Fuel Cell Reformer Emissions

2003 Hydrogen and Fuel Cells Merit Review Meeting

Berkeley CA

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Work in Progress

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The purpose of this study is to determine the emissions from fuel cell vehicles with on-board reformers

- Fuel cell vehicles must meet the most stringent emission standards in order to provide value to the greatest number of stakeholders
- Quantifying emissions from reformer systems needs to take into account very low detection limits in order to verify emission benefits
- Data from fuel processor systems is used to evaluate potential emissions from vehicles with on-board fuel processors

DOE Technical Targets: Integrated FC Fuel Processor System
Operating on Tier 2 Gasoline (30 ppm S)

Characteristics	Units	Calendar year		
		2003	2005	2010
Energy efficiencya @ 25% of rated power	%	34	40	45
Energy efficiency @ rated power	%	31	33	35
Transient response (time from 10 to 90% power)	sec	15	5	1
Emissions [a]	g/mi	< Tier 2 Bin 5, 0.07 NOx and 0.01 PM		

a Emissions levels will comply with emissions regulations projected to be in place when the technology is available for market introduction.

DOE R&D Plan

Fuel Processor Technical Barrier K: Emissions and Environmental Issues. Data on the effects of fuel/fuel blend properties on the potential formation of toxic emissions are limited. Fuel processor and stack emissions (including evaporative emissions) are not adequately characterized. Standardized emission test procedures are lacking. Start-up emissions are not well characterized.

Prior to finalizing our analysis, we intend to obtain input from a range of potential stakeholders in both conventional and hydrogen fuel chains.

Task		FY02				FY03				
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
1	Test Planning									
2	Nuvera, Gasoline B System ATR									
3	McDermott, Gasoline ATR									
4	Nuvera, Ethanol ATR - PEMFC									
5	Nuvera Gasoline Star System ATR									
5	On-road emissions evaluation									
	Milestones									

