Control of Fuel Processor for Hydrogen Generation in Fuel Cell Applications

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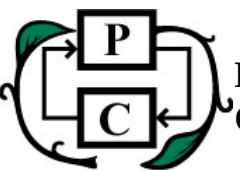
Work funded by
U.S. Army Center of Excellence for Automotive Research (ARC)
and NSF-CMS 0201332 and CMS-0219623

Thanks to
Prof. Huei Peng and Jay Pukrushpan (UMICH)
Scott Bortoff and team (UTRC and UTC-FC)

Woong-Chul Yang and Scott Staley (Ford, Th!nk)
Herb Dobbs and Eric Kalio (US-Army NAC)



Powertrain
Control Lab

Problem—Hydrogen Supply

On-board storage ("direct")

- Cryogenic (liquid) hydrogen
  Liquifying hydrogen is expensive and storing this extremely cold fuel on a vehicle is difficult.
- Pressurized (gaseous) hydrogen
  Requires significant energy for compression, stringent safety precautions and bulky, heavy and expensive storage tanks.
- Metal hydride or Carbon nanofiber storage
  New technology
  far from commercial development.

Adams et al., "The Development of Ford's P2000 Fuel Cell Vehicle," SAE 2000-01-1061

Table 5. Direct Hydrogen Fuel Storage Options (for equivalent vehicle range).

	System Weight (kg)	System Volume (liters)
Compressed Gas (5,000 psia)	50	330
Cryogenic Liquid	45	190
Metal Hydride	200 - 600	180
Gasoline	50	70

Onboard fuel processors ("reformer")

Convert hydrocarbon fuel, such as methanol or gasoline, to a H_2 rich gas.

On-Board Reforming

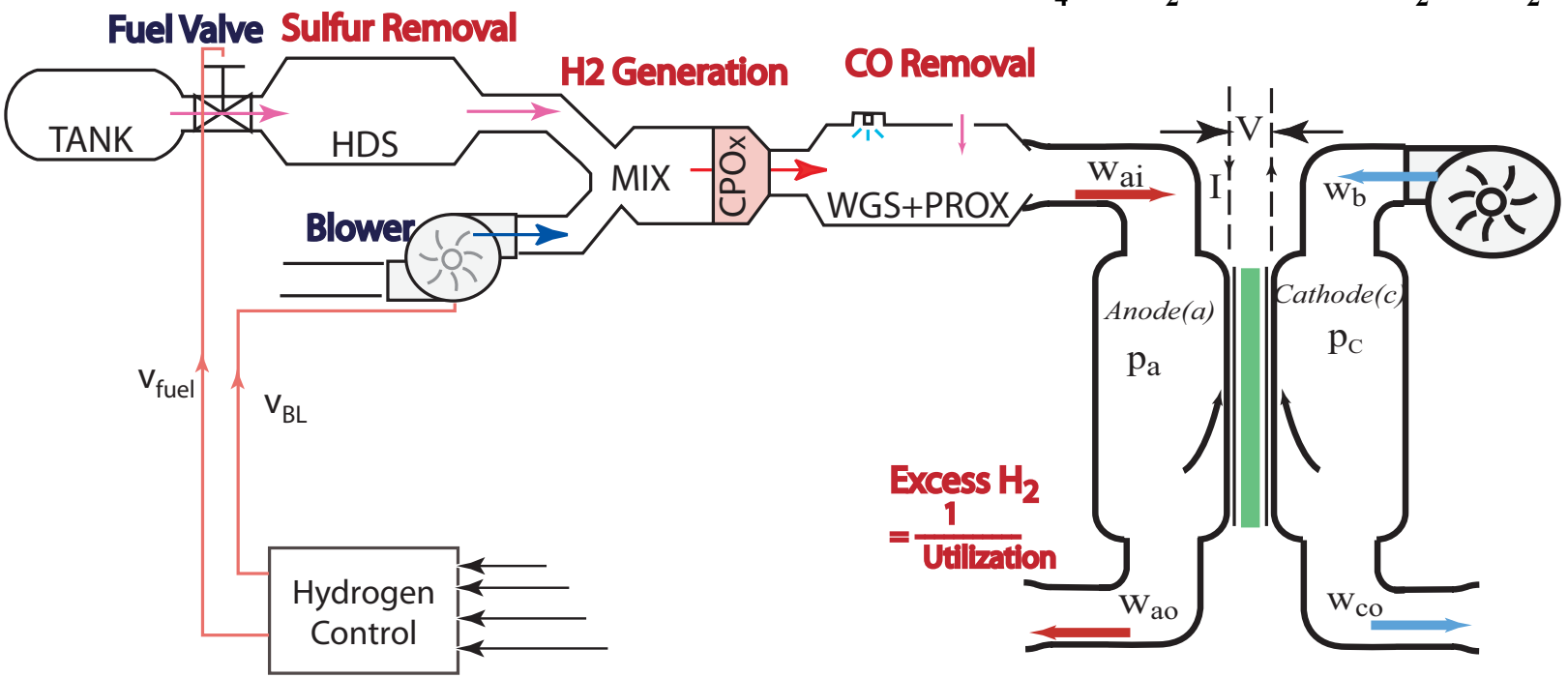
- **Advantage: Widely Available, Inexpensive, Consumer Acceptance, Fuel Flexibility**
- **Liquid Fuels From Petroleum and/or Other Sources (e.g, Ethanol)**
- **Natural gas**
  - **Large potential reserves, distributed worldwide**
- **H_2 From Catalytic Partial OXidation (CPOX)**
  - **Partial Oxidation: $CH_4 + 0.5O_2 + Heat = CO + 2\ H_2$ (at 700^o)**
  - **Total Oxidation: $CH_4 + 2O_2 + Heat = CO_2 + 2\ H_2O$**
  - **Water-Gas Shift: $CO + H_2O = CO_2 + H_2$**
    - **Autothermal point balances heat input/output**
    - **0.25-0.5 % (2500-5000 ppm) of CO remains in the feed**
    - **Unacceptable performance if CO% is 0.001% (10ppm)**
- **Preferential Oxidation (PrOX) is needed!!**
  - **Precise Control of O2 feed for the CO oxidation**
    - **Any extra O2 will react with H2 (loss of fuel)**

From Direct Hydrogen to Reformate Hydrogen

H_2 generation from Catalytic Partial OXidation (CPOX)

Partial Oxidation: $CH_4 + 0.5O_2 + Heat = CO + 2\ H_2$ (at 700°)

