Fuel-Flexible, Fuel-Processing Subsystem Development

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Phoenix Family of Companies

PhoenixGasSystems

Industrial Hydrogen Generation

PHOENIX FUEL CELL SYSTEMS

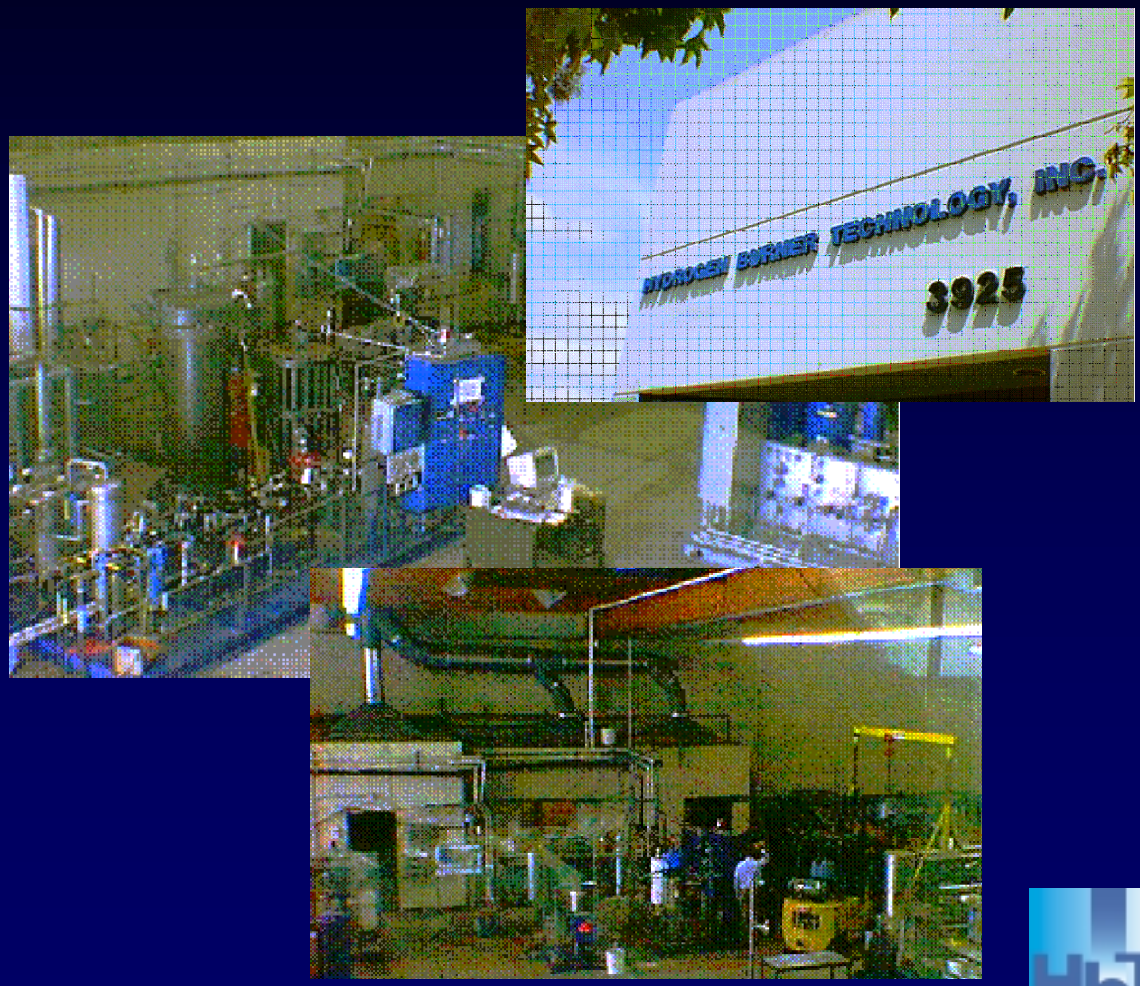
Reformers for Fuel Cell Systems