Nuvera Gasoline B FP Pretest and Test

McDermott Gasoline FP Test

Nuvera Ethanol Test

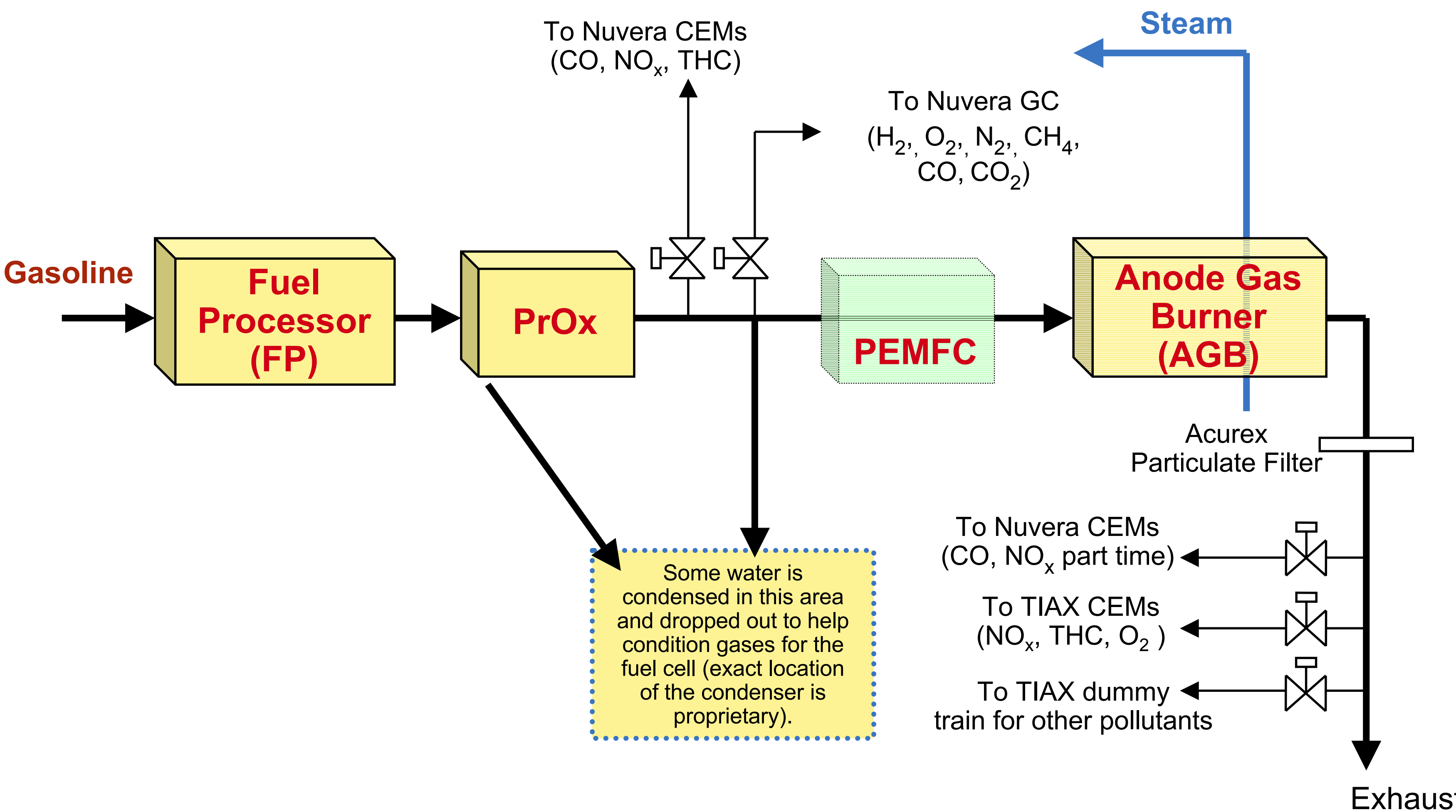
Nuvera Star Test

Draft and Final Report

Four fuel processor systems will be tested.

System	Date Tested	AGB Feed	Power Rating
Nuvera, Gasoline B System ATR	October 2000	Gasoline Start-up PrOx Reformate (100% output)	50 kWe
McDermott, Gasoline ATR	September 2002	Gasoline	50 kWe Tested @ 10kWe PrOx
Nuvera, Ethanol ATR - PEMFC	January 2003	Ethanol Start-up PEMFC Anode Gas	10 kWe
Nuvera Gasoline Star System ATR	June 2003	Gasoline Start-up PrOx Reformate	50 kWe

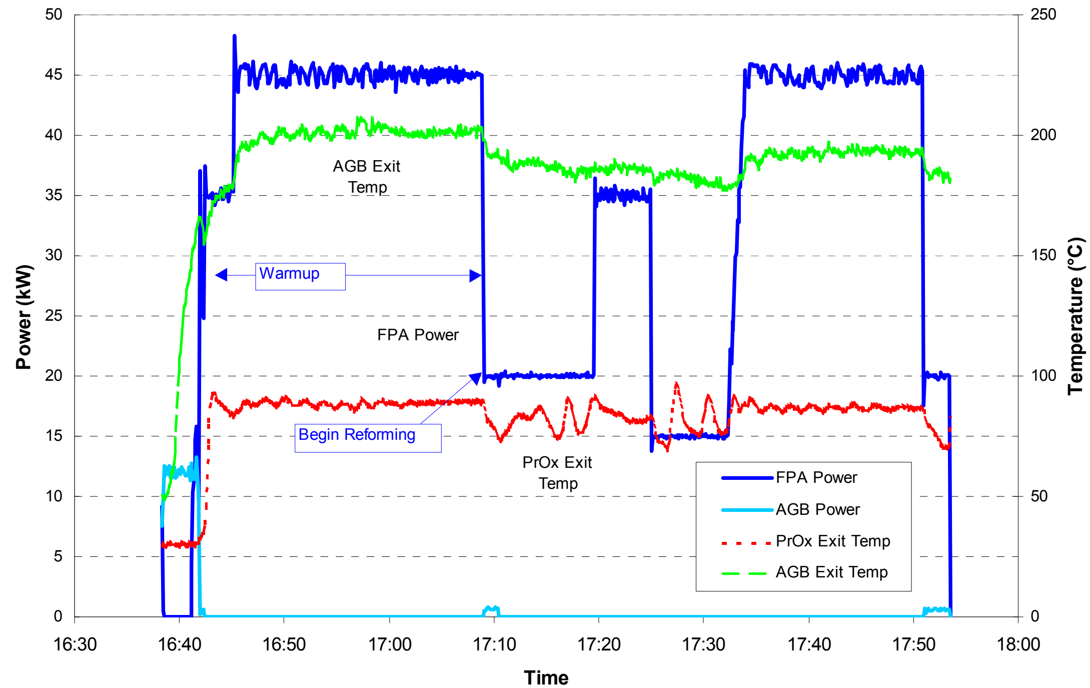
The Nuvera system was tested after the PrOx and after the AGB, without a fuel cell.



