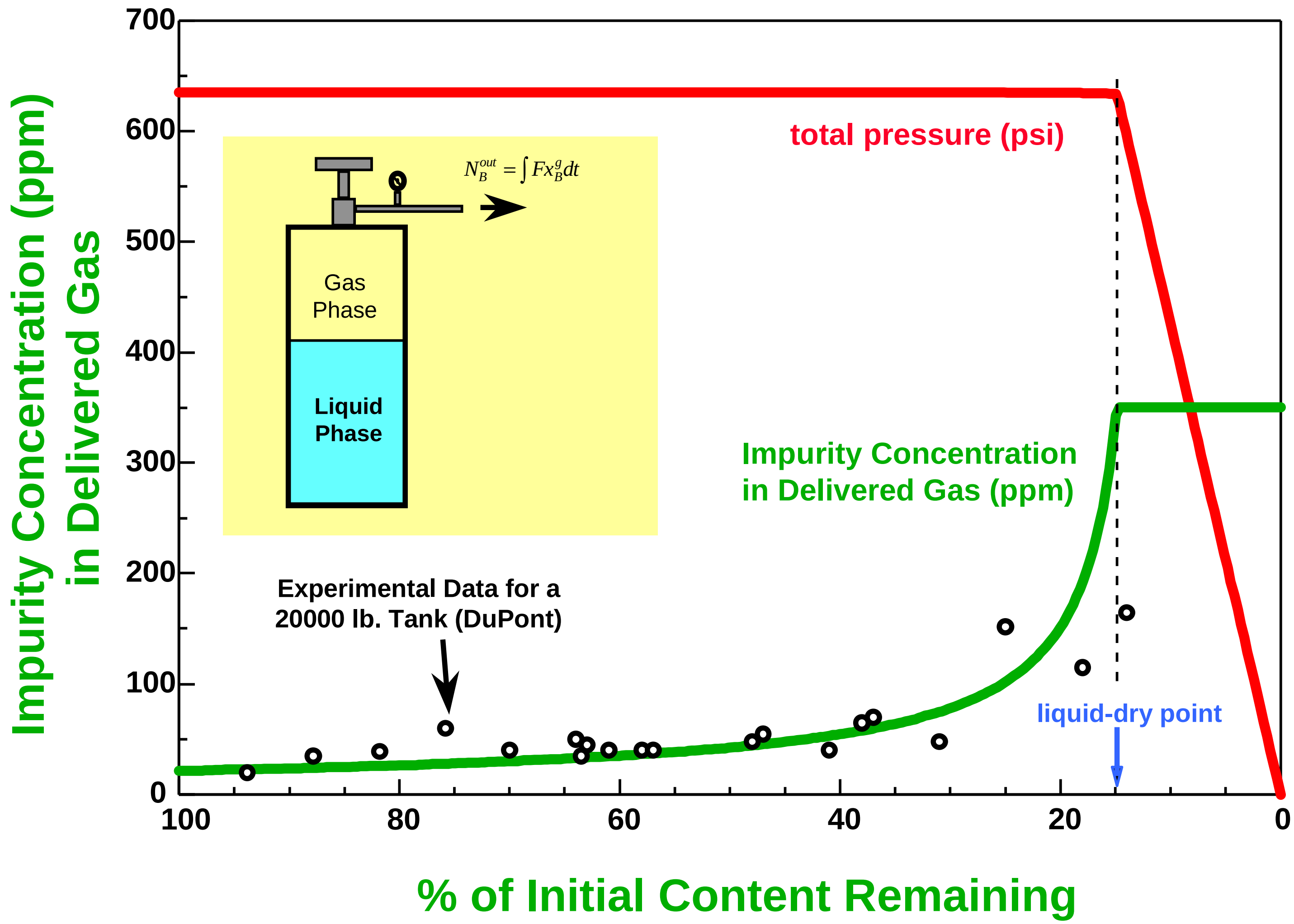
Physically-Based
Dynamic Simulation for Engineering

- **Physical and chemical models can be incorporated into dynamic simulators using commercial simulation platforms (Windows)**
- **Such simulators reveal time-dependent behavior critical to semiconductor manufacturing equipment, process, sensor, and control behavior**
- **Dynamic simulators have been validated against experiment**
- **Applications of dynamic simulators include design, control, optimization, and education/training**

Impurity Concentrations in Liquid Source Delivery (w/ Motorola)



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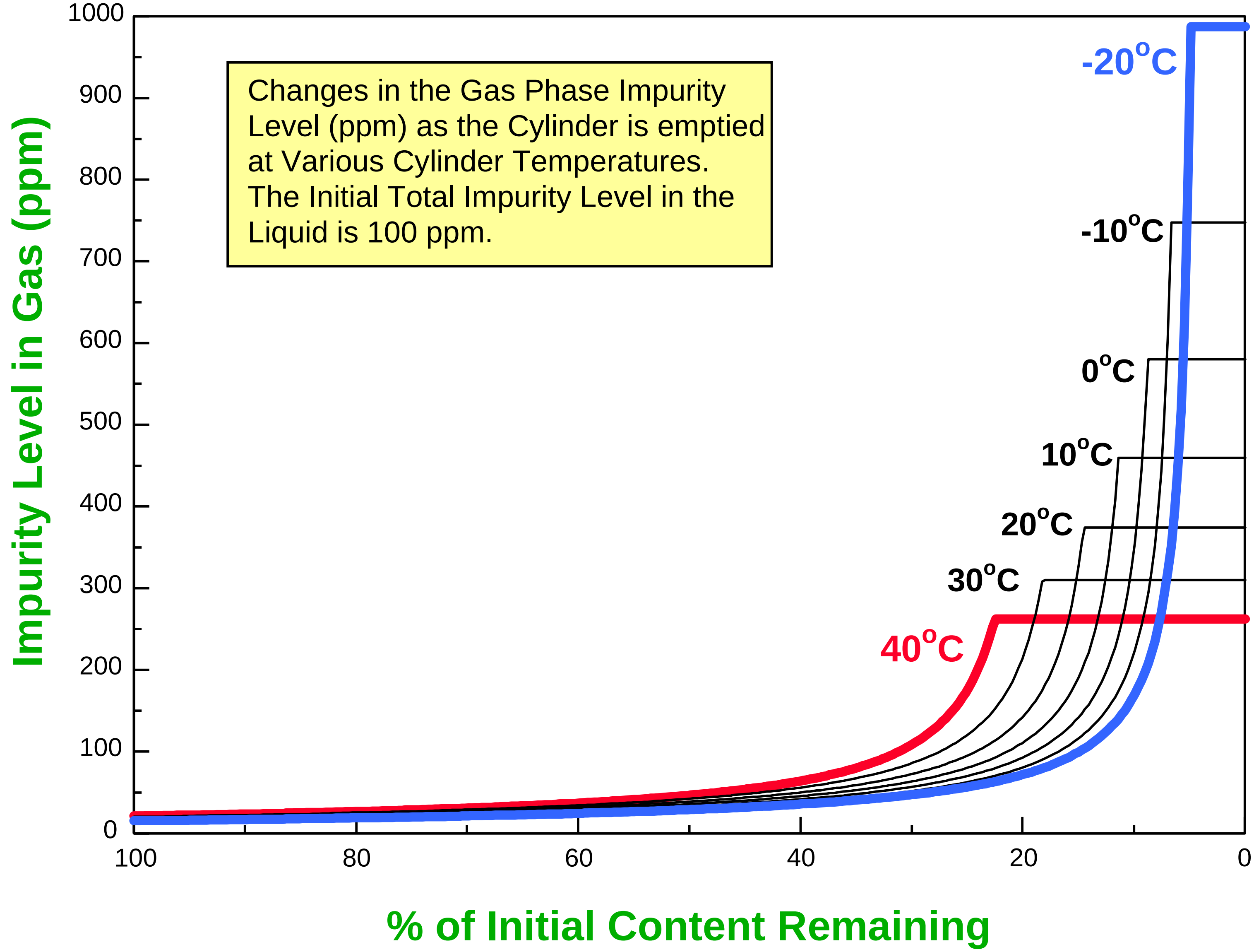
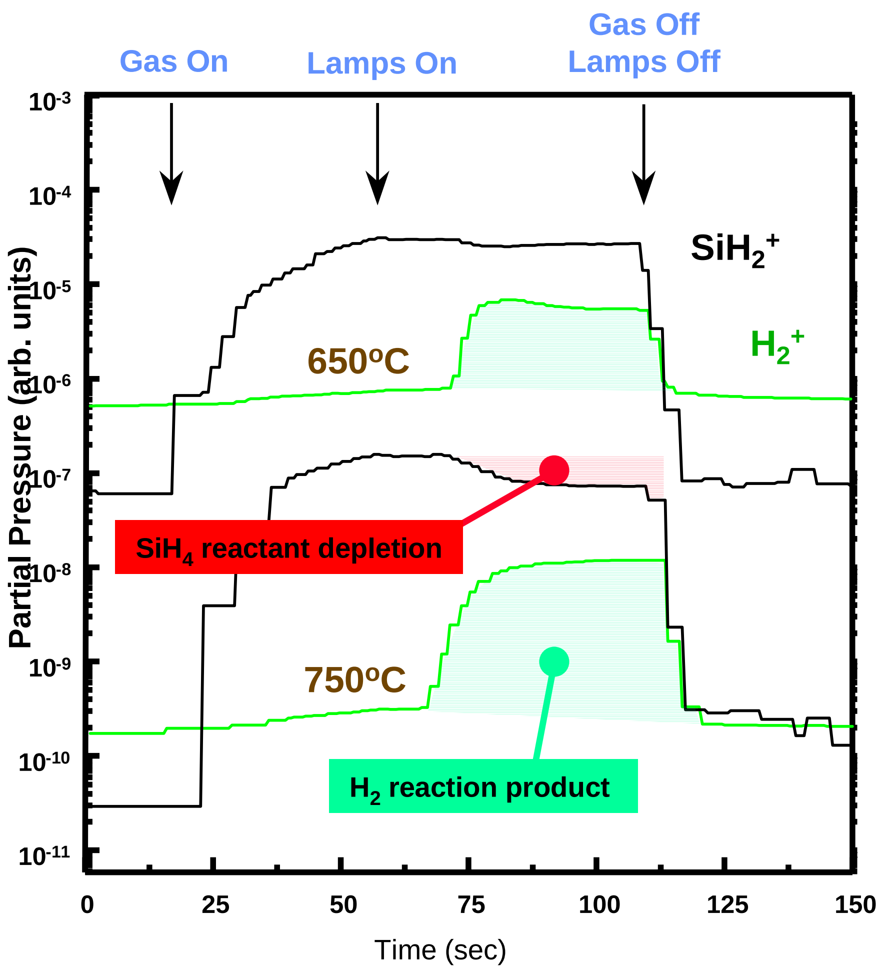
Impurity Concentration Delivery Profile vs. Source Temperature