PHOENIX COMBUSTION SYSTEMS

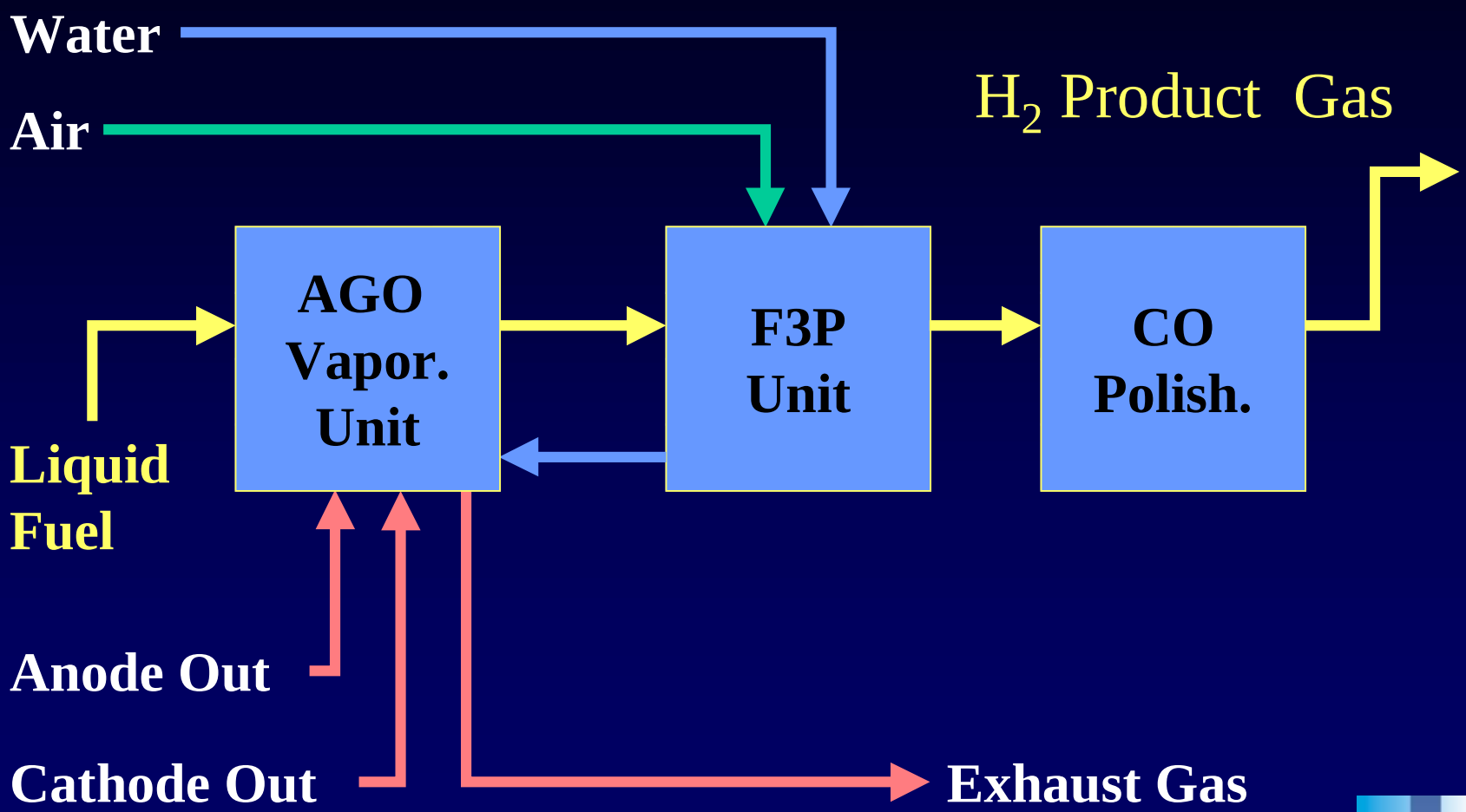
Combustion Equipment

HBT's Long Beach Facility

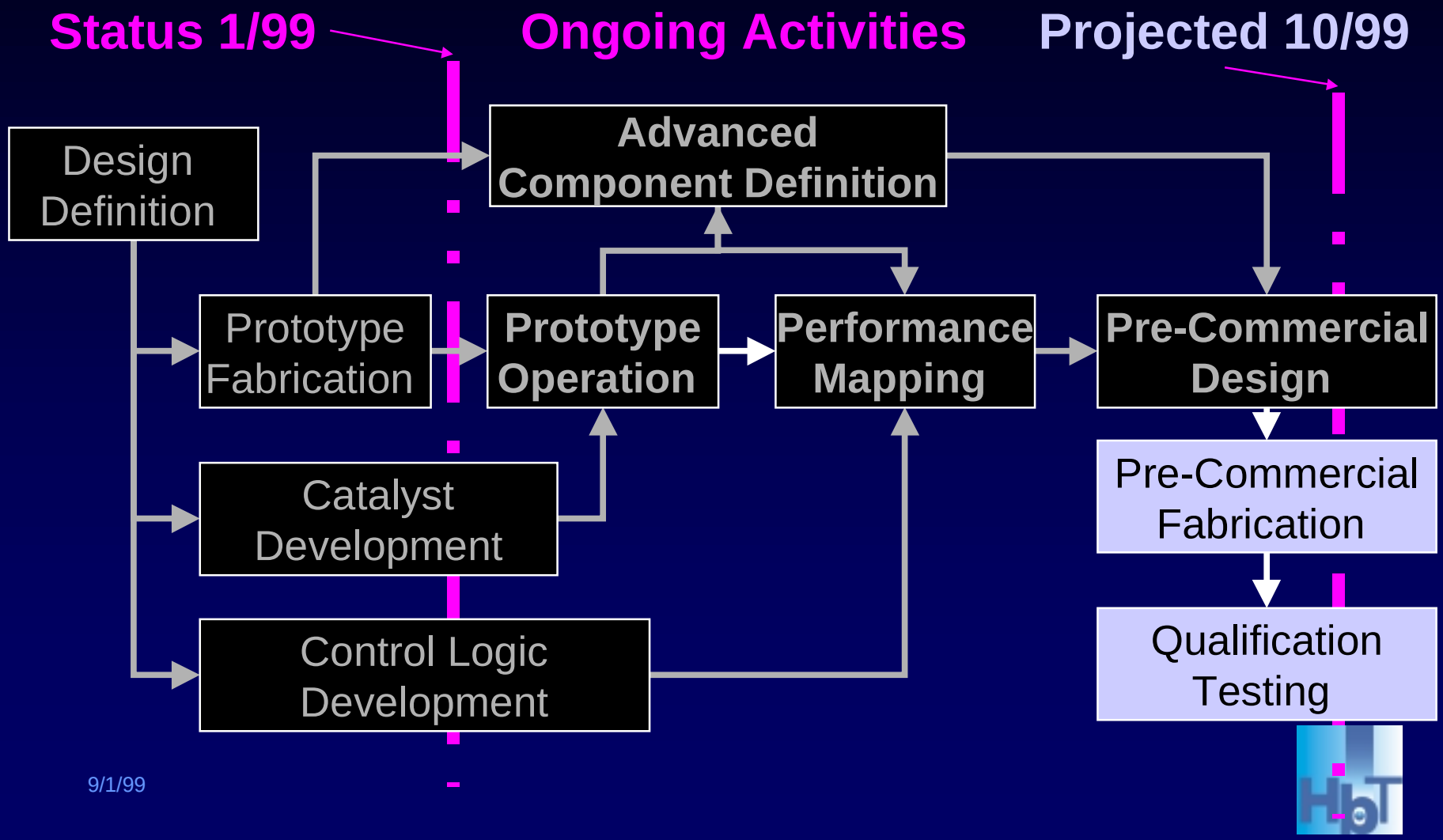
- Floor Space
  - 16,000 ft^2
  - 1/3 Office
  - 2/3 Mfg
- Staffing
  - 35 people
  - 1/2 HBT
  - 1/2 PGS