One test was completed in October 2000

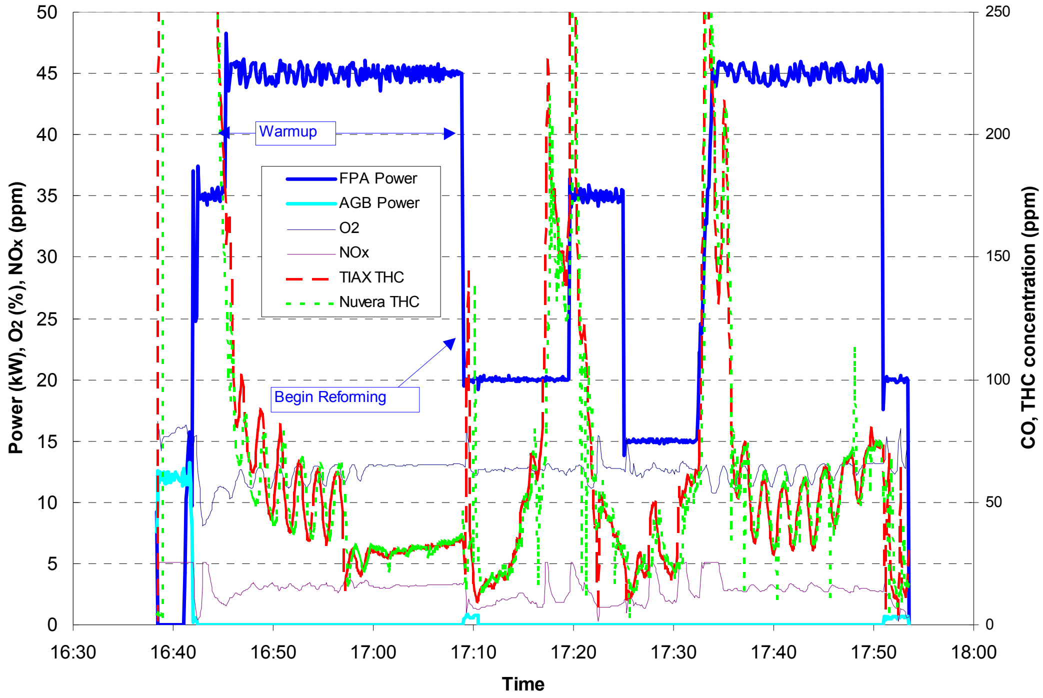
Test Cycle

- Initial AGB warmup to 150°C
- FPA heatup
  - PrOx exit to 90°C
  - AGB exit to 200°C
- FPA load
  - 20 kW initial
  - Rapid increase to 35 kW
  - Rapid decrease to 15 kW
  - Gradual increase to 45 kW
  - Gradual decrease to 20 kW