Real-Time Mass Spectrometry for Thickness Metrology in RTCVD polySi from SiH_4

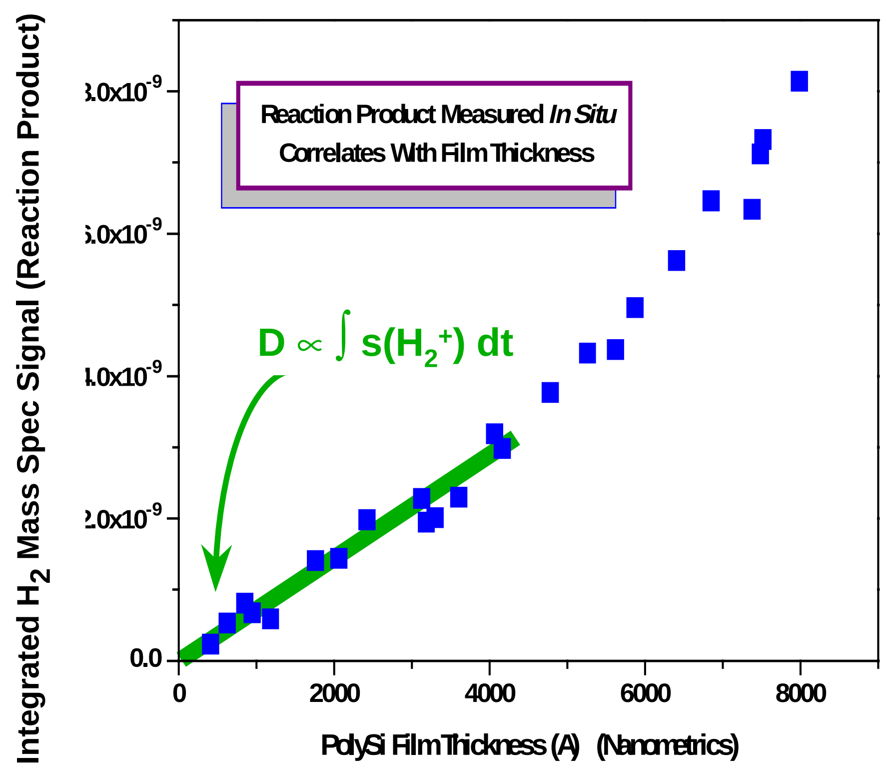
Real-time mass spectrometry through process cycle



$SiH_{4(g)} \rightarrow Si_{(s)} + 2\ H_{2(g)}$

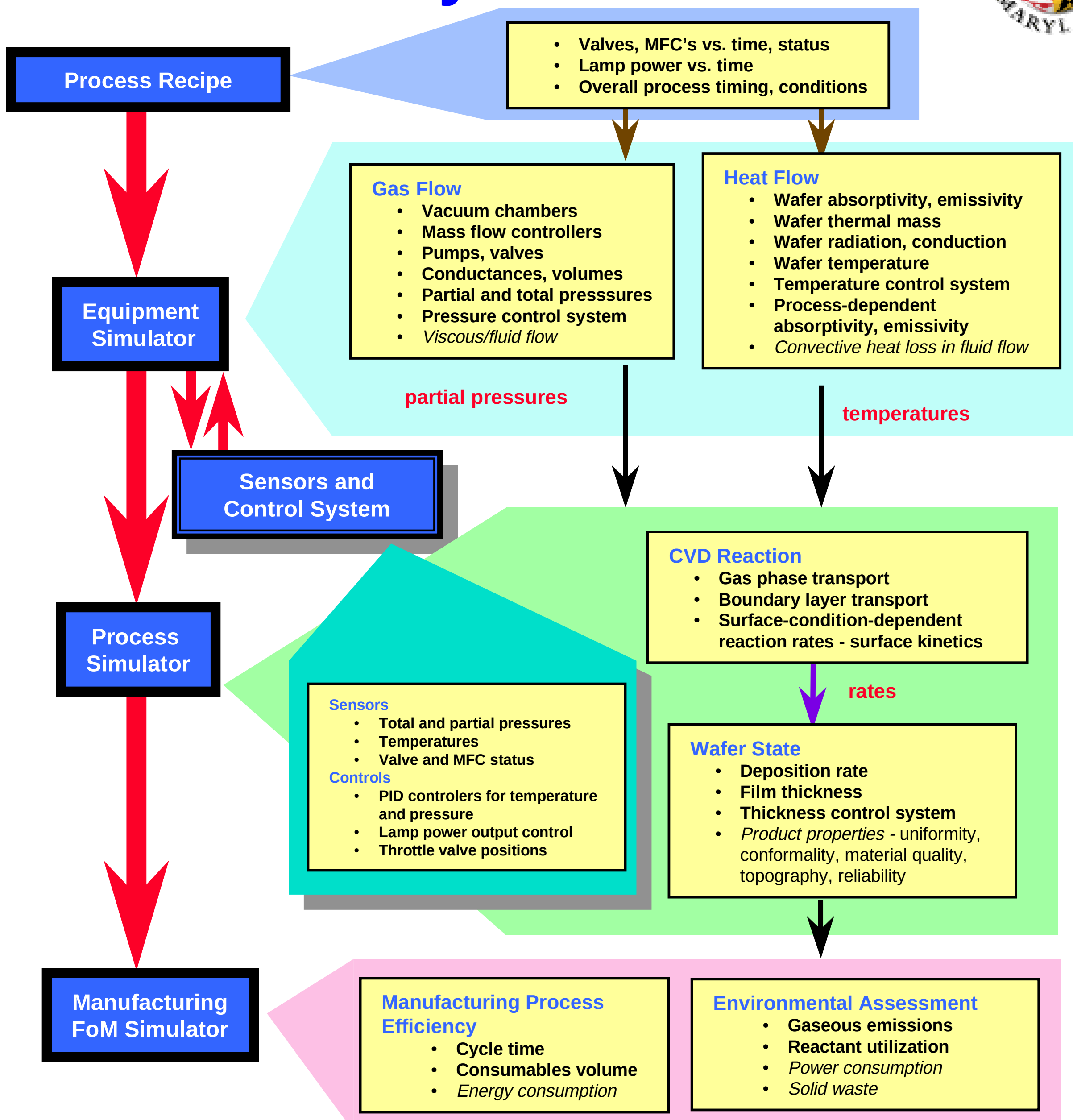
300 sccm 10% SiH_4/Ar

Integrated H_2 product signal used for real-time, in-line thickness metrology



Dynamic RTCVD PolySi Simulator

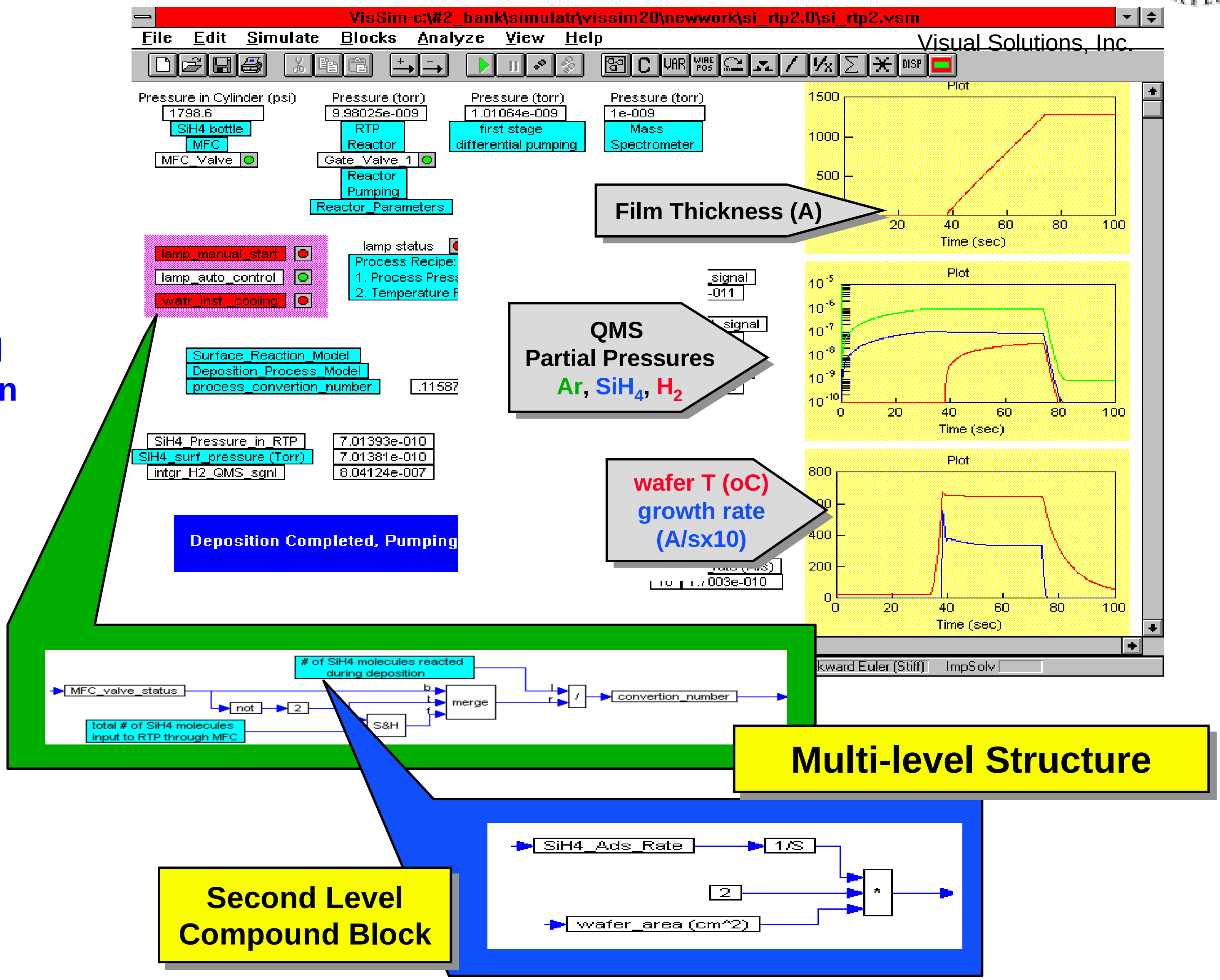
- Dynamic simulation can realistically represent complex systems, including
  - *equipment*
  - *process*
  - *sensors*
  - *control*
- Results validated against experiment
  - *timing/dynamics*
  - *subtle systematics*
- Numerous applications
  - *systems analysis*
  - *optimization*
  - *sensor-in-tool models*
  - *control system design*
  - *training ==> learning*
- Platforms commercially available (Windows)
- Exploit rapidly growing software base