F^3P Subsystem



Program Scope Overview

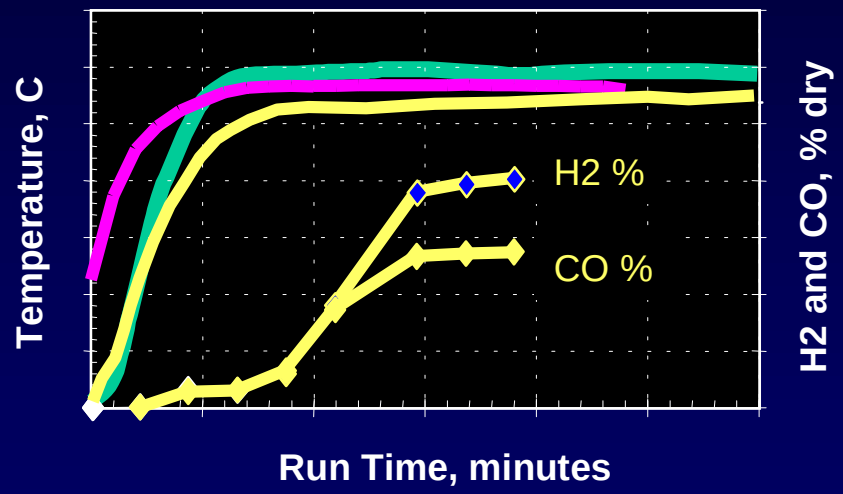


Accomplishments To Date

- Hardware Fabrication
  - Three Prototypes Delivered
  - Three Additional Prototypes in Construction

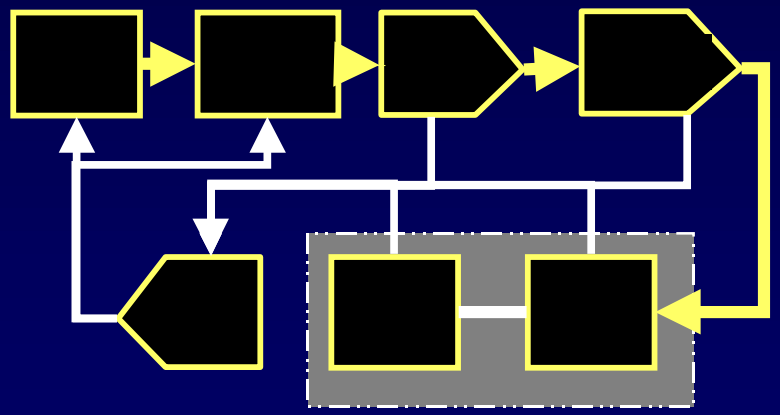
Accomplishments To Date

- Hardware Fabrication
- Operational Experience Over 120Hours
  - Gasoline
  - Pipeline Gas
  - Methanol



Accomplishments To Date

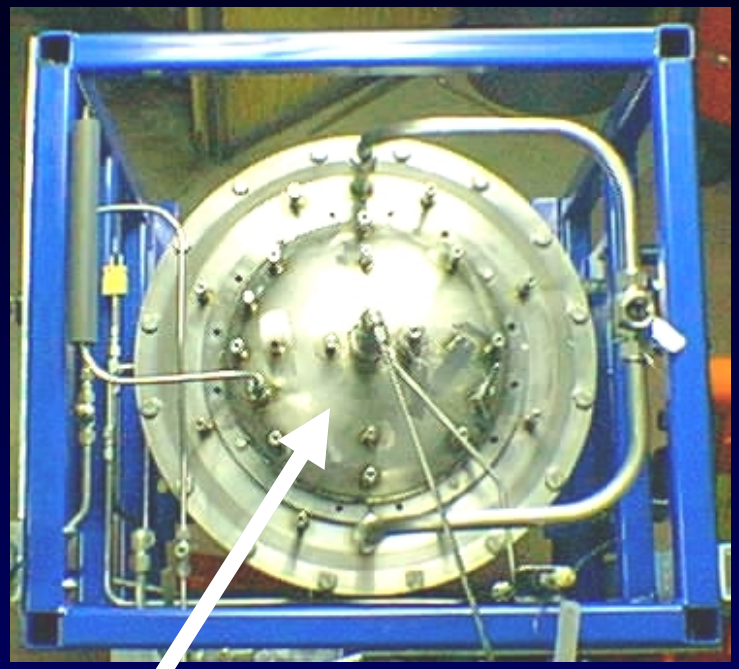
- Hardware Fabrication
- Operational Experience Over 100Hours
- Software Development
  - Manual Operation Implemented
  - Process PID Loops Developed



Accomplishments To Date

- Hardware Fabrication
- Operational Experience Over 100Hours
- Software Development
- Catalyst Developments
  - Three Advanced Shift Catalyst Tested
  - Autothermal Reform Catalyst Tested