Total Oxidation: $CH_4 + 2O_2 + Heat = CO_2 + 2\ H_2O$



Goals:

Coordinate fuel (methane) and air flow to achieve

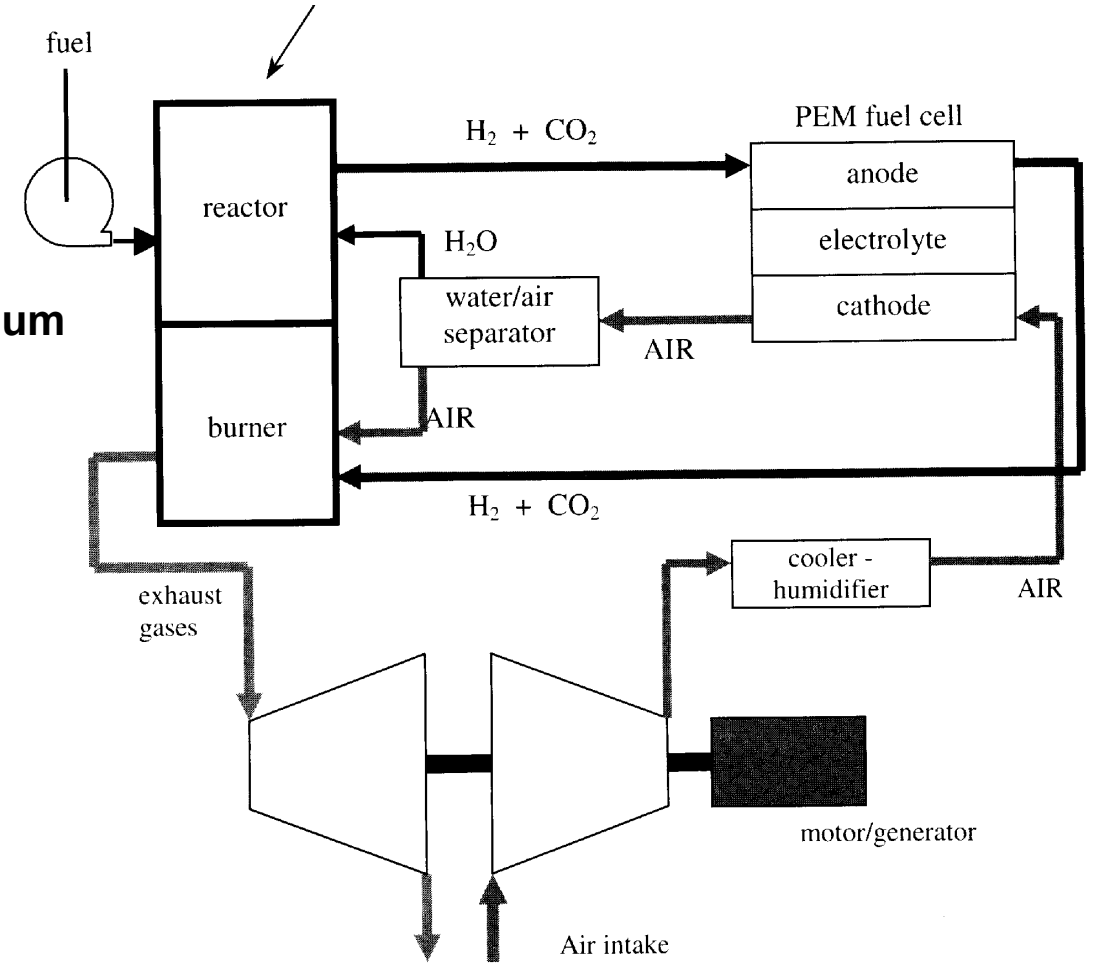
-- high conversion of H_2 (regulate CPOX Temperature)

-- maximize H_2 utilization

Integrated FPS+FCS+CBrn

Burn the excess H2 (Catalytic burner) use the heat for
(i) heating (or vaporizing) the fuel
(ii) recover power throughTC