Dynamic RTCVD PolySi Simulator

Understand dynamic system behavior

Build basis for control and optimization



Optimizing for Manufacturing & Environment

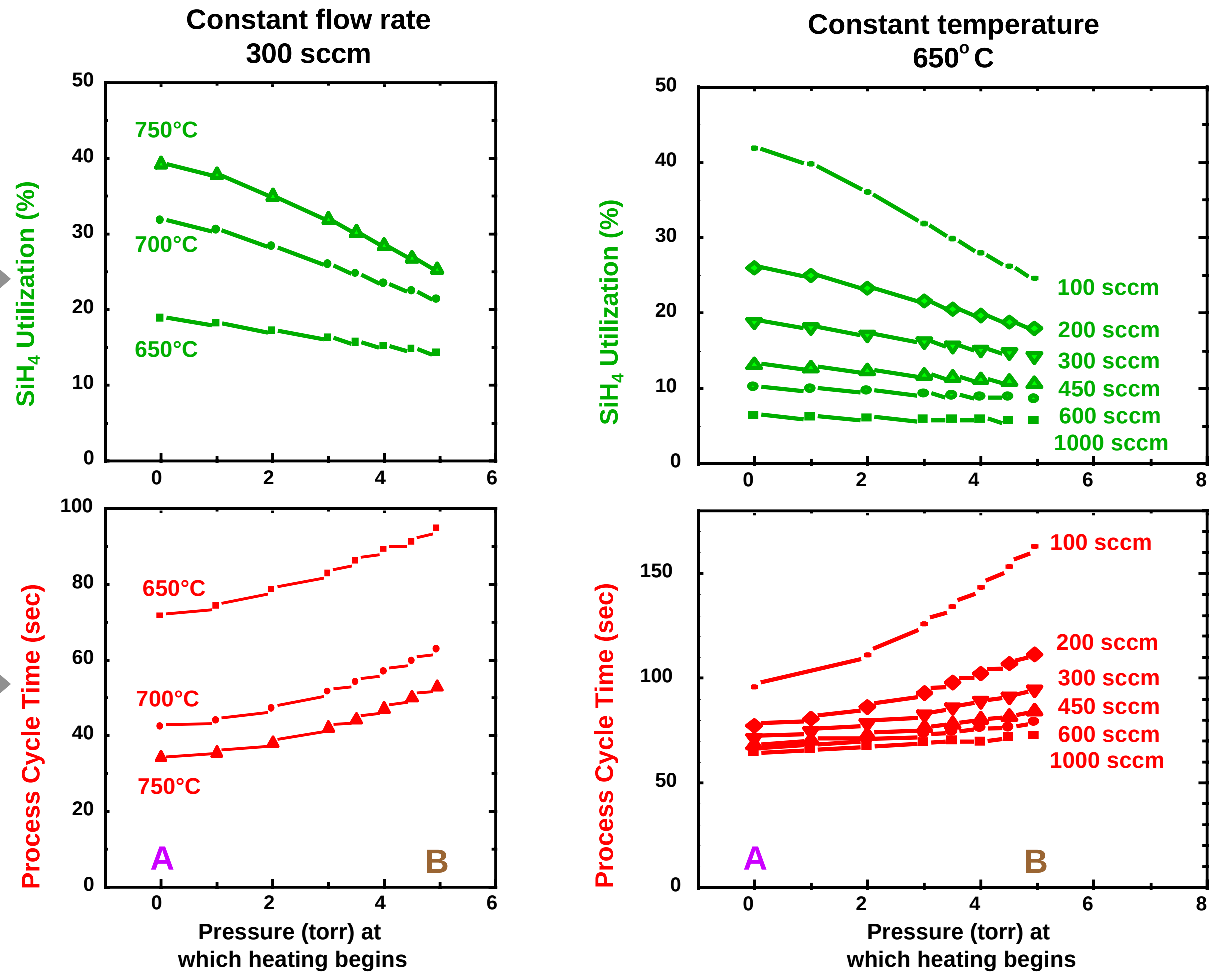
SiH_4 Utilization

Environment

Manufacturing

Process Cycle Time

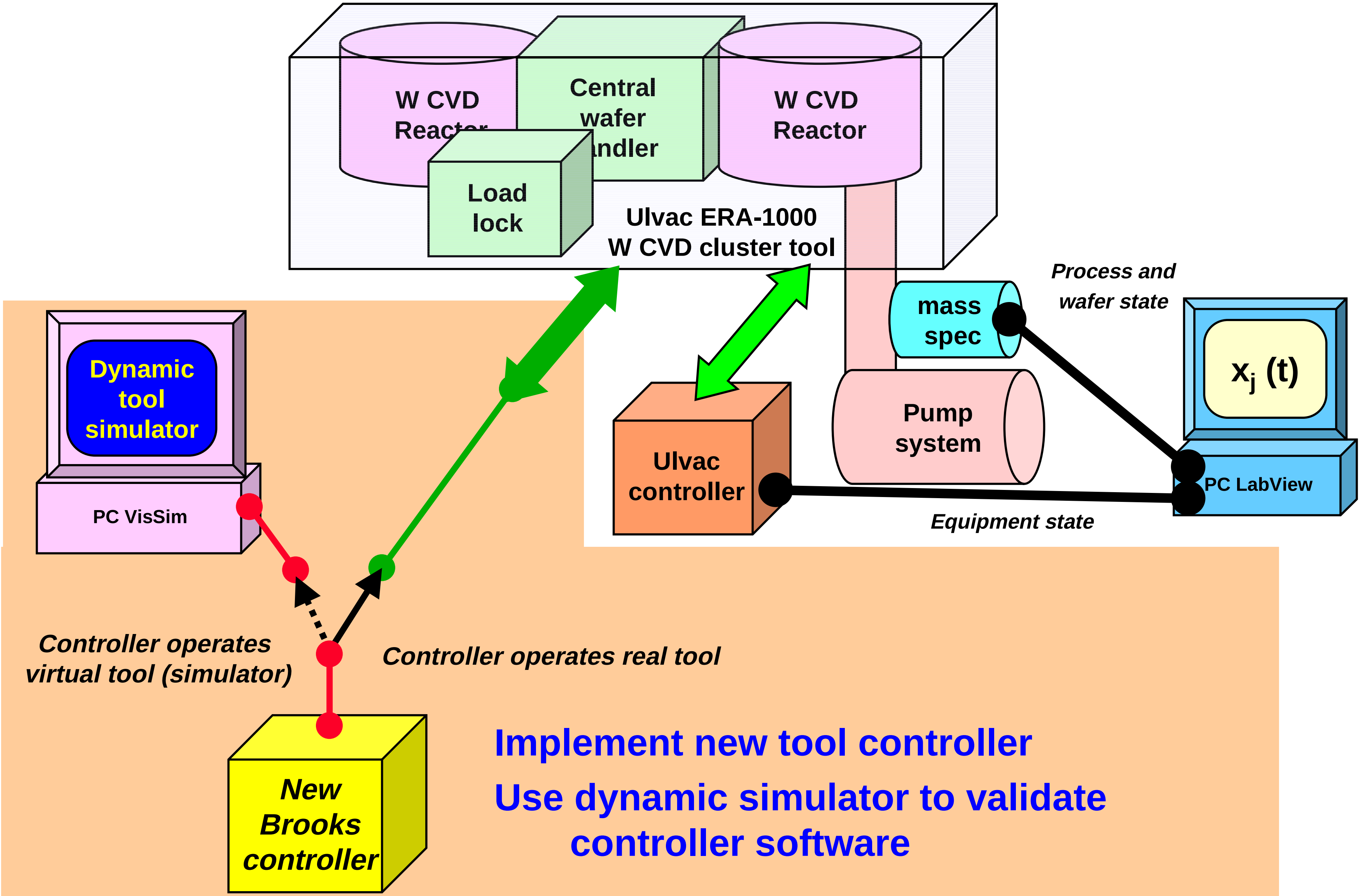
Manufacturing



A: start gas flow and heating simultaneously

B: start heating after gas flow established

Multi-Sensor Integration and Control



Implement new tool controller

Use dynamic simulator to validate controller software

Motivation

Simulation is a powerful engineering tool, but usability is increasingly limited as complexity and validity increases

User interface design is crucial to usability and effectiveness

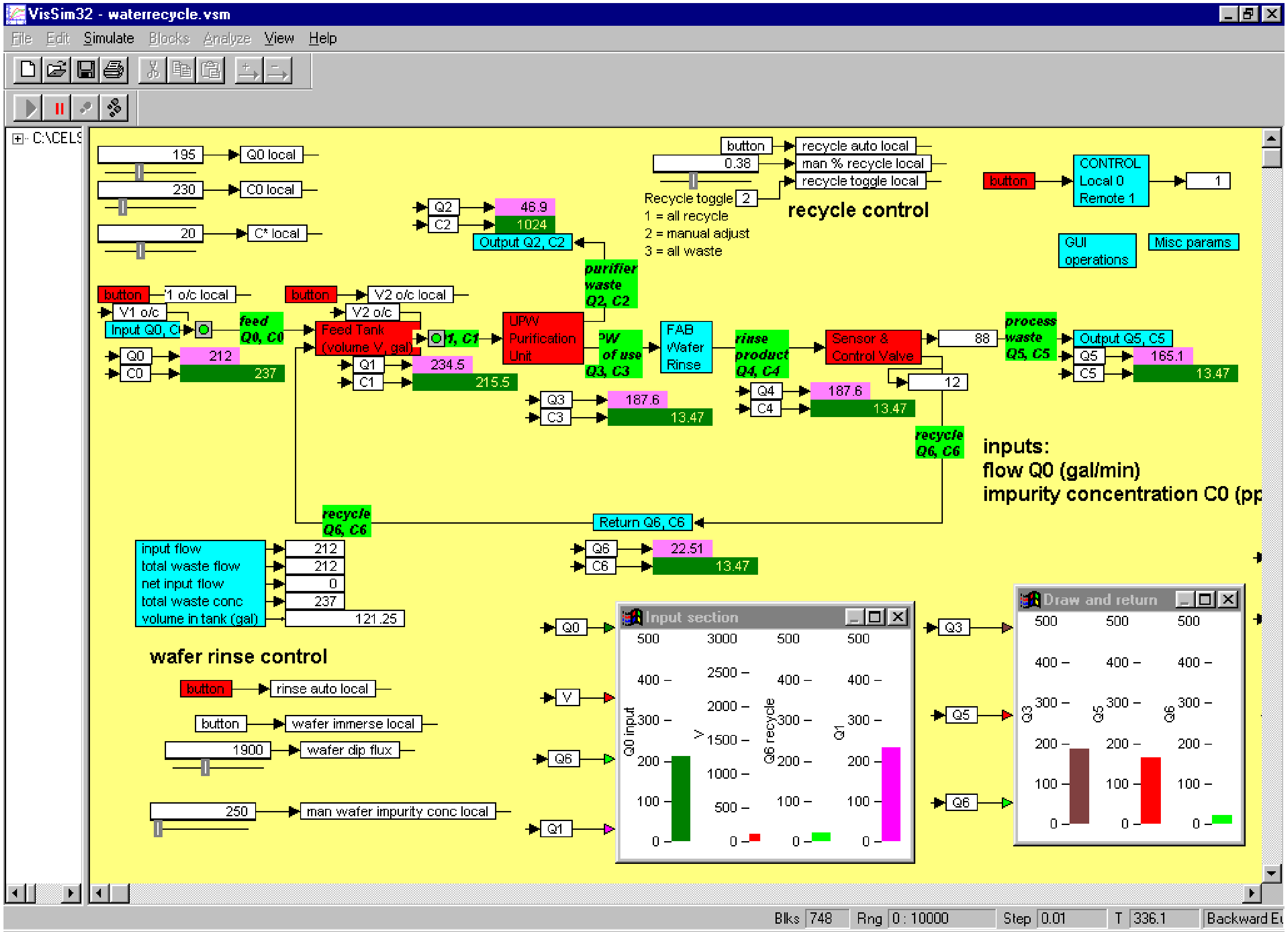
Simulation could provide active learning experiences which enhance education and training

Simulation must be encapsulated in a rich exploratory environment for effective learning at any/all levels

Engineered Learning Systems

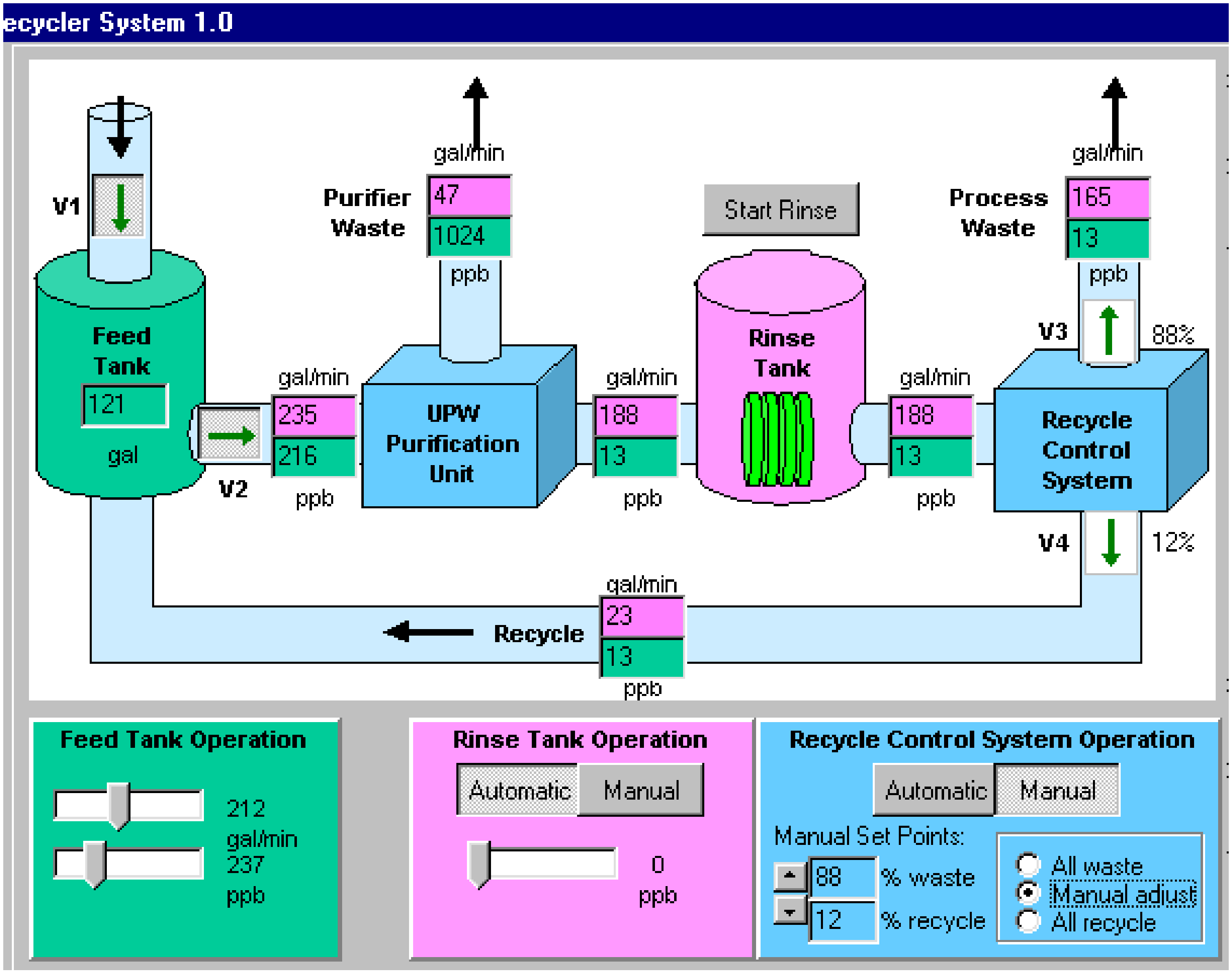
- effective user interface designs
- simulation experiences for active learning
- closely coupled guidance material
- software tools as learning aides
- easy authoring
- educational continuum
  - *novice to expert*
  - *classroom to on-the-job*