Prototype F3P Assembly Configuration

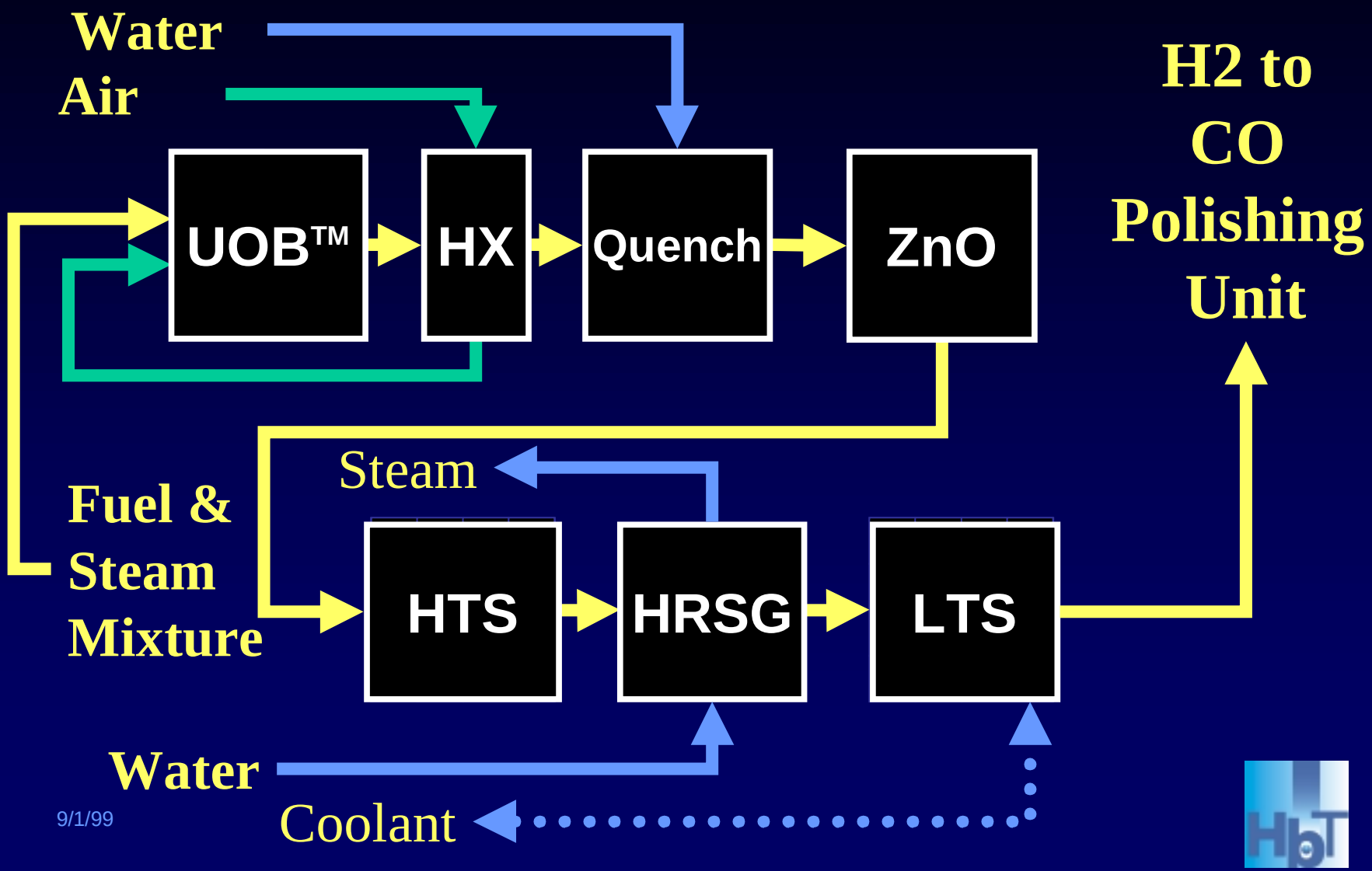


Top View with Test Frame

Side View with Test Frame

Prototype summary
- **230 LB at 38kW Demo.**
- **350W/kg Verified**

Integrated F^{3}P Assembly

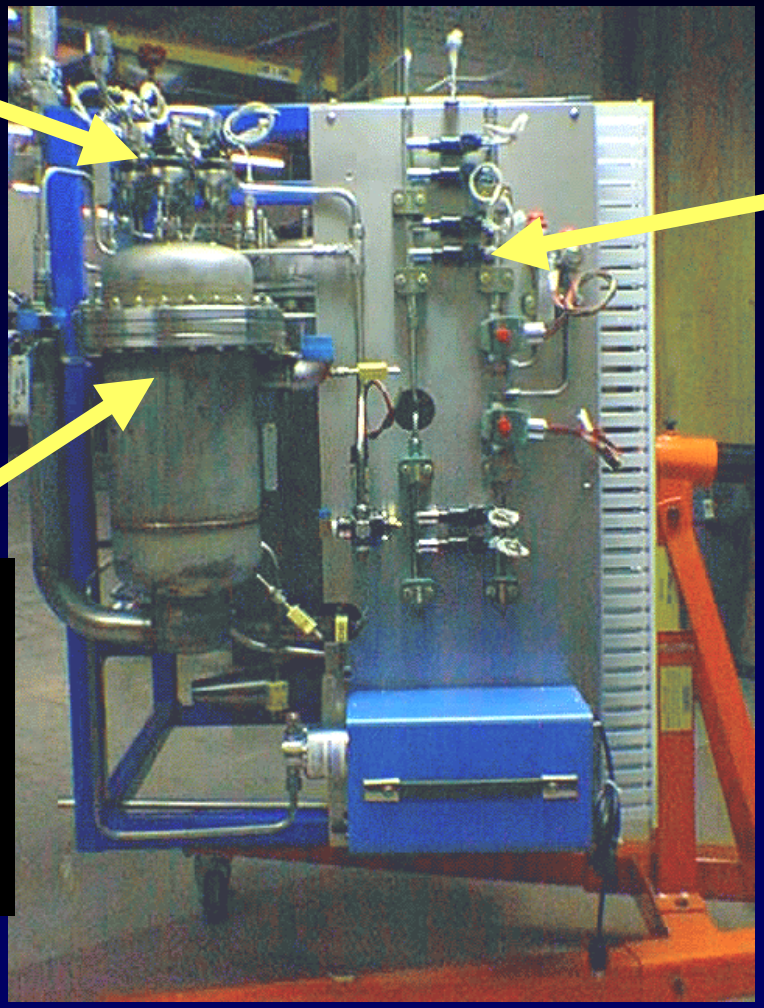


Hardware Fabrication

- One Set of 3 F3P Subsystems Completed
  - DOE/HBT Prototype (12/98)
  - Automotive Manufacturer (3/99)
  - LANL Prototype (5/99)
- Second Set of 3 F3P Subsystems in Process
  - Fuel Cell Integrator A (POX) (8/99)
  - Fuel Cell Integrator A (Autothermal) (10/99)
  - Fuel Cell Integrator B (11/99)
- Third Set of F3P Subsystems on Order
  - DARPA Project (1 units) (TBD)
  - CECERT (1 units) (12/99)
  - DOE Pre-Commercial (1 unit) (12/99)

Simplified Control Concepts

Digital
Fuel Control
Valves



Low Cost
Pulse Width
Modulating
Water Flow
Control
Valves

Integrated
Anode-Off
Gas Oxidizer
and Vaporizer

Operating Experience Summary

	S/N 001	S/N 002	S/N 003	S/N 004
Customer	HBT DOE	Auto MFG	LANL	FC Devel.
Fabrication	12/30/99	2/20/99	3/9/99	7/1/99
Delivered	1/1/99	3/5/99	5/28/99	TBD
Runs	26	11	13	11
Operating	36 Hrs	18 Hrs	24 hrs	46 hrs
Fuels	NG, Gasoline	NG, Gasoline	NG, Gasoline, Methanol	NG

Fuel Flexibility Comparison

Fuel Type	Target, % dry	Status, % dry
– Methanol	– > 40%	– 40%
– Ethanol	– ~ 40%	– Not Tested
– Natural Gas	– ~ 35%	– 33% (45%)
– Gasoline	– ~ 35%	– 31%
– Kerosene	– ~ 35%	– Not Tested
– Diesel	– ~ 33%	– Not Tested