Highly coupled system with non-minimum phase response → very slow start-up



Baseline Controller

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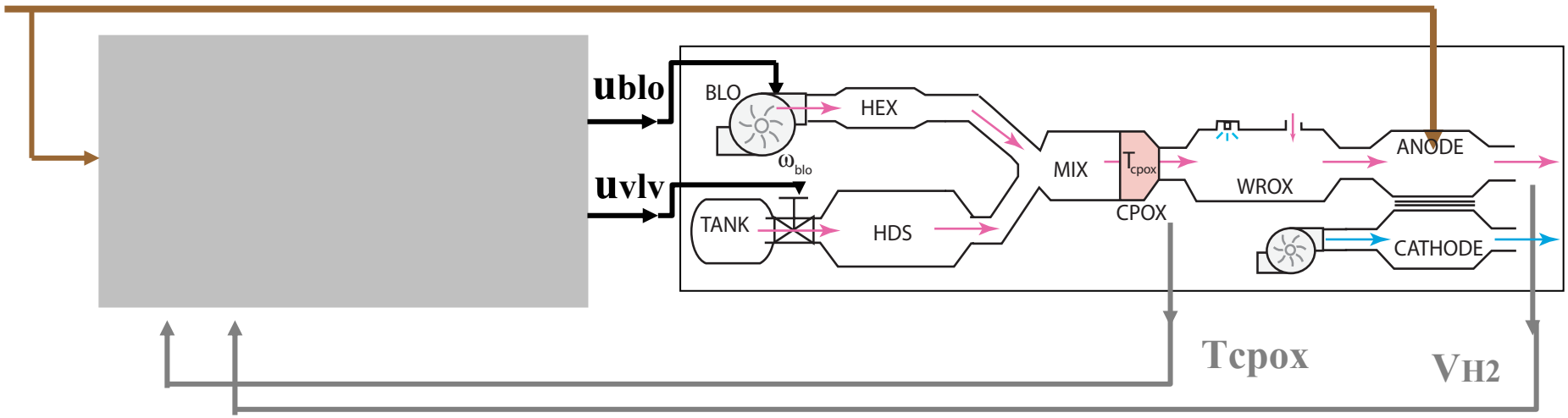
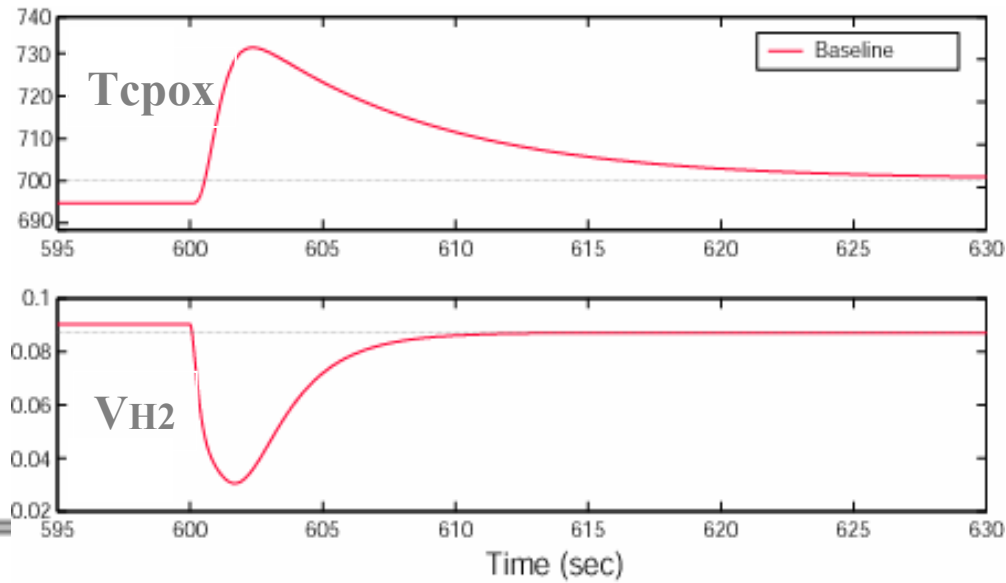
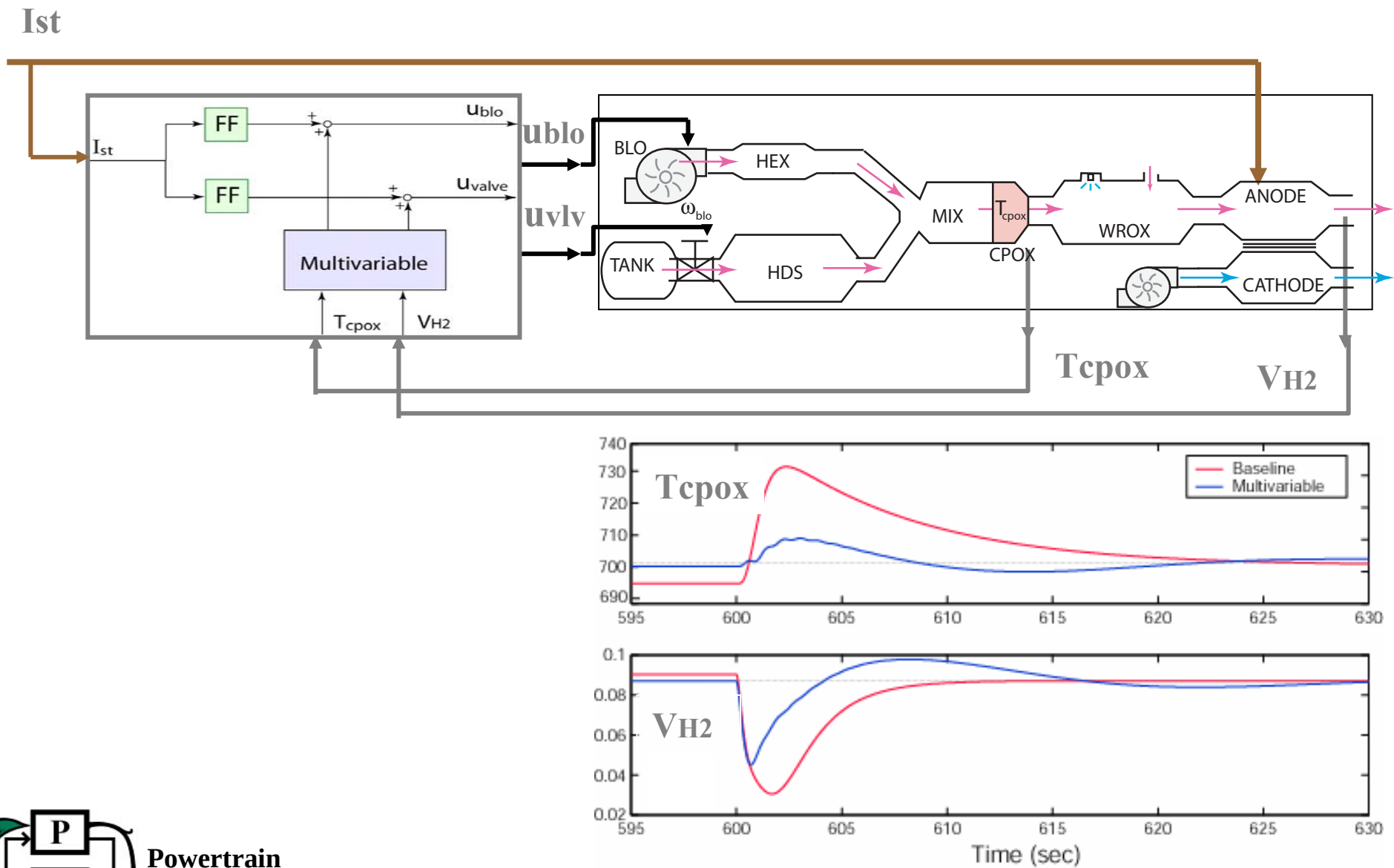




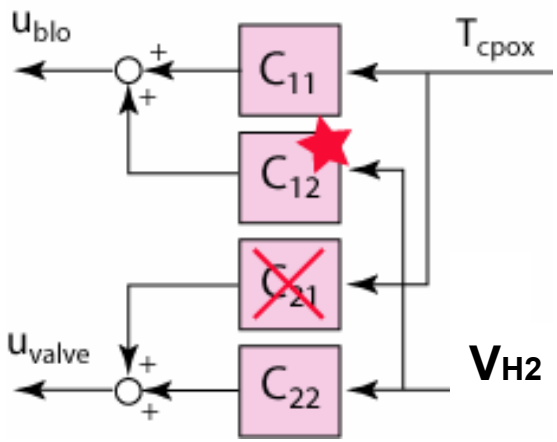
Multivariable Controller



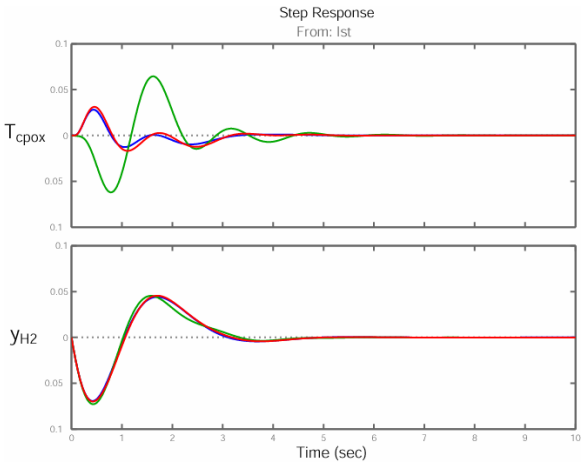
Analysis of MIMO Controller

$$\begin{bmatrix} u_{blo} \\ u_{valve} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{bmatrix} T_{cpox} \\ V_{H2} \end{bmatrix}$$