Dynamic Simulator

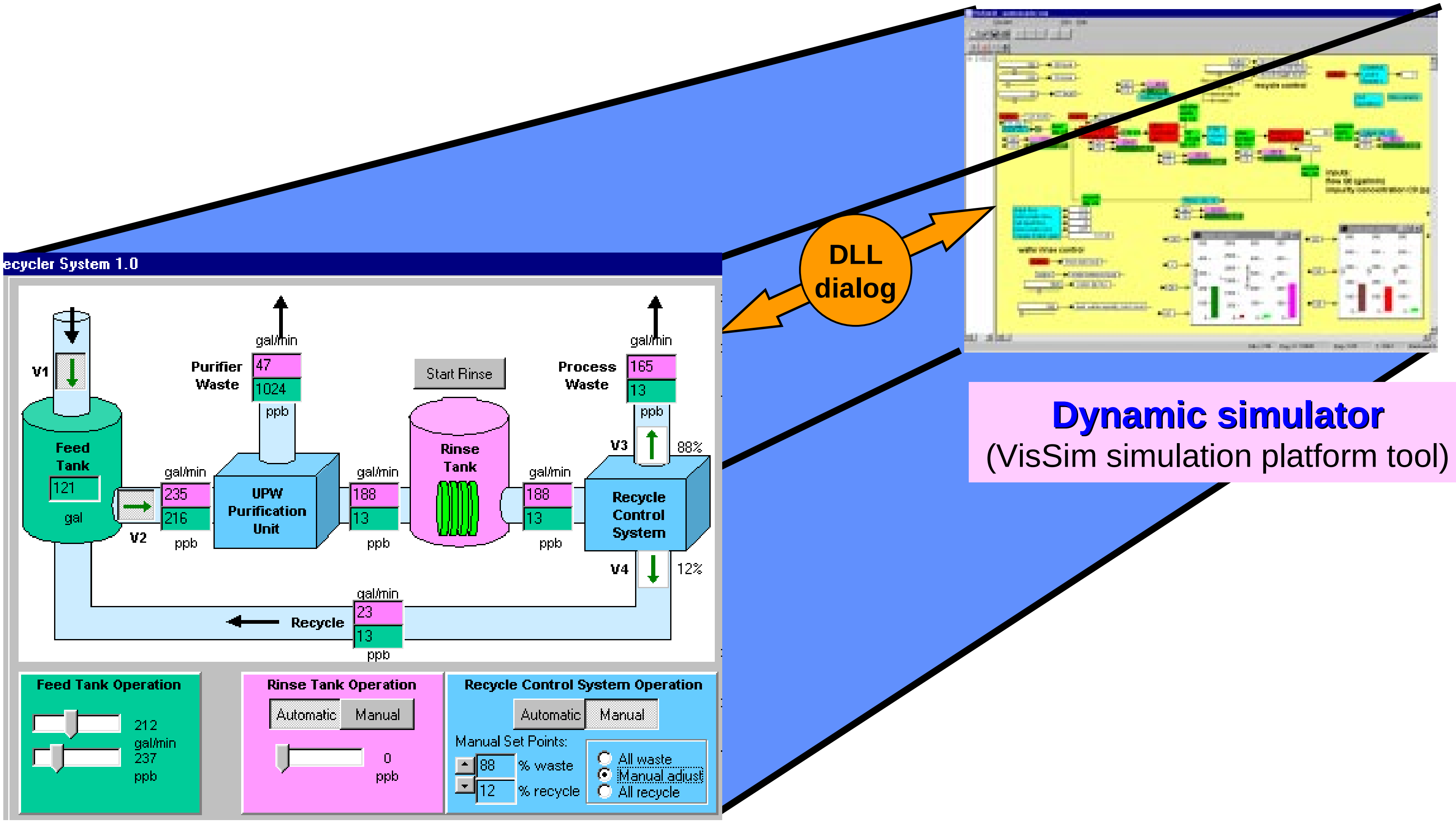


Commercial VisSim PC simulation platform (Visual Solutions Inc)

Enhanced User Interface for Simulator

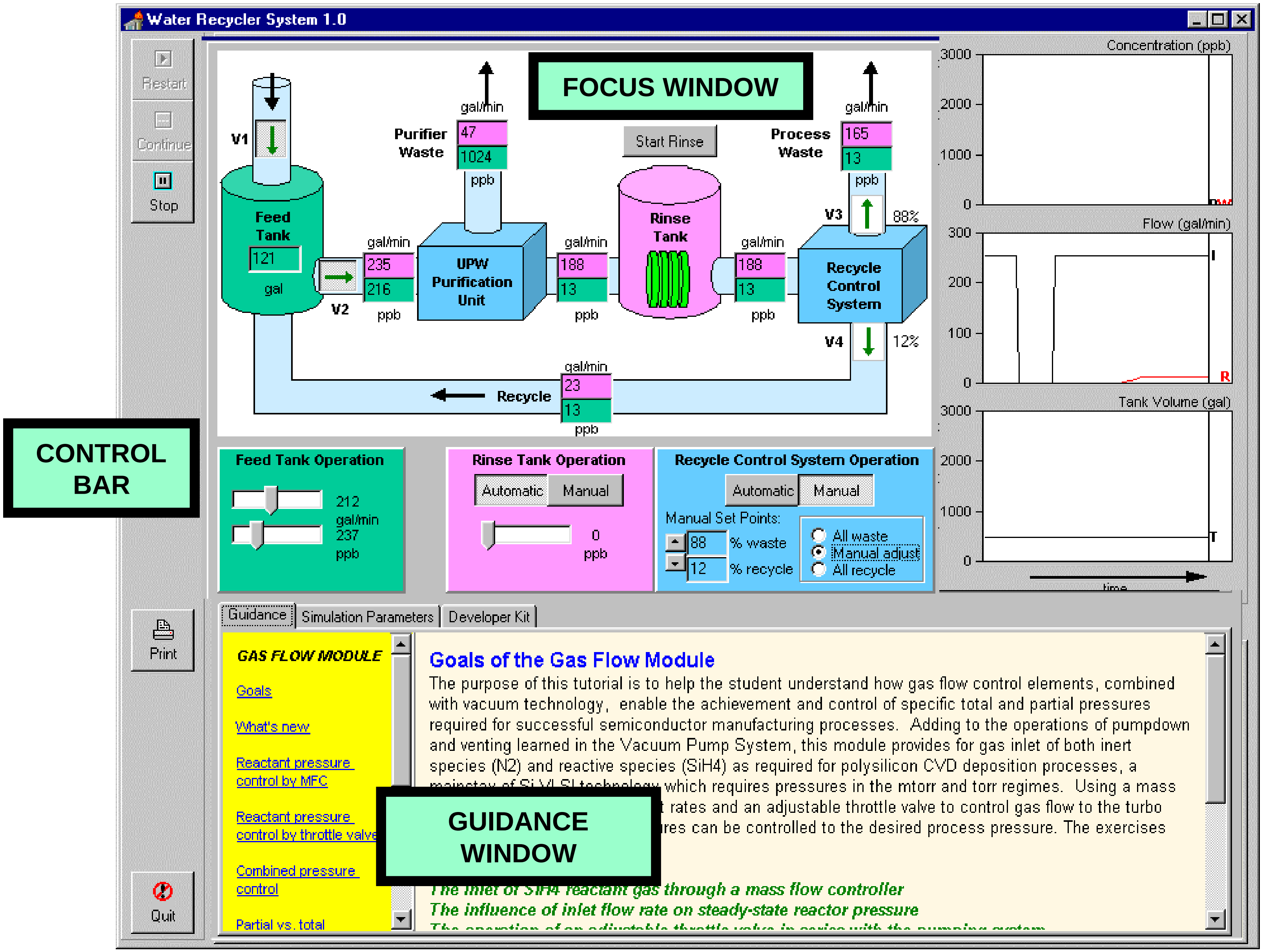


Enhanced User Interface for Learning



Enhanced user interface
(Delphi visual development platform)