Summary Verification Status

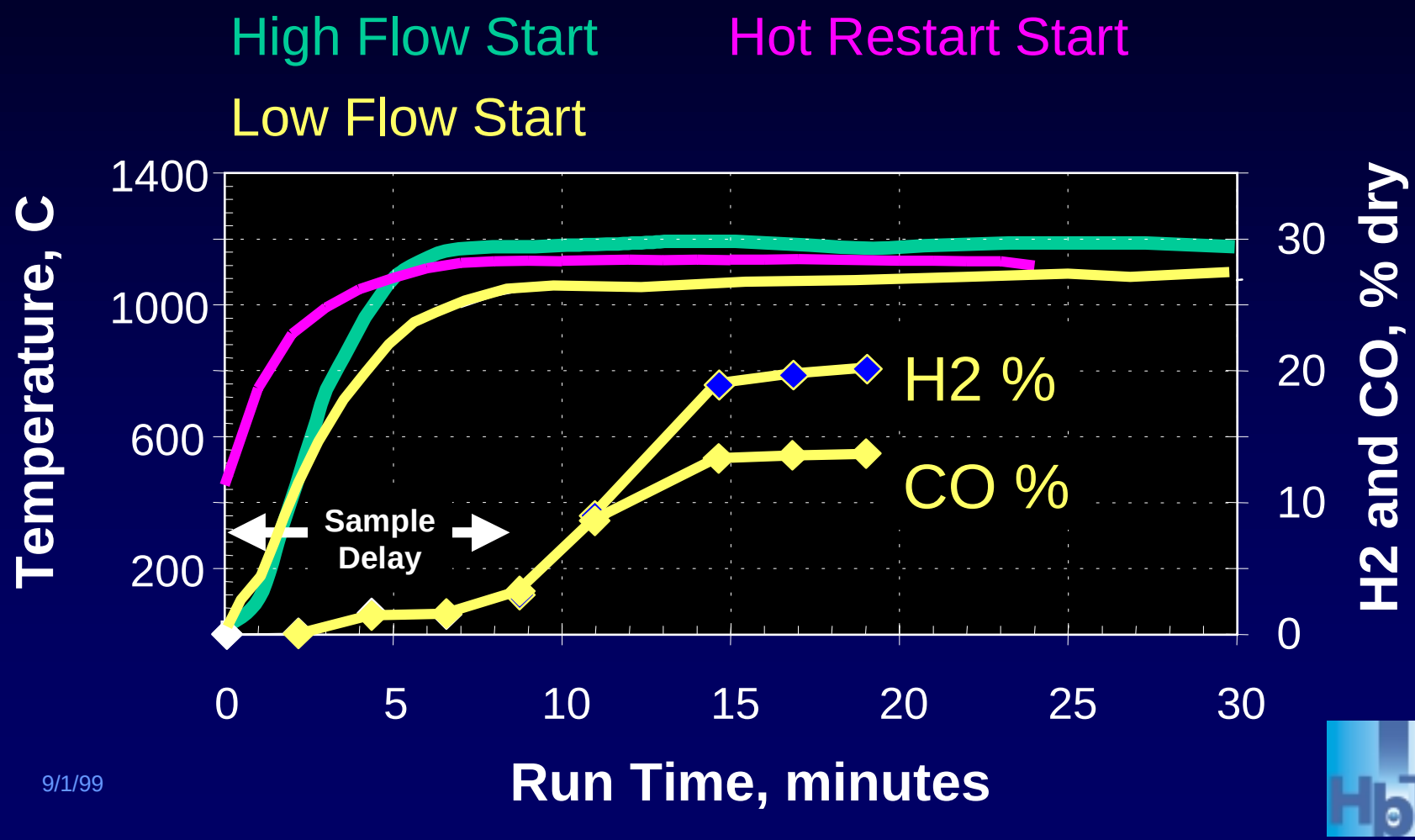
	Methanol	Nat. Gas	Gasoline
Minimum SR	0.33	0.40	0.42 - 0.45
Efficiency	<76%	~70%	~68%
Max H_2, %dry	40%	33%	30%
Min CO, (LTS only)	0.3 to 0.1%	0.4 to 0.1%	0.5 to 0.1%
Max Capacity, kWe***	38kWe	25kWe	20kWe

* Note preliminary performance based on ~ 100 hrs operation.