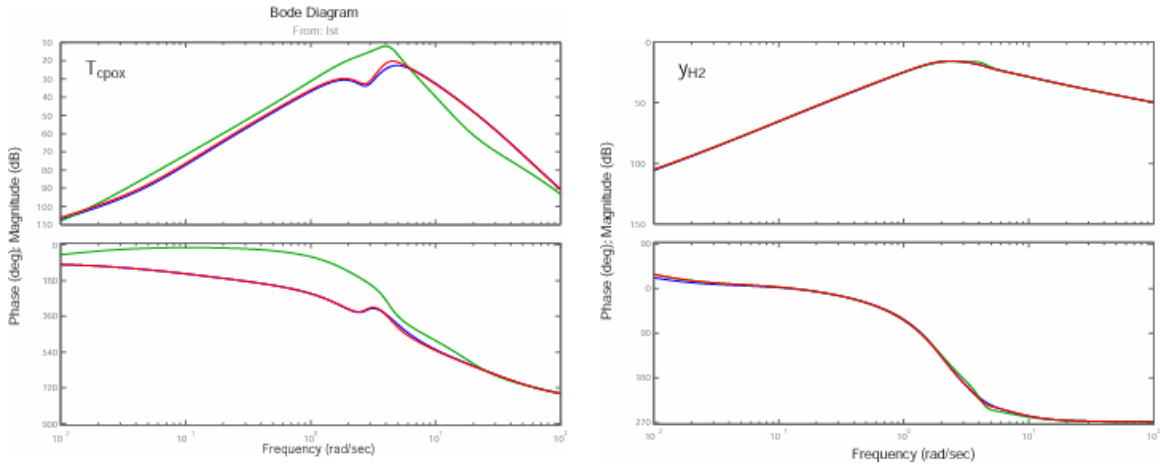
$$\begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \quad \begin{bmatrix} C_{11} & 0 \\ 0 & C_{22} \end{bmatrix} \quad \begin{bmatrix} C_{11} & C_{12} \\ 0 & C_{22} \end{bmatrix}$$



C12 term is important



Closed-loop step response



Closed-loop frequency response

Multivariable Controller → Coordination

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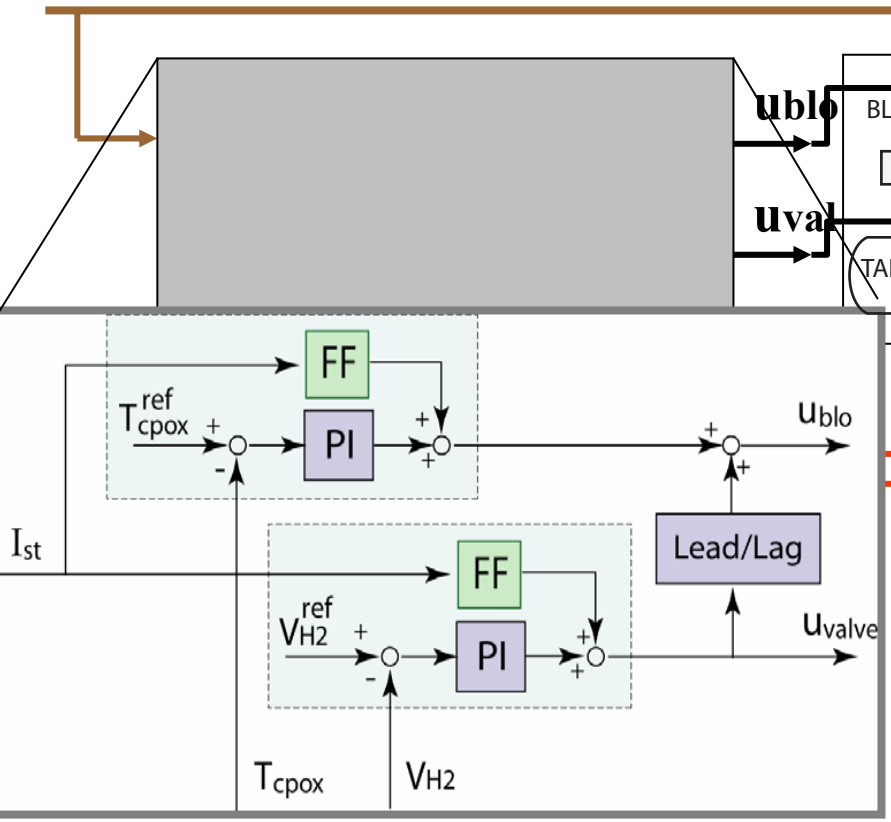
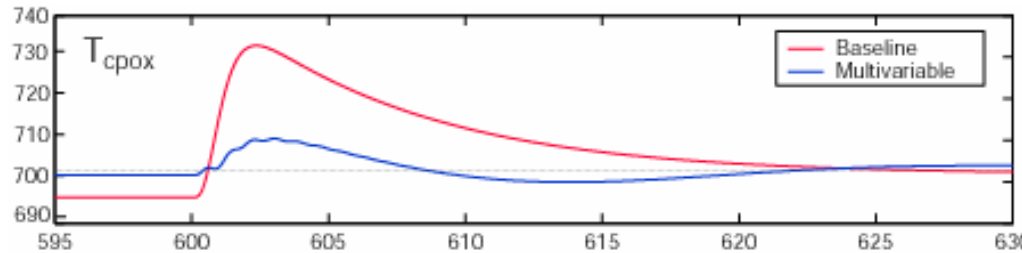
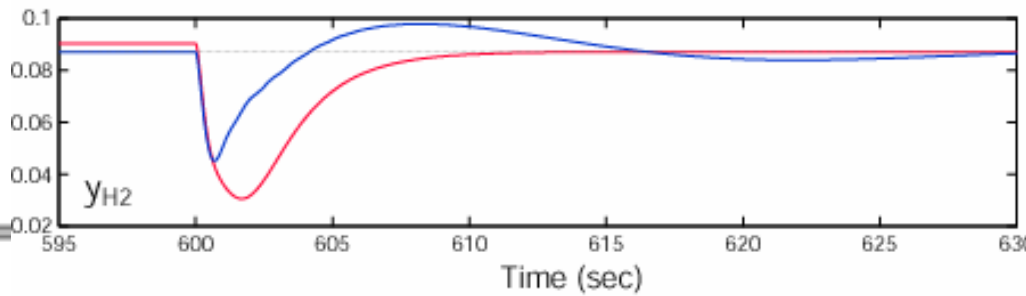