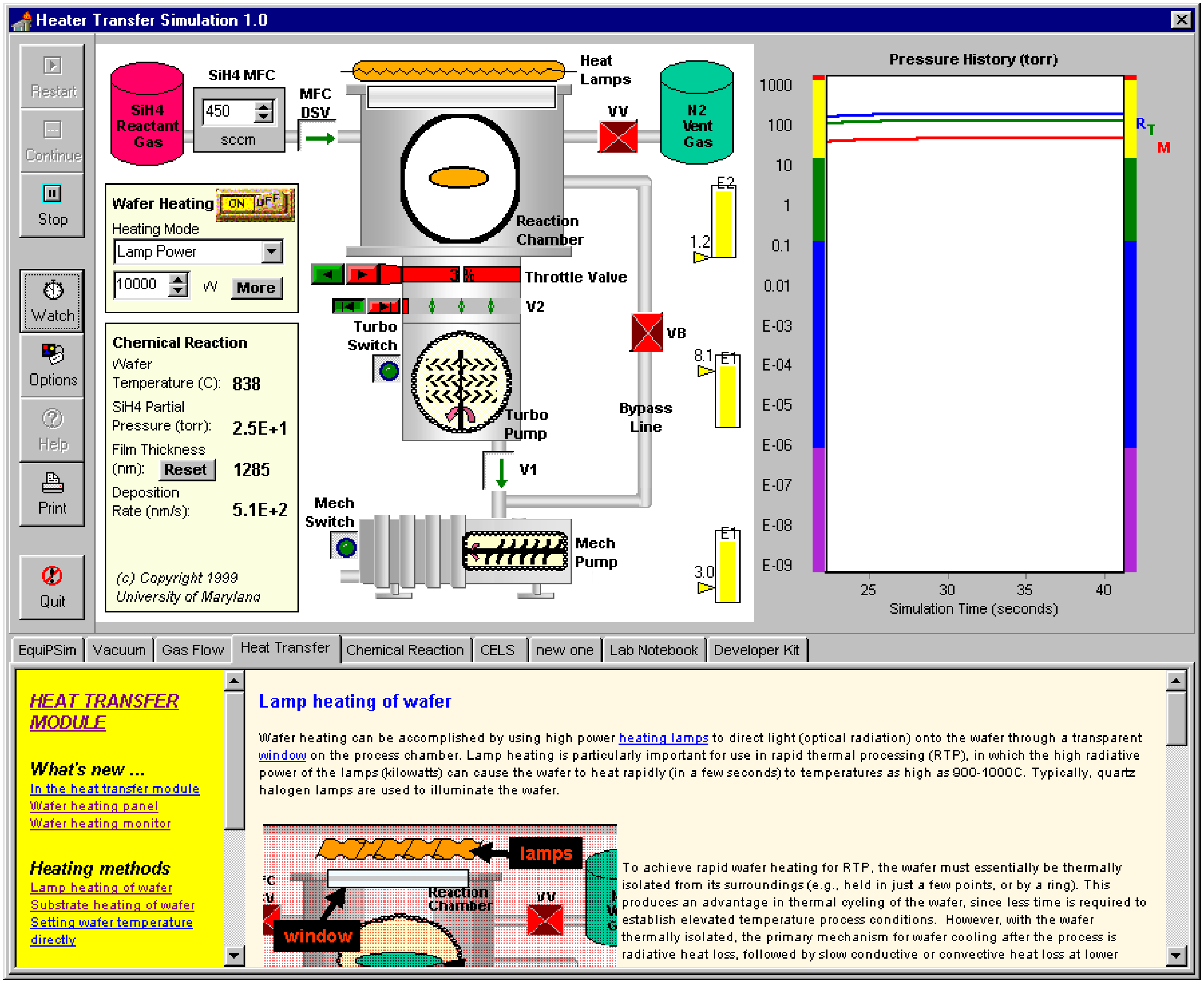
Engineered Learning System



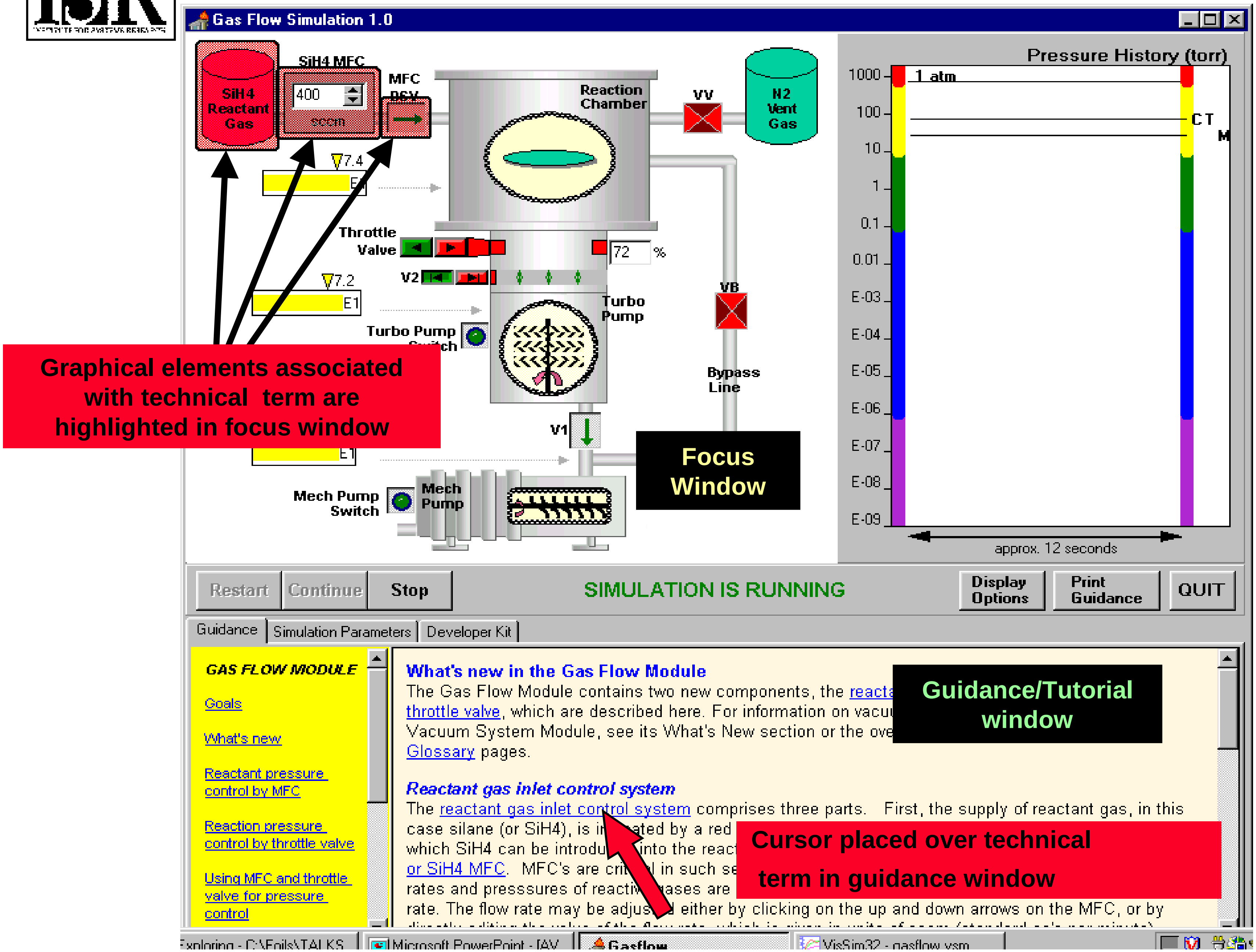
Current R&D Directions for Learning Systems

- **Tools for experimentation and collaborative design**
  - ***Free and guided exploration, annotation, simulation experience sharing***
  - ***Models and simulations of system architecture, hardware elements, control systems***
- **Increasing ability for system alteration and redesign by user**
  - ***Lab notebook, annotation, and collaboration***
  - ***User-choice in functional elements***
  - ***Network reconfiguration***
- **Incorporation of different modeling/simulation tools, including legacy codes**
  - ***Excel, Java, Fortran, C/C++, ...***
- **Broad applications set on common, commercial software base**
  - ***Manufacturing, control, optimization, equipment, ...***
  - ***Environment, hydrology, geopolitics, …***
  - ***Commercial platforms for modeling/simulation and user interface design***
  - ***Commercialization of learning systems products***