AGB Emissions

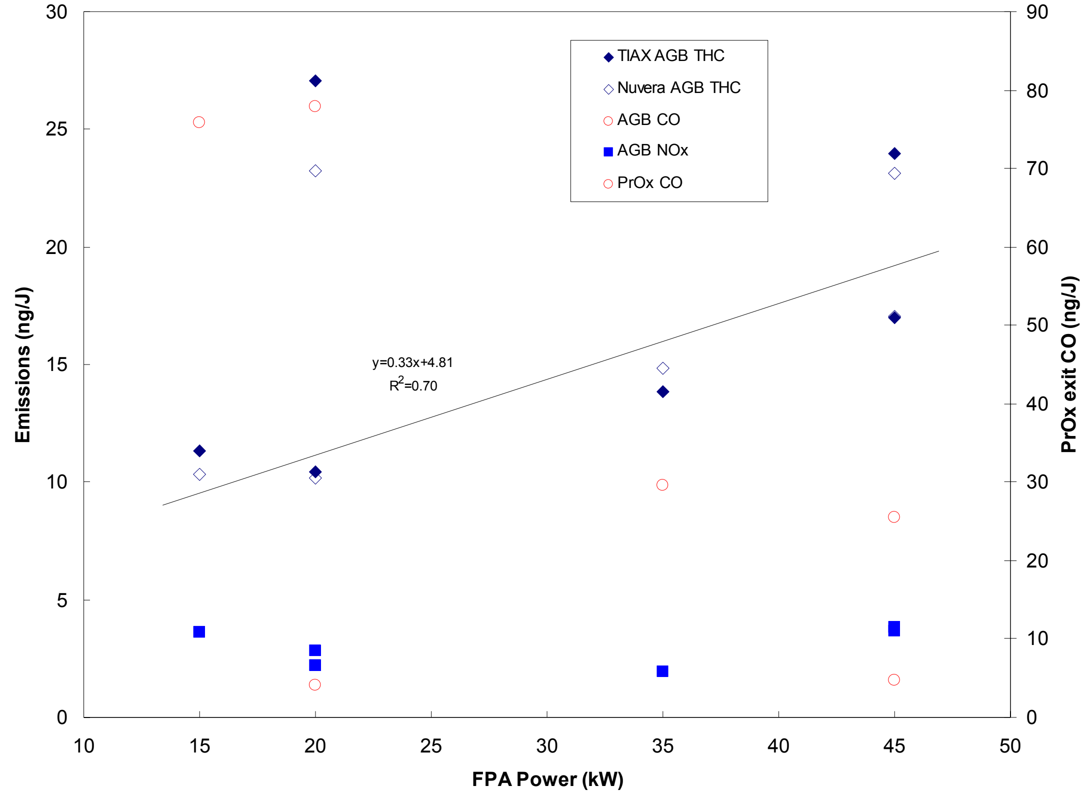
- AGB exit THC: TIAX and Nuvera instruments agree
- AGB exit NO_x
  - Pegs low level monitor (5 ppm) during AGB warmup
  - Nominally 3 ppm throughout remainder with a few spikes
- AGB exit O_2
  - Above 15% during AGB warmup
  - Nominally 12.7% throughout remainder
  - Cyclic during early FPA warmup, rated load operation
  - THC & NO_x cycles follow: dilution