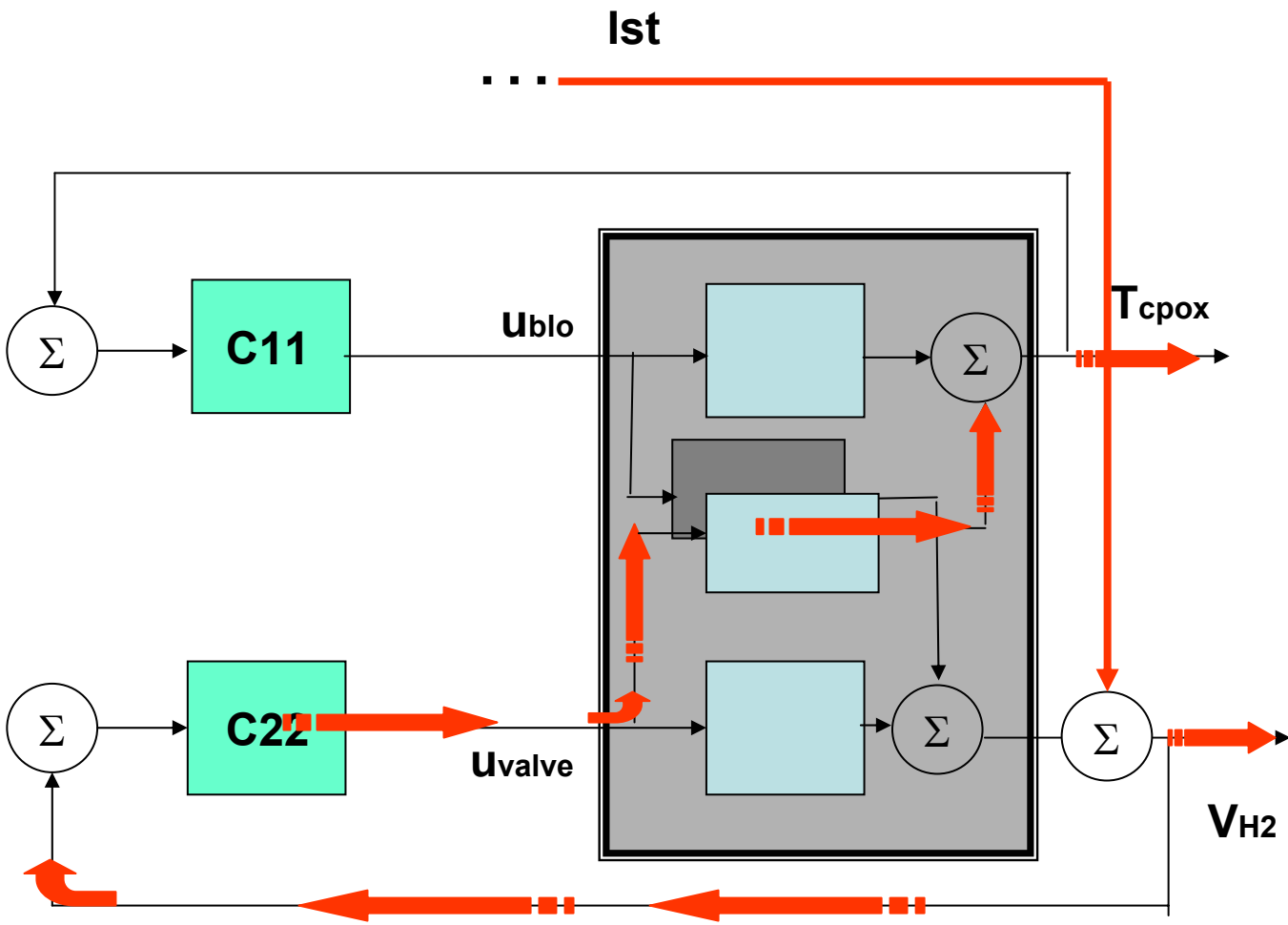
Analysis of the FPS+FC Interaction

The current command affects hydrogen…

The error in hydrogen is detected by the controller through the C22 (typically a PI controller).

The fuel valve tries to compensate for the detected hydrogen error

… and causes a disturbance to the Tcpox through the P12 plant interaction



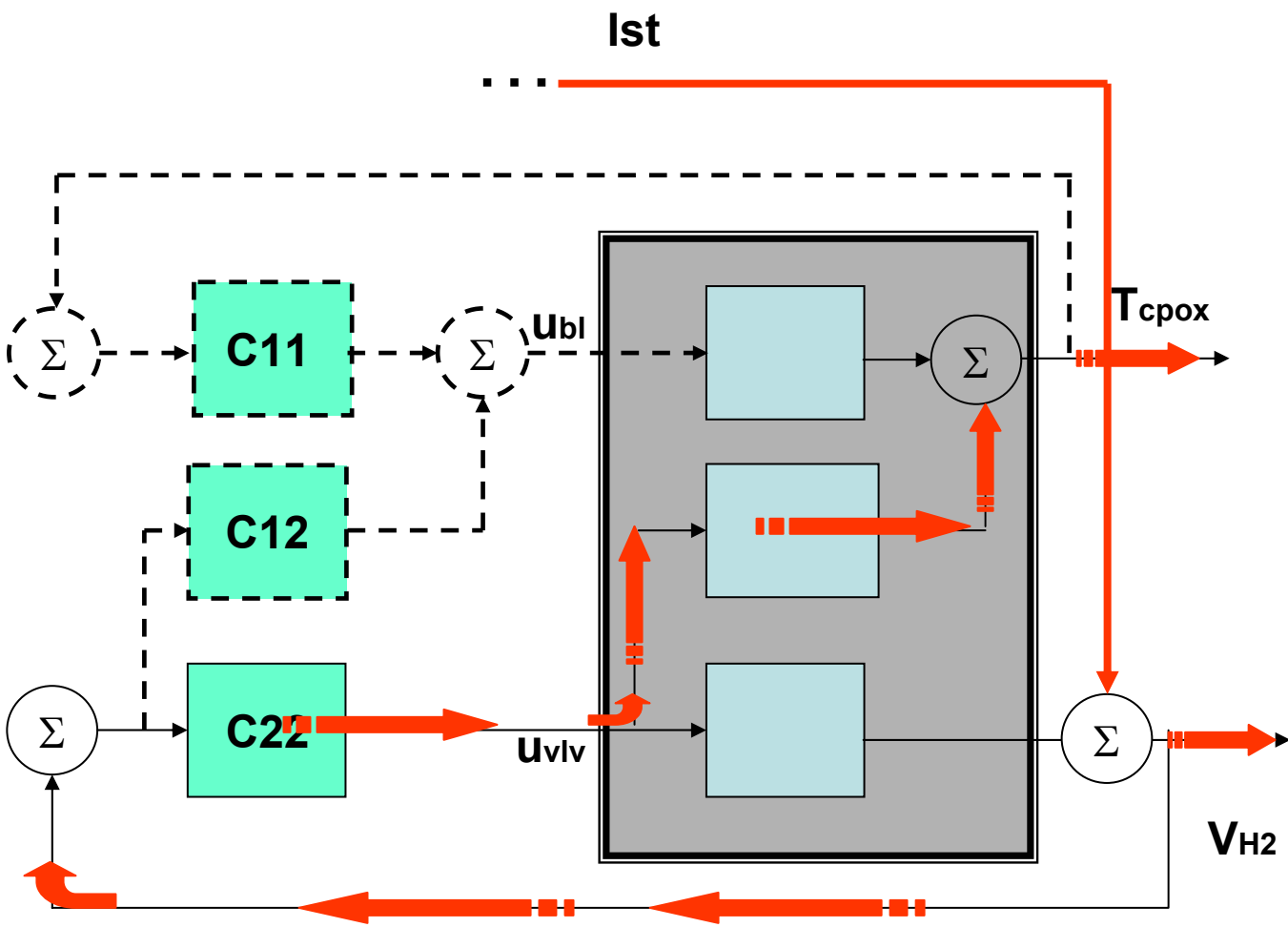
Analysis of the FPS+FC Interaction (cont.)

… and causes a disturbance to the Tcpox through the P12 plant interaction

The Tcpox pertrubation Is detected by the PI controller in C11

That energizes the blower signal which eventually rejects the P12 disturbance.

… for faster response, one can use a direct command to the blower signal based on the fuel valve excursion. This is accomplished by the C12 term!!



Adding Measurements from FPS → Robustness+Performance

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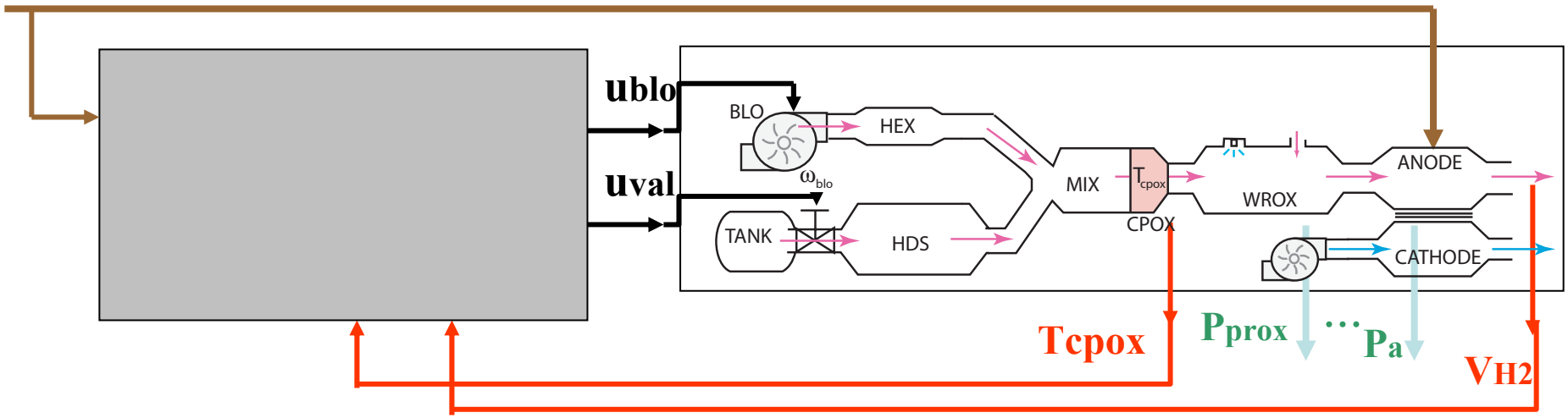
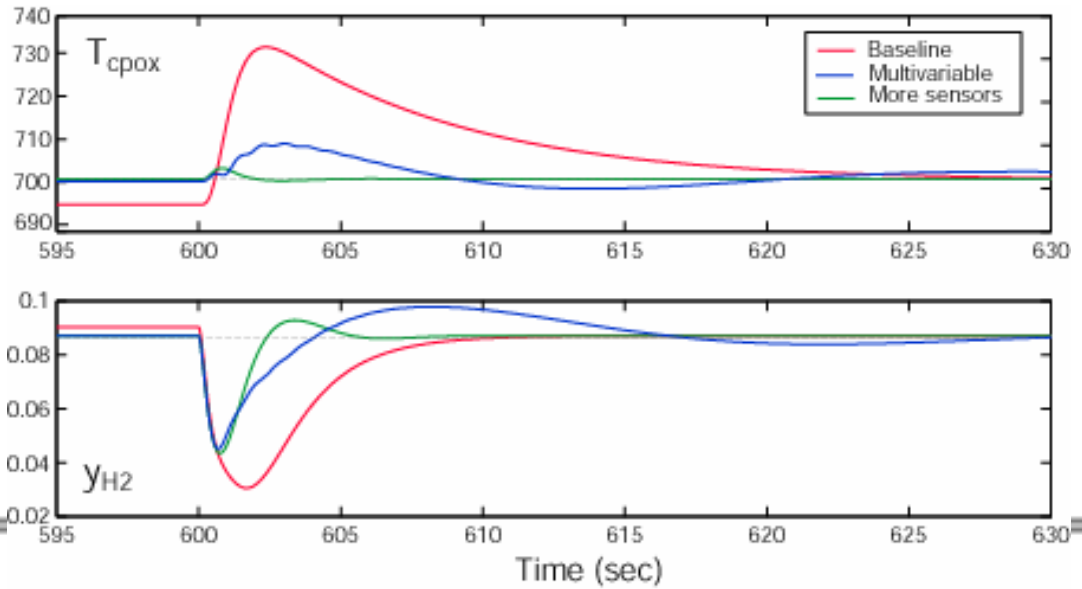




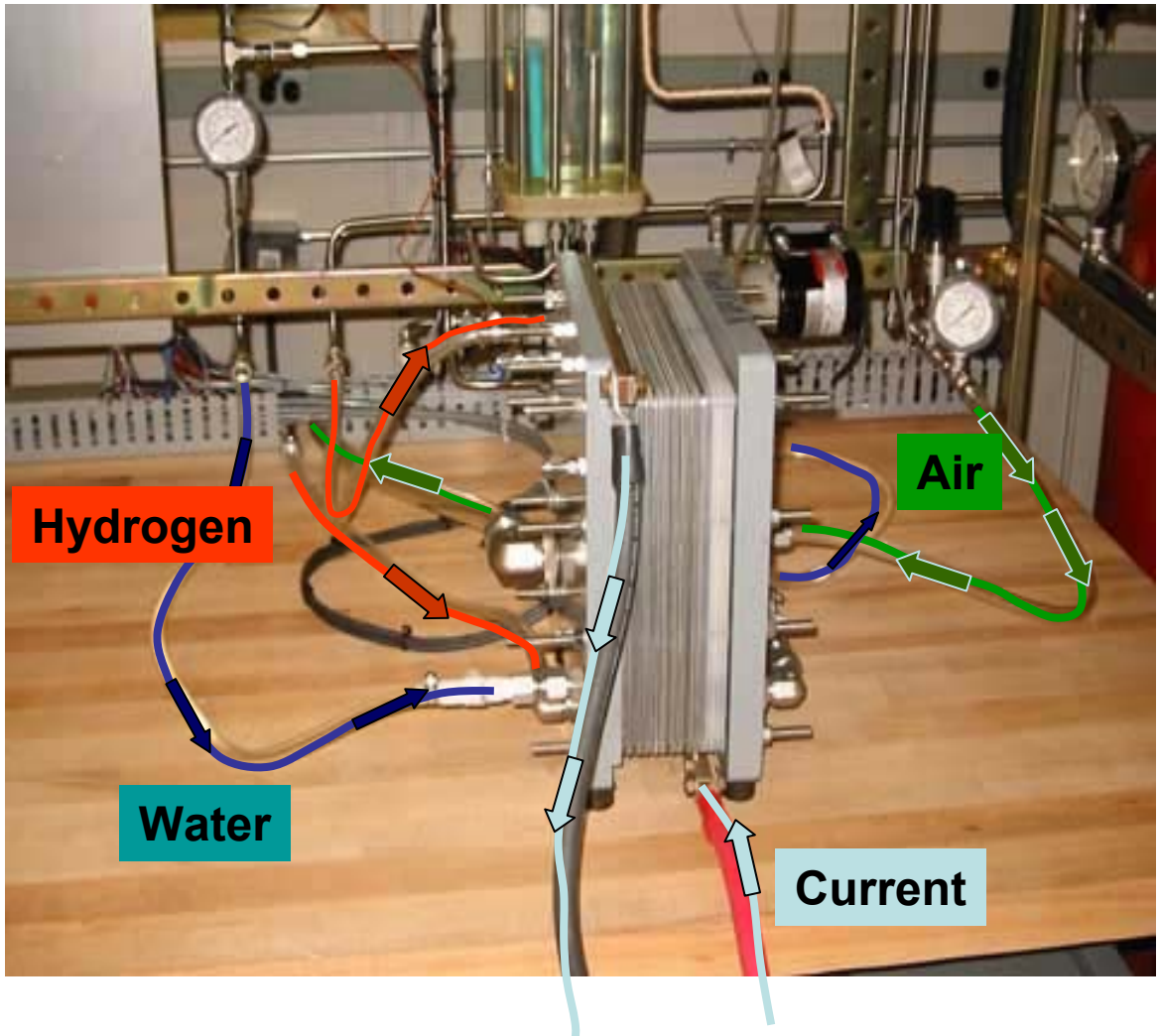
Fuel Cell Control Test Station

Designed by The Schatz Energy Research Center (SERC)
Humboldt State University, Arcata, CA

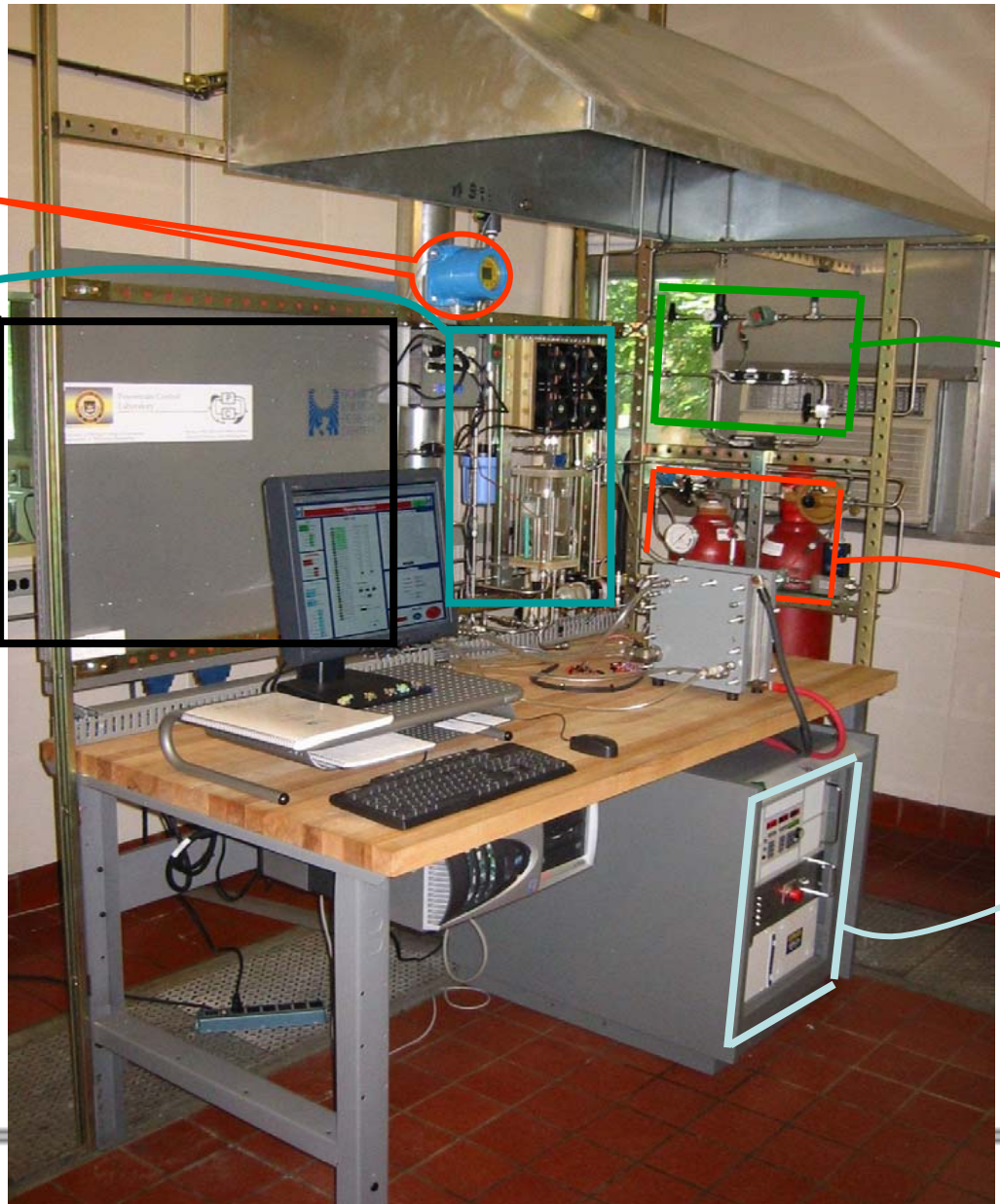
1082 WE Lay Auto Lab

Powertrain Control Lab

PEM Fuel Cell (2.4 kW)



Fuel Cell Control Test Station



Hydrogen Sensor

Thermal Management

Data-Acquisition with LabView

Mass Air Controllers

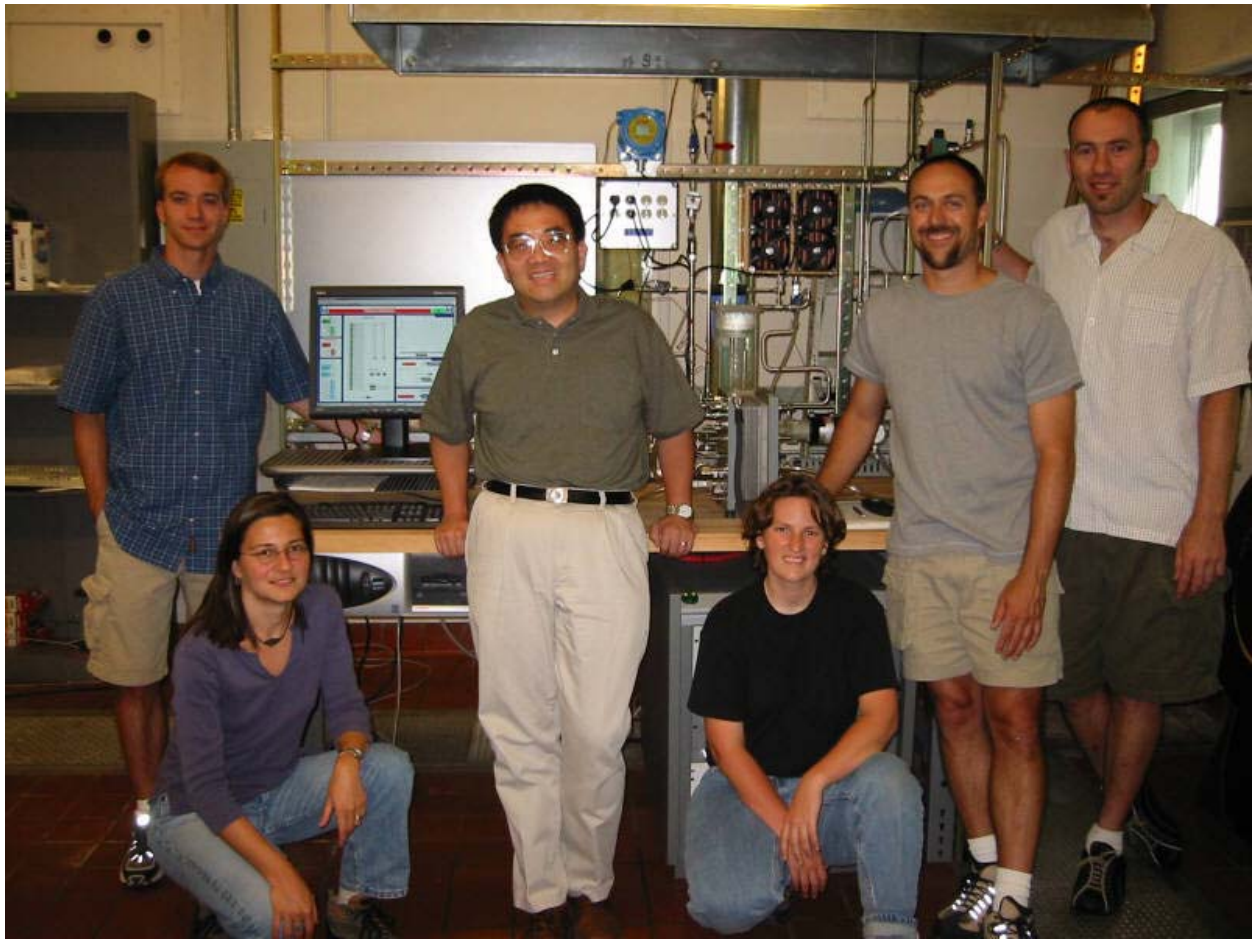
Hydrogen Storage and Pressure Regulation

Controllable Load

1082 WE Lay Auto Lab

Powertrain Control Lab

Thanks!!!



Graduate Students
Jay Pukrushpan
Don Lochner
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UnderGraduate St.
Marietsa Edje
Dave Nay

Visiting Students
Sylvain Gelfi
Denise McKay

Thanks to Professor Peng

-- Scott Bortoff and Shubro Ghosh (UTRC and UTC-FC)
-- W-C Yang and Scott Staley (Ford SRL and Th!nk)
-- Charles Chamberlin, Peter Lehman (SERC)