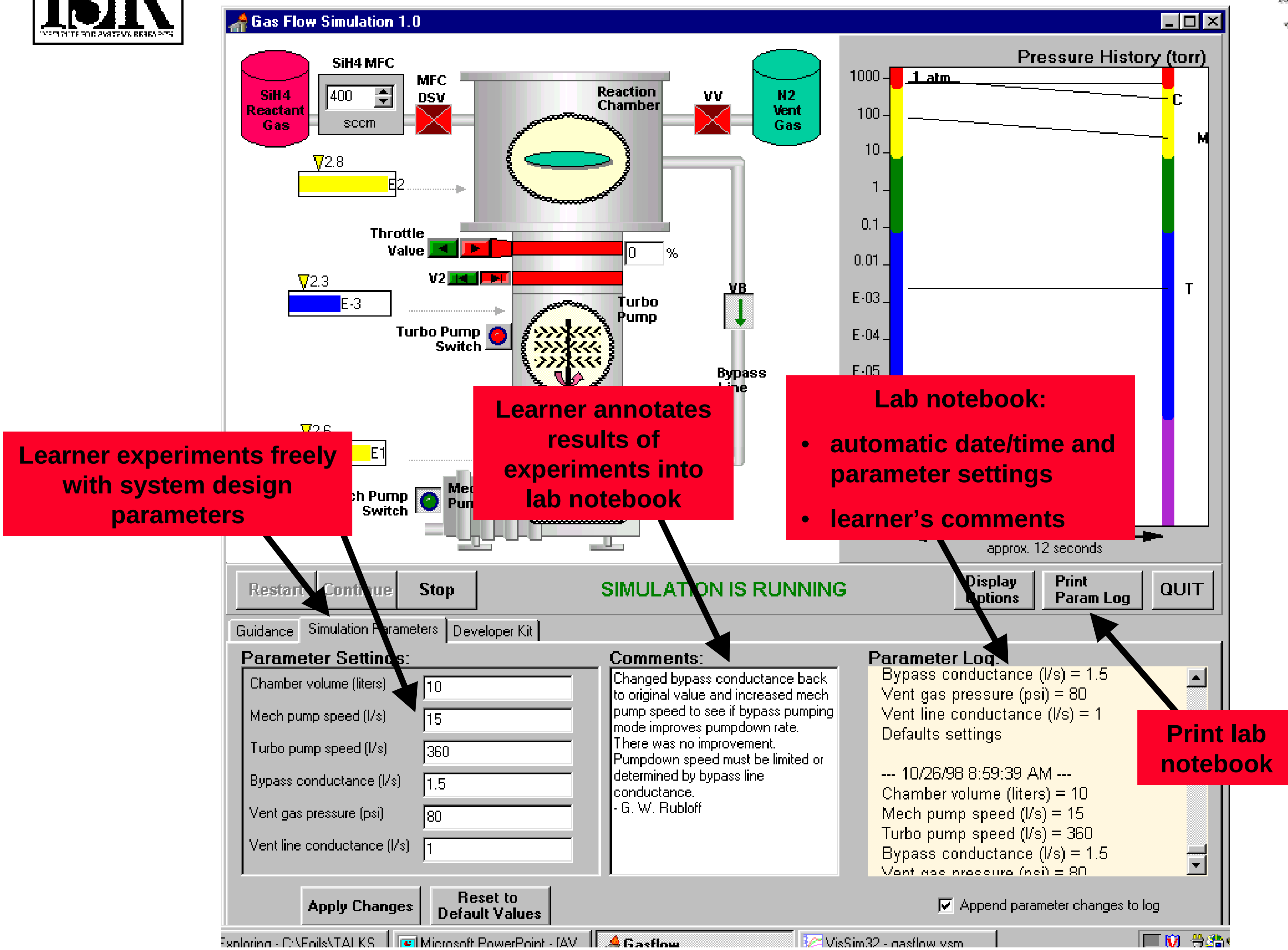
Heat Transfer and Chemical Reaction



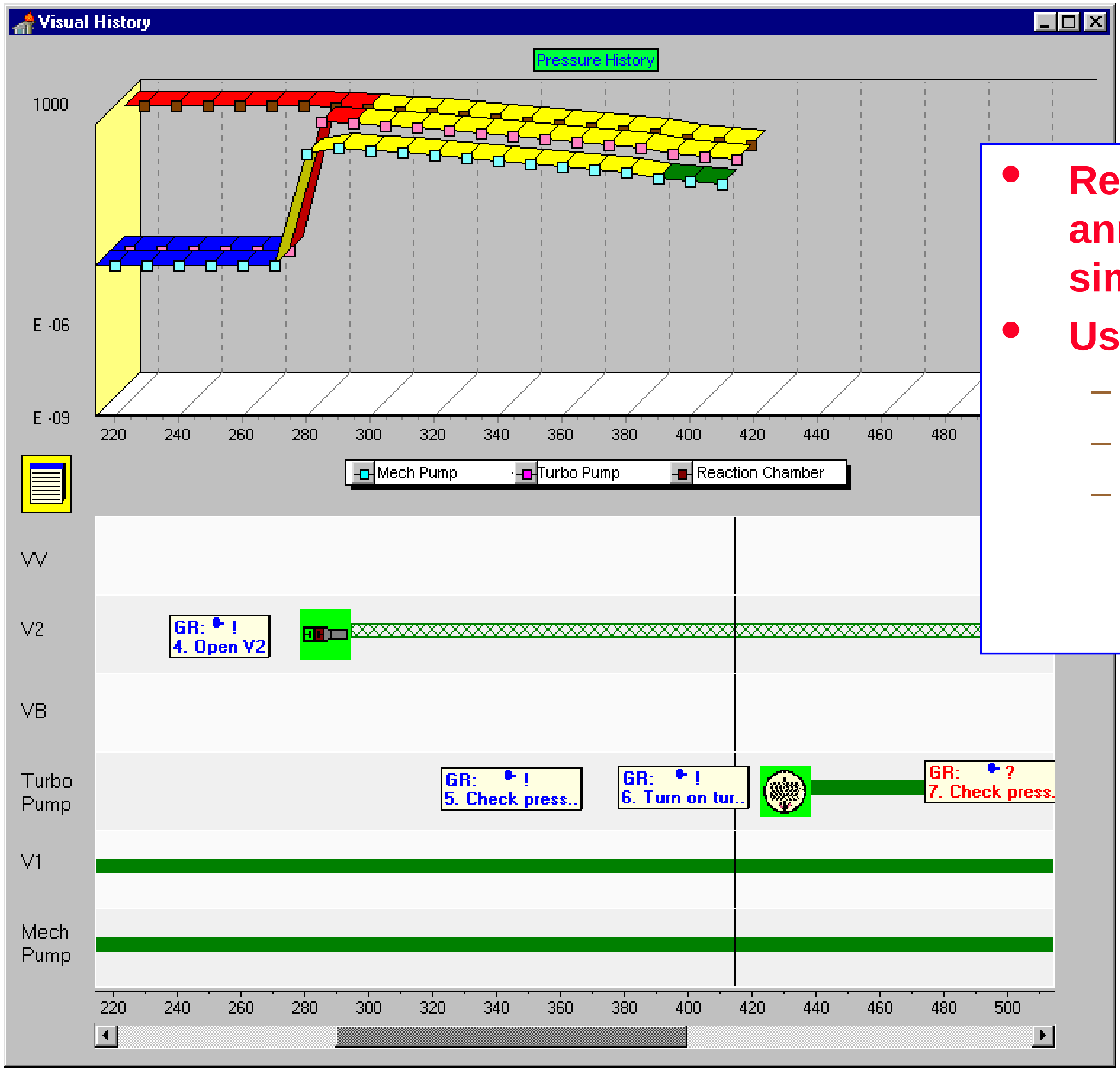
Guidance Highlighter



Lab Notebook

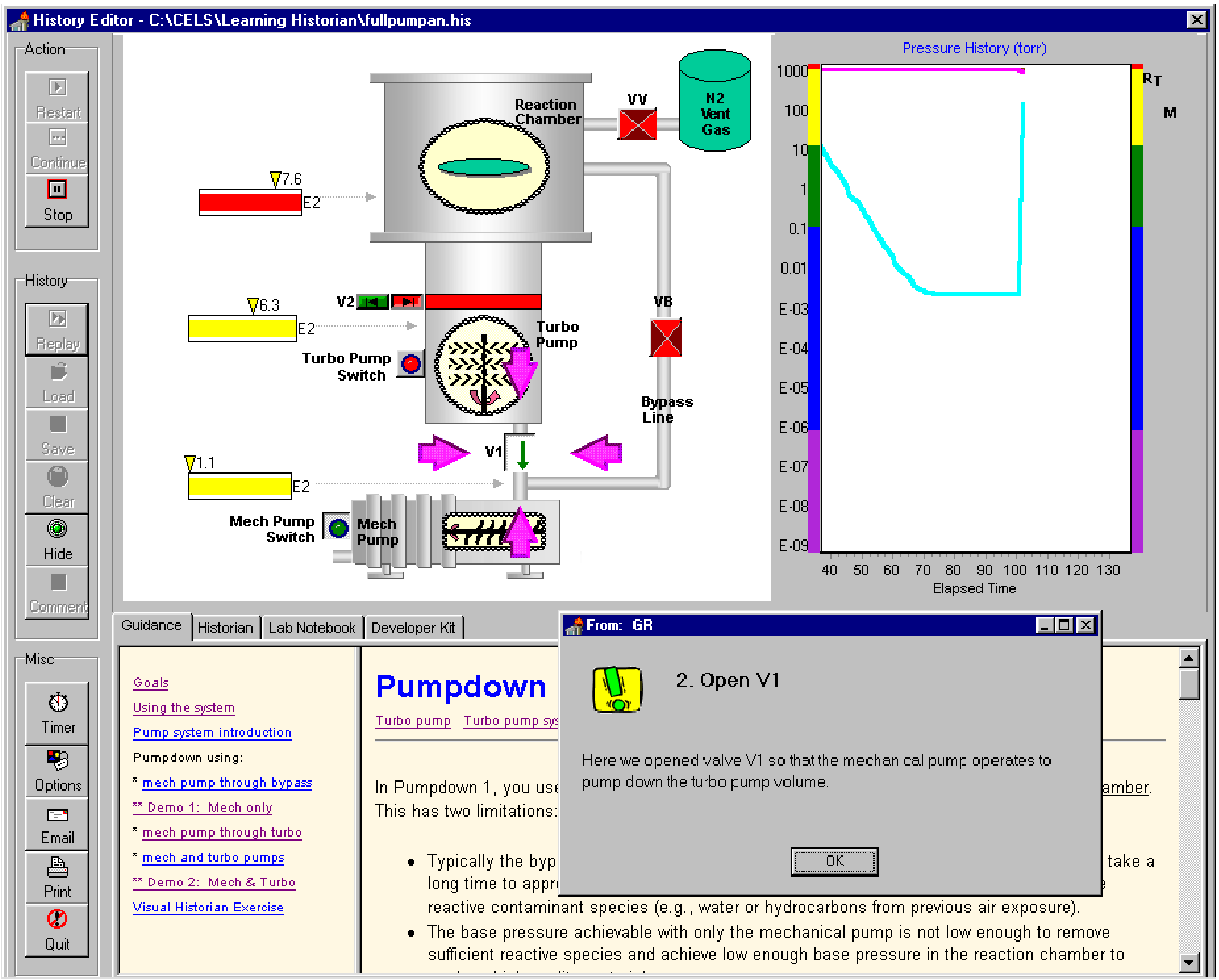


Learning Historian - Record of Events



- **Record, revise, replay, and annotate event histories in simulation experiments**
- **Use for**
  - *tutorial generation*
  - *questions to teacher/expert*
  - *peer collaboration*

Learning Historian - Replay of Simulation



Design for Authoring

- **Enable independent authoring of**
  - *engineering/technical material vs.*
  - *user interface and software design*

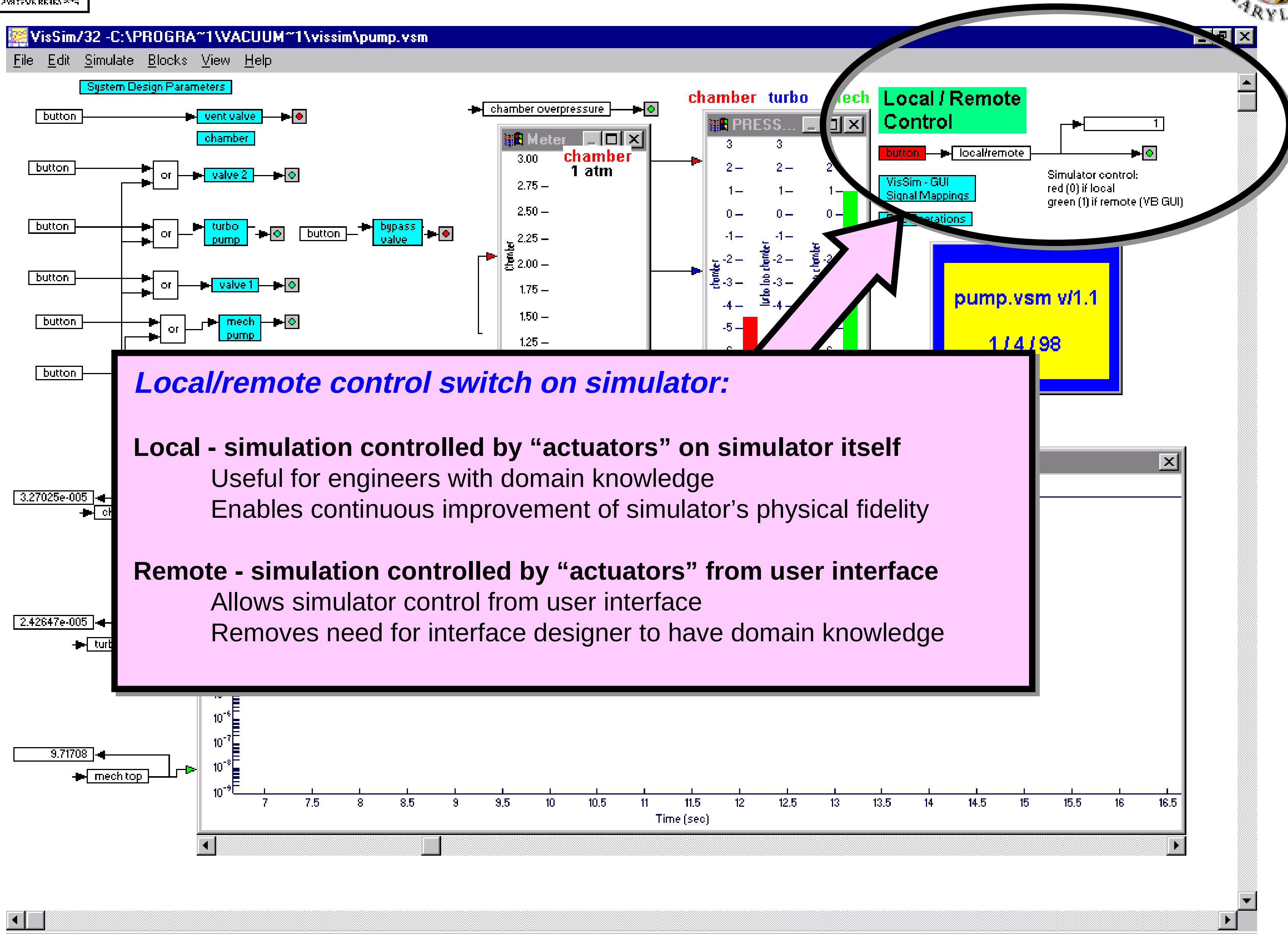
- **Provide effective authoring tools to *engineering expert***
  - *minimal if any software knowledge required*
  - *reusable library of simulator objects*

- **Provide effective authoring tools to *software/interface designer***
  - *minimal if any engineering knowledge required*
  - *reusable library of user interface and software objects*

- **Anticipate sequence of learning modules which can bring learner from novice to knowledgeable practitioner status**
  - *learning tool becomes on-the-job assistant*

- **Assess authoring efficiency from diverse set of application experiences**

Simulator: Local and Remote Control



Local/remote control switch on simulator:

Local - simulation controlled by "actuators" on simulator itself

Useful for engineers with domain knowledge

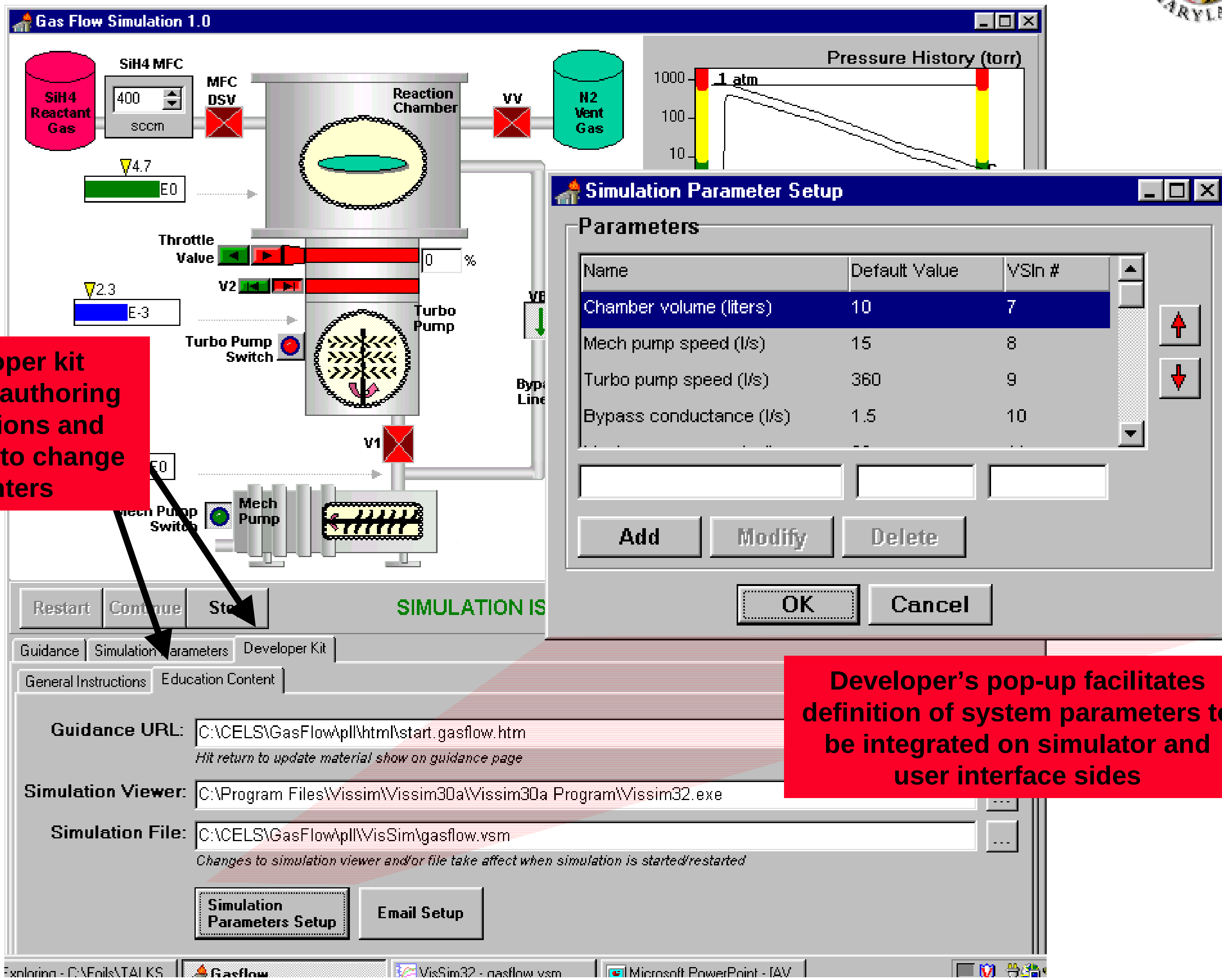
Enables continuous improvement of simulator's physical fidelity

Remote - simulation controlled by "actuators" from user interface

Allows simulator control from user interface

Removes need for interface designer to have domain knowledge

Authoring - User Interface

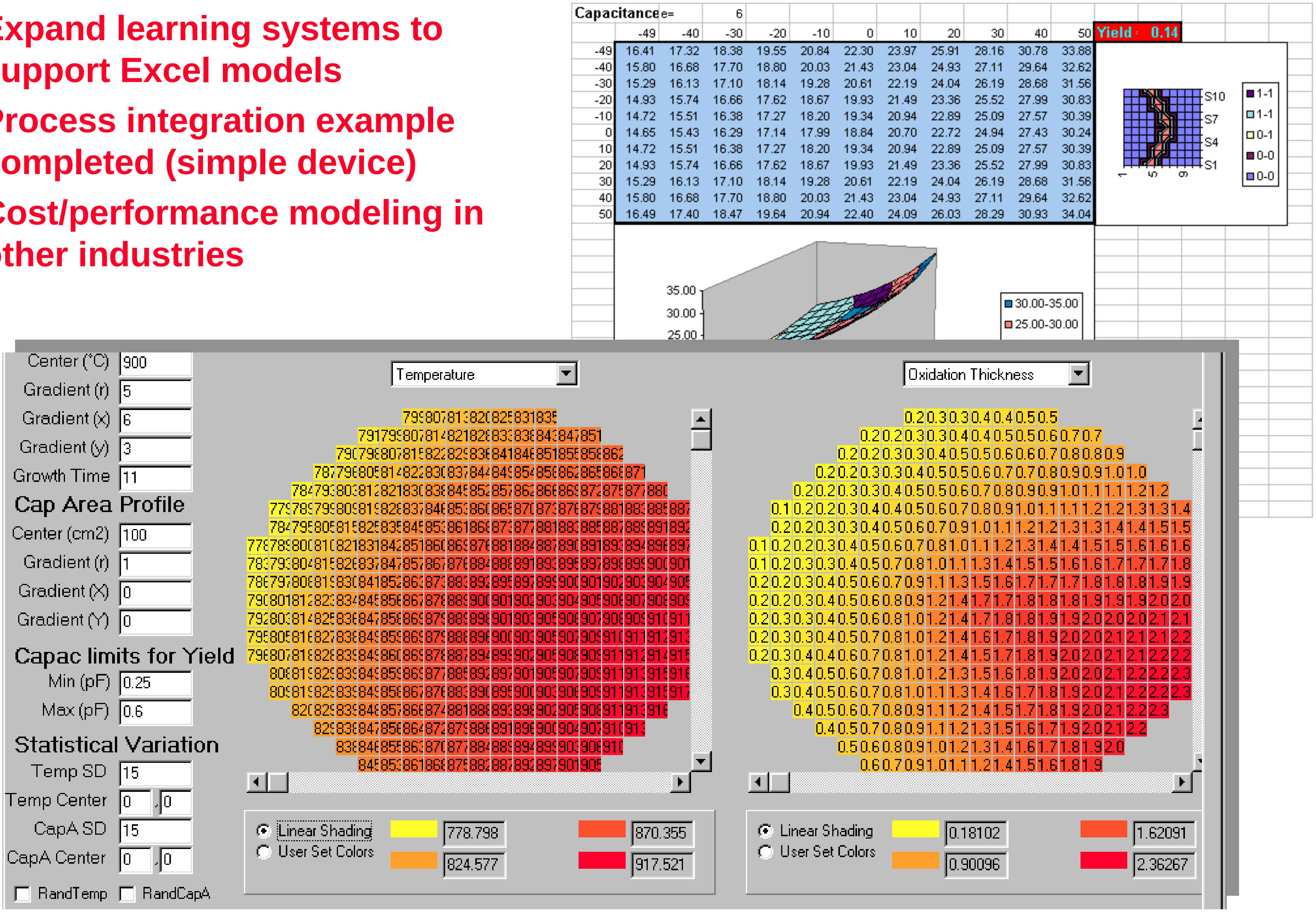


Developer kit provides authoring instructions and flexibility to change pointers

Developer's pop-up facilitates definition of system parameters to be integrated on simulator and user interface sides

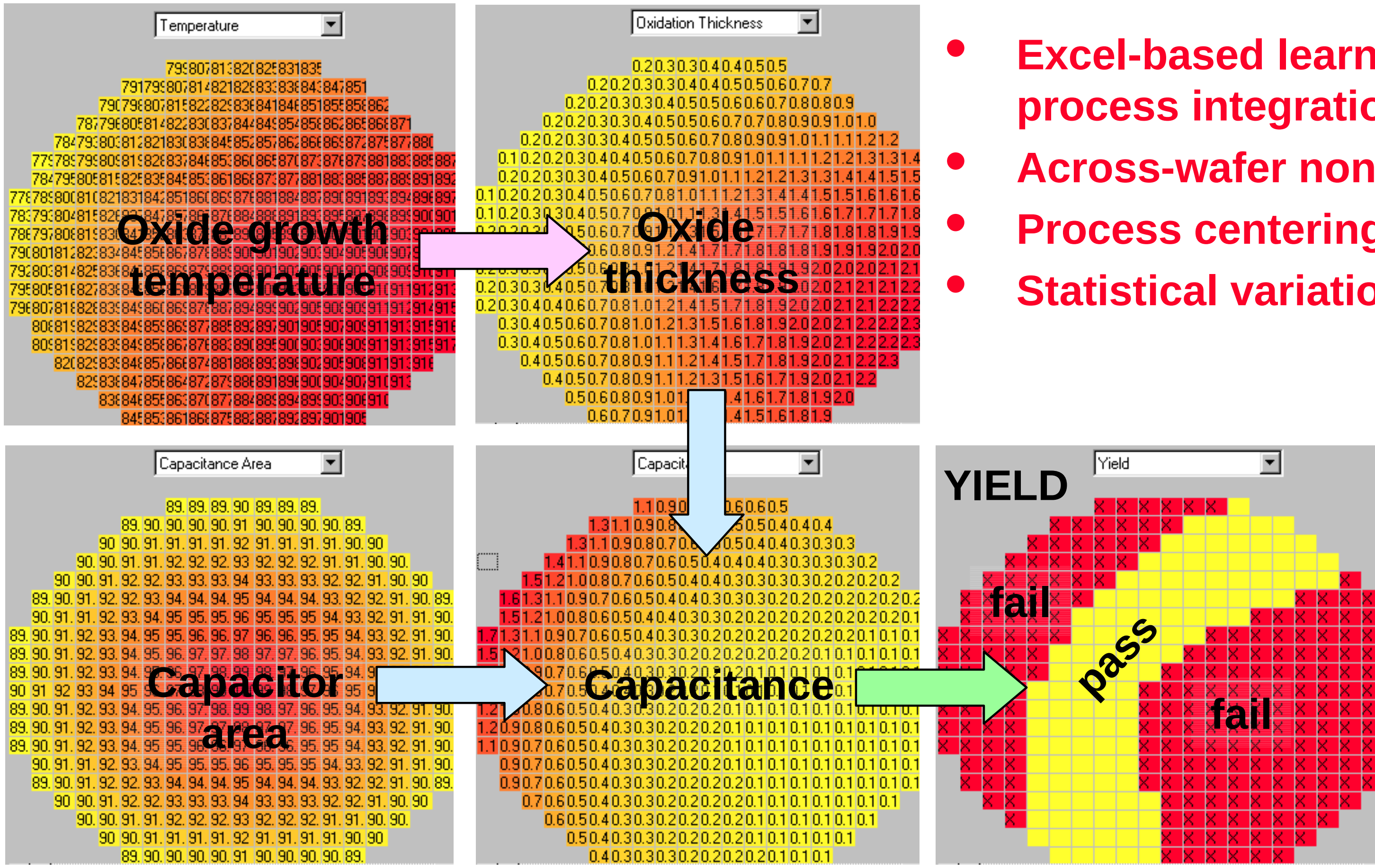
Process Integration and Yield Modeling

- **Expand learning systems to support Excel models**
- **Process integration example completed (simple device)**
- **Cost/performance modeling in other industries**



	-49	-40	-30	-20	-10	0	10	20	30	40	50
-49	16.41	17.32	18.38	19.55	20.84	22.30	23.97	25.91	28.16	30.78	33.88
-40	15.80	16.68	17.70	18.80	20.03	21.43	23.04	24.93	27.11	29.64	32.62
-30	15.29	16.13	17.10	18.14	19.28	20.61	22.19	24.04	26.19	28.68	31.56
-20	14.93	15.74	16.66	17.62	18.67	19.93	21.49	23.36	25.52	27.99	30.83
-10	14.72	15.51	16.38	17.27	18.20	19.34	20.94	22.89	25.09	27.57	30.39
0	14.65	15.43	16.29	17.14	17.99	18.84	20.70	22.72	24.94	27.43	30.24
10	14.72	15.51	16.38	17.27	18.20	19.34	20.94	22.89	25.09	27.57	30.39
20	14.93	15.74	16.66	17.62	18.67	19.93	21.49	23.36	25.52	27.99	30.83
30	15.29	16.13	17.10	18.14	19.28	20.61	22.19	24.04	26.19	28.68	31.56
40	15.80	16.68	17.70	18.80	20.03	21.43	23.04	24.93	27.11	29.64	32.62
50	16.49	17.40	18.47	19.64	20.94	22.40	24.09	26.03	28.29	30.93	34.04