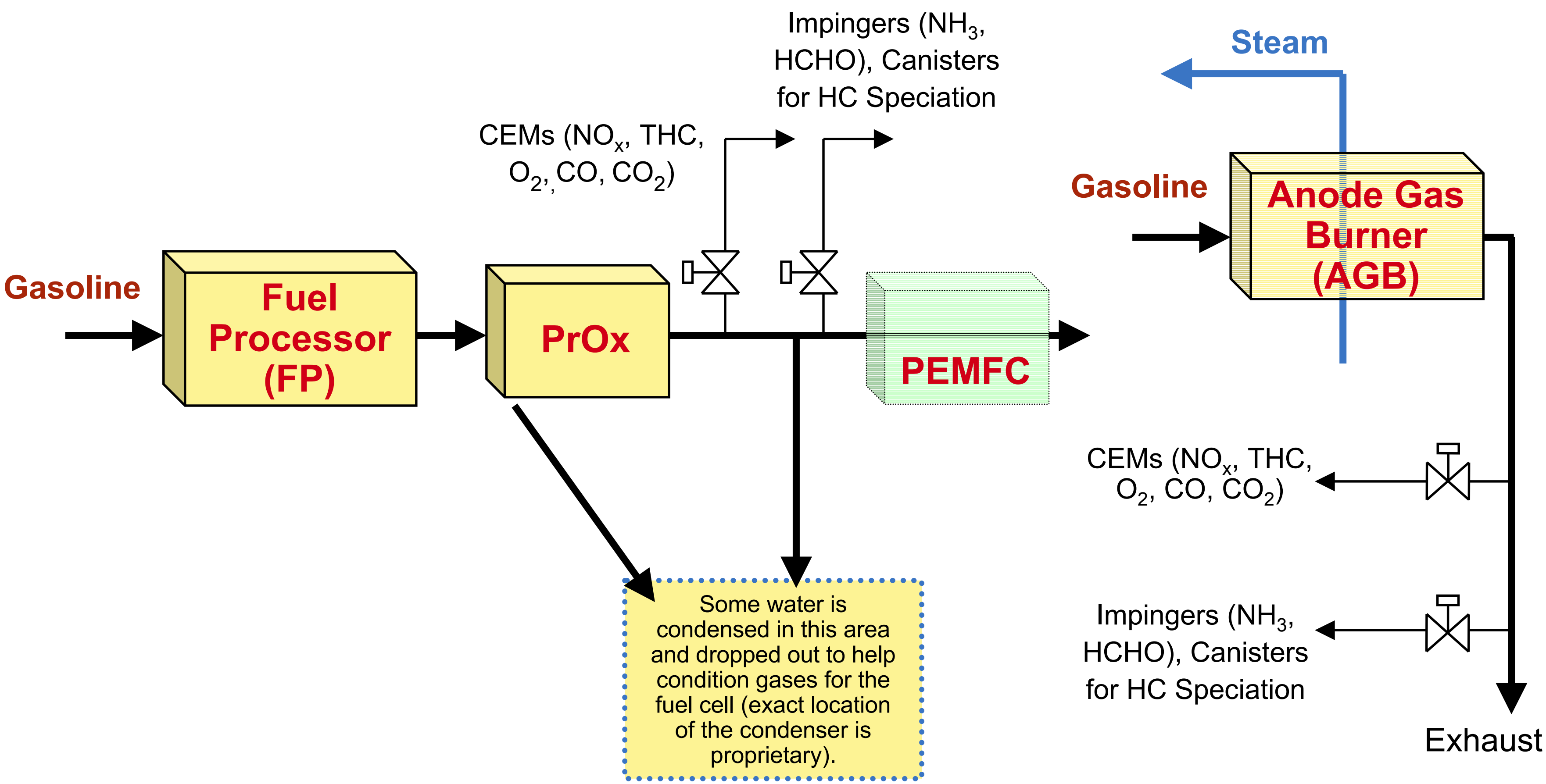
Nuvera Test Results Steady Operation Emission Rates

Emission rates (ng/J)

- AGB NO_x emissions low & invariant with load, 3.0 ng/J
- AGB CO emissions low & invariant with load, 1.5 ng/J
- AGB THC emissions appear to increase with FPA load
  - Ignoring high initial 20 kW result, acceptable linear correlation