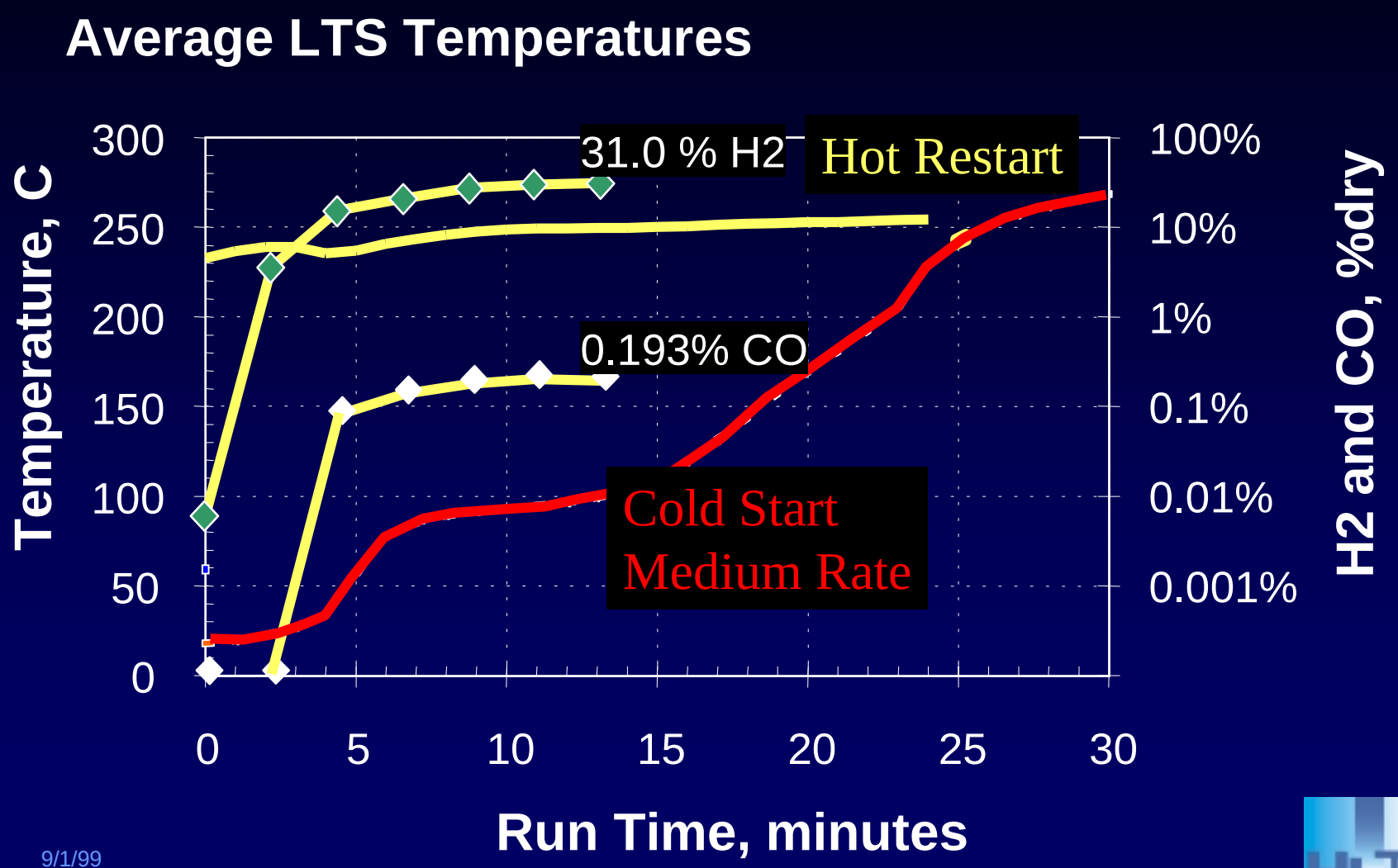
*** Estimated Capacity based on Fuel Consumption and H2 Concentration.

UOB™ Start Up Characteristics

UOB™ Reactor Temperatures



Comparison of Start-Up Tests



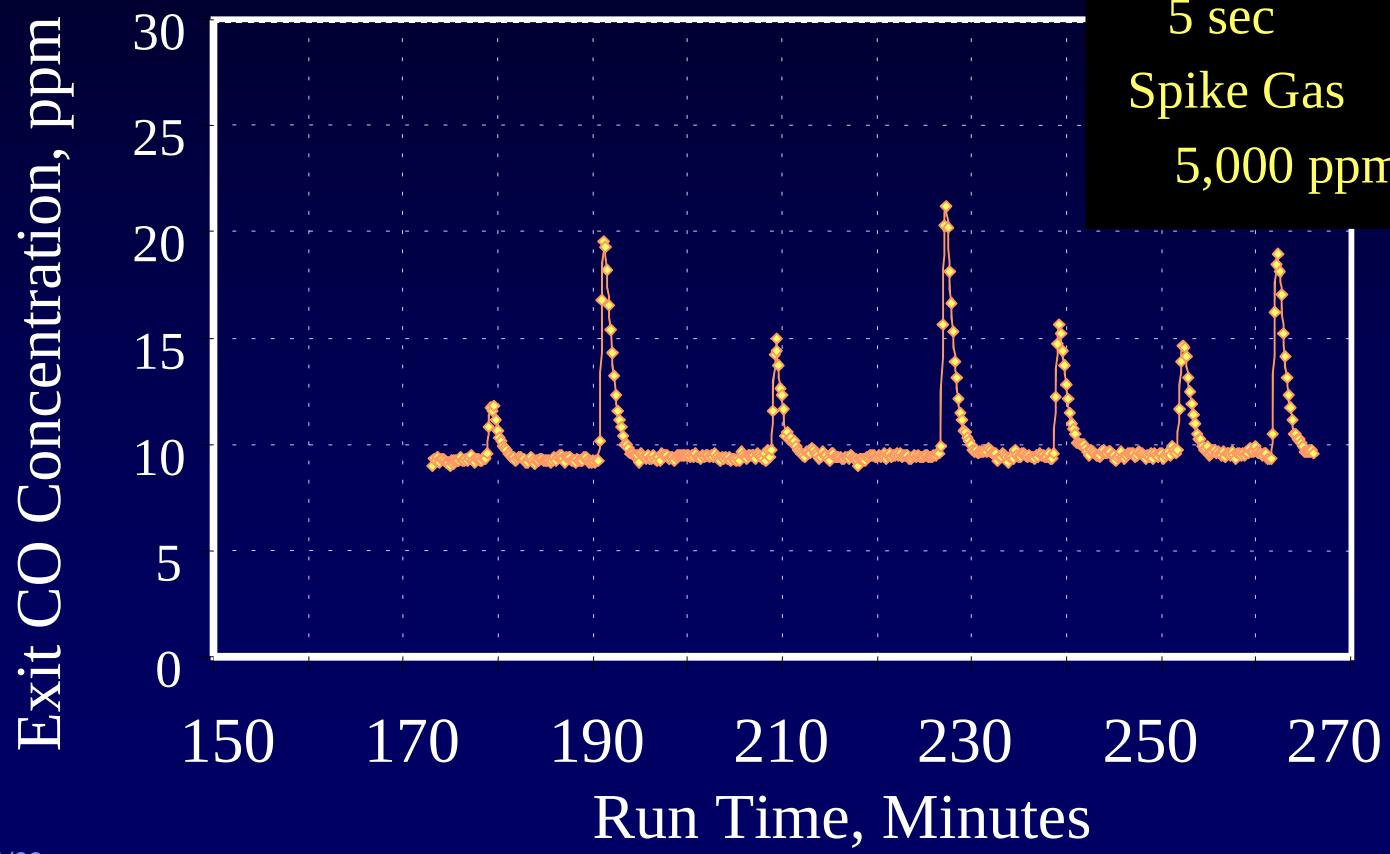
CO Polishing Testing

- Three Hardware Concepts Being Evaluated
- Preliminary Testing Conducted on Methanation
- PROX Reactor to be Tested in September 99

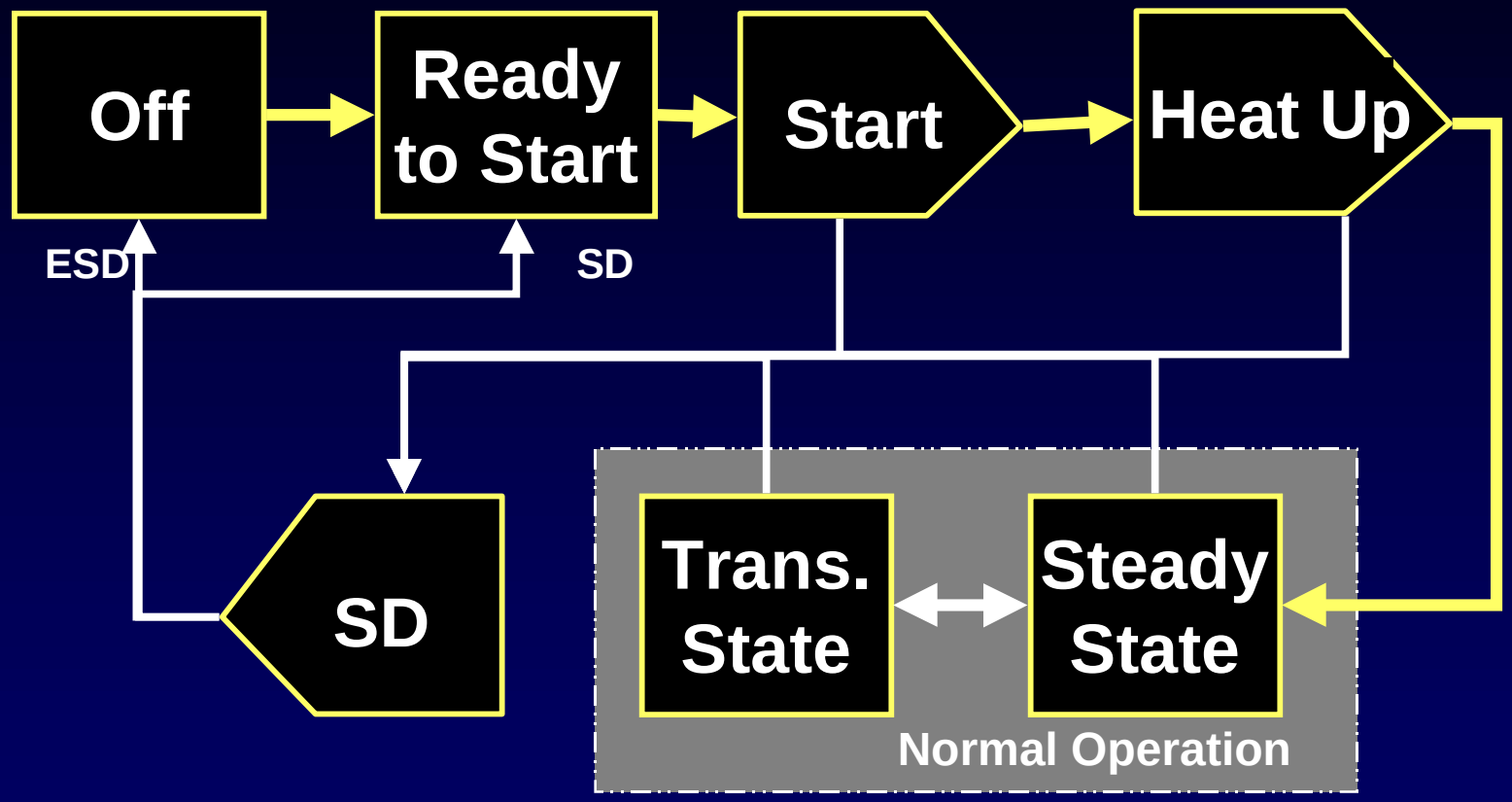
Methanation Response to Spike

Institute of Gas Technology Results

Spike Duration
5 sec
Spike Gas
5,000 ppm CO



Automatic Control Logic Structure

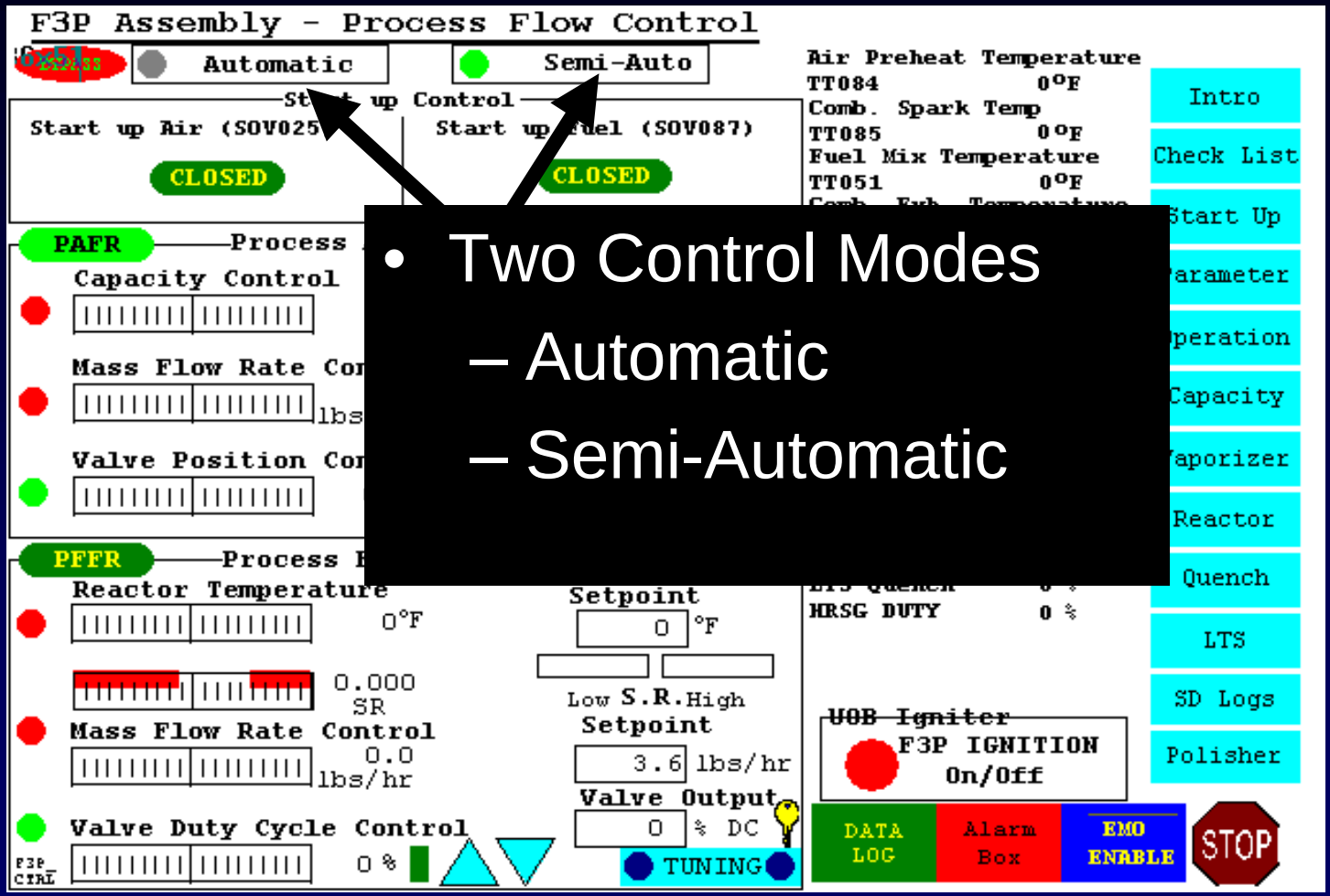


Continuous Stage

Temporary Stage

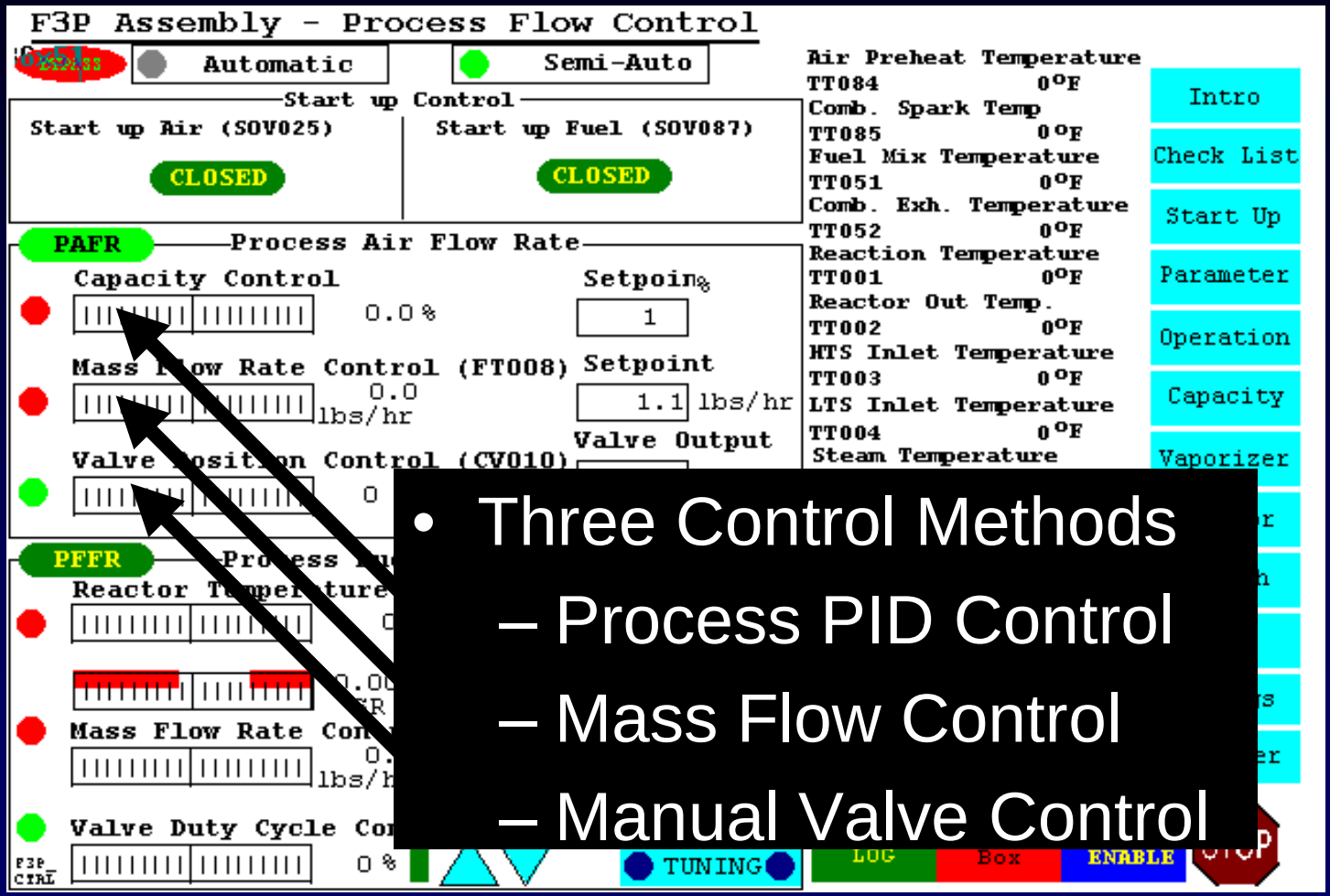
Transition Between Stages

Control Interface Screens



- Two Control Modes
  - Automatic
  - Semi-Automatic

Control Interface Screens



- Three Control Methods
  - Process PID Control
  - Mass Flow Control
  - Manual Valve Control

Autothermal Reforming Catalyst

- Standard F3P Hardware Configuration
- Simple Modification
- Catalyst Provided by Engelhard Corporation
- Initial Testing
  - 10 runs & 20 Hrs
  - 42% to 50% H_2 Equivalent
  - CH_4 Slip 1-6% Range
- ATR Subsystem to be Delivered 10/99

Summary and Conclusions

- F3P Subsystem Development Effort
  - Established the Process Integration Issues and Opportunities
  - Verified On-Board Hardware Operational Characteristics
  - Evaluated Automotive Subsystem Needs and Criteria
  - Identified Advanced Concept Hardware and Packaging Approaches