Process Integration and Yield Modeling

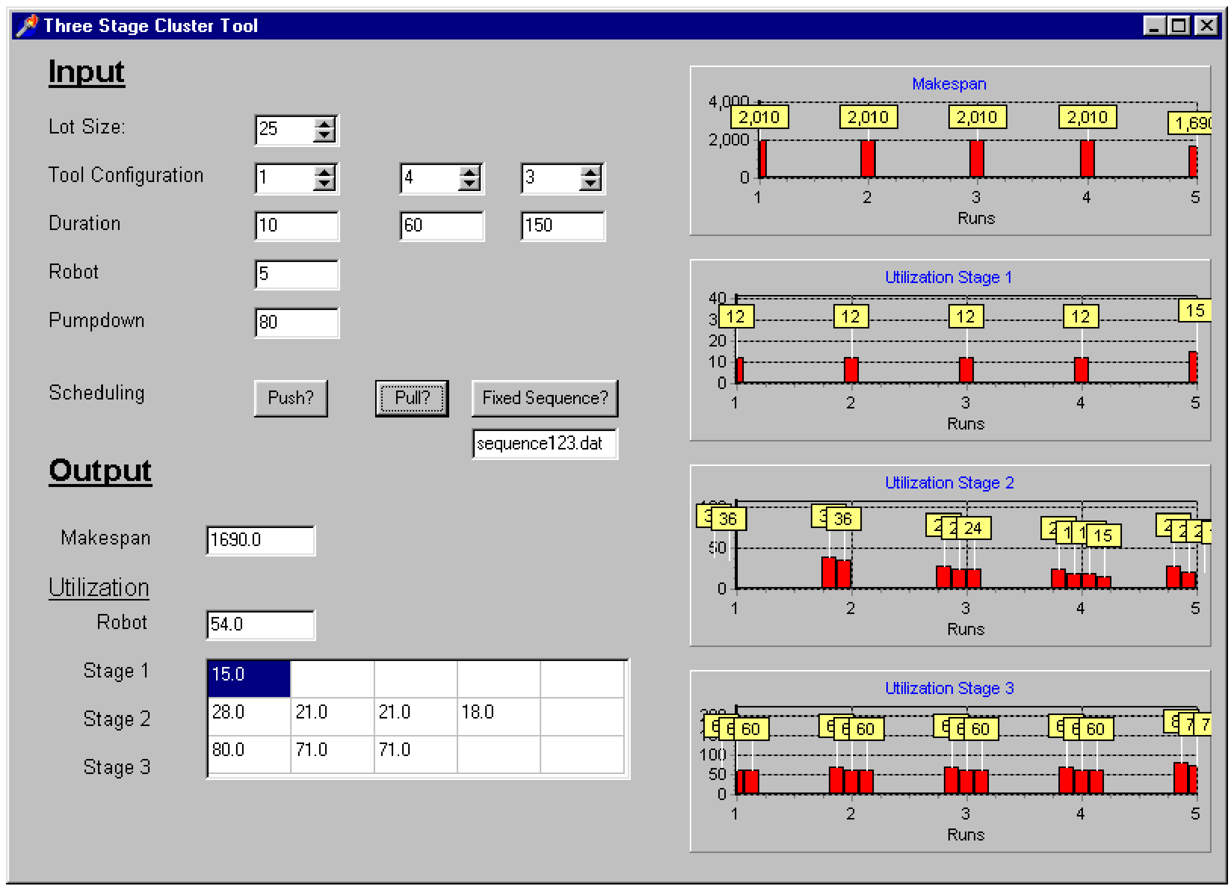


- Excel-based learning system for process integration and yield
- Across-wafer nonuniformity
- Process centering
- Statistical variation

Discrete Event Simulation and Factory Operations

- **Expand learning systems to support legacy code (Fortran, C/C++, …)**
- **Cluster tool simulator (logistics, scheduling) - implemented in Java, now incorporated into engineered learning system**

- **Factory operations simulator (Factory Explorer), consisting of Excel front end which drives simulation engine, now incorporated into engineered learning system**



Simulator-Based Manufacturing Education and Training for Microelectronics Processing

- **NSF grant EEC - 9526147, 9/15/95 - 8/31/00, PI G. W. Rubloff, $600K**

- **Goal**
  - ***Develop and assess methodologies in which physically-realistic simulation tools can be incorporated into broader software-based learning environments which are available anytime, anywhere, and which can provide value not only for experienced engineers, but also for manufacturing operators or technicians with little relevant technical background***

- **Manufacturing Training Modules - for operators, technicians, and students with little technical background**
  - ***Vacuum-Based Process Equipment***
  - ***Heat Transfer***
  - ***Chemical Processes***

- **Engineering Design Modules - for practicing engineers and graduate students**
  - ***Statistics and Design Optimization***
  - ***Process Control***

Center for Engineered Learning Systems

CELS

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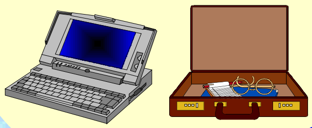
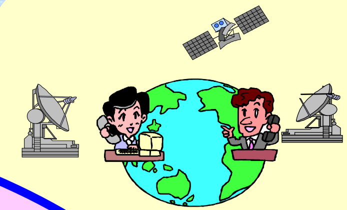
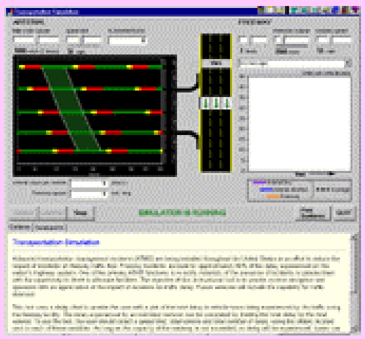
Portable, standalone



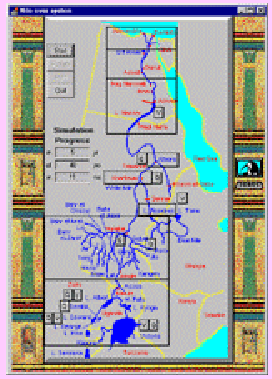
Internet-connected



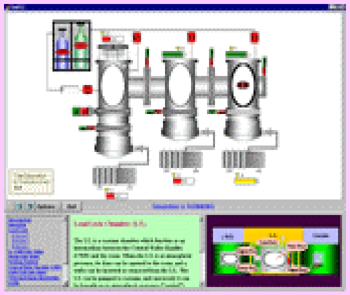
APPLICATIONS



Systems management



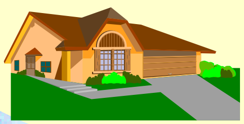
Politics, history, economics, and society

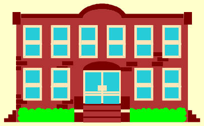


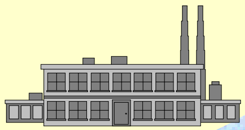
Science and technology

Individual and group active learning experiences

Real-time and asynchronous collaboration and counsel







At work, in school, and at home

CELS is administered as a Center within the Institute for Systems Research, an entity of the A. James Clark School of Engineering at the University of Maryland.

Other Simulator-Based Learning Systems

CELS

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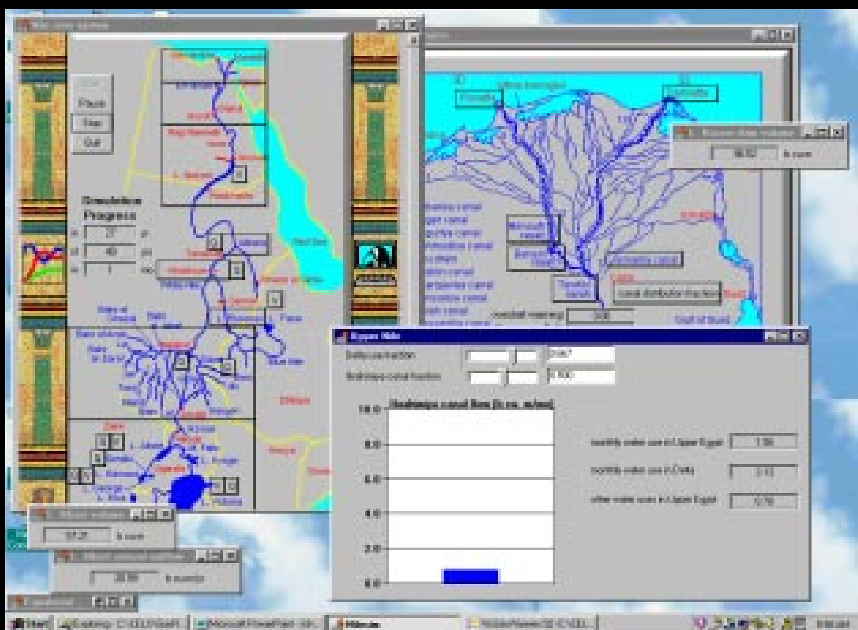
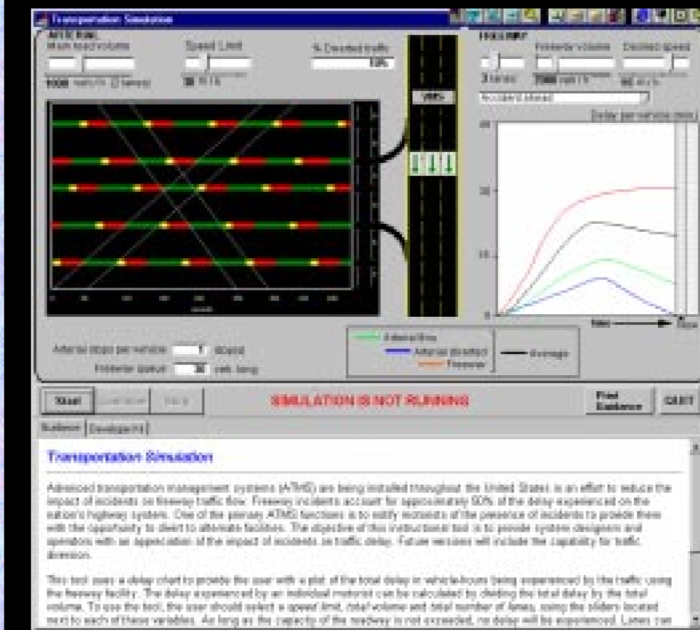
NileSim



TrafficSim



Simulation-Based Learning Systems for Environmentally-Benign Semiconductor Manufacturing

- **NSF grant EEC (recommended), 10/1/99-9/30/02, $400K**
- **PI G. W. Rubloff (U. Maryland ISR), Co-PI F. Shadman (U. Arizona CEBSM)**
- **Goals**
  - ***Education modules at 3 levels: undergraduate, graduate, practitioners***
  - ***Incorporation of legacy simulators***
  - ***Simulation explorer***
  - ***Educational assessment***

Wish List for ESH Learning Systems

- **User-driven system design**
  - *Choose individual system components*
  - *Expand and reconfigure network*
- **Exploit existing models and simulations**
  - *Utilize existing codes directly (Fortran, …)*
  - *Generate compact models in simple, systematic fashion*
- **Facilitate design and optimization of control system**
  - *Incorporate various control systems elements*
  - *Experiment with optimization and fault management algorithms*
- **Build the basis for systems design and optimization**
  - *Educate new practicioners*
  - *Support systems engineering for current practicioners*

Conclusions

- High quality **user interface design** expands value of simulation to engineering and education

- Effective **engineered learning systems** combine
  - *Simulation with good user interfaces*
  - *Tightly coupled guidance materials*
  - *Software learning aides*
  - *Tools to facilitate experimentation and collaboration*
  - *Easy authoring for both domain knowledge and software environment*

- Learning system **enhancements in progress**
  - *Tools for experimentation and collaborative design*
  - *Increasing ability for system alteration and redesign by user*
  - *Incorporation of different modeling/simulation tools, including legacy codes*
  - *Broad applications set on common, commercial software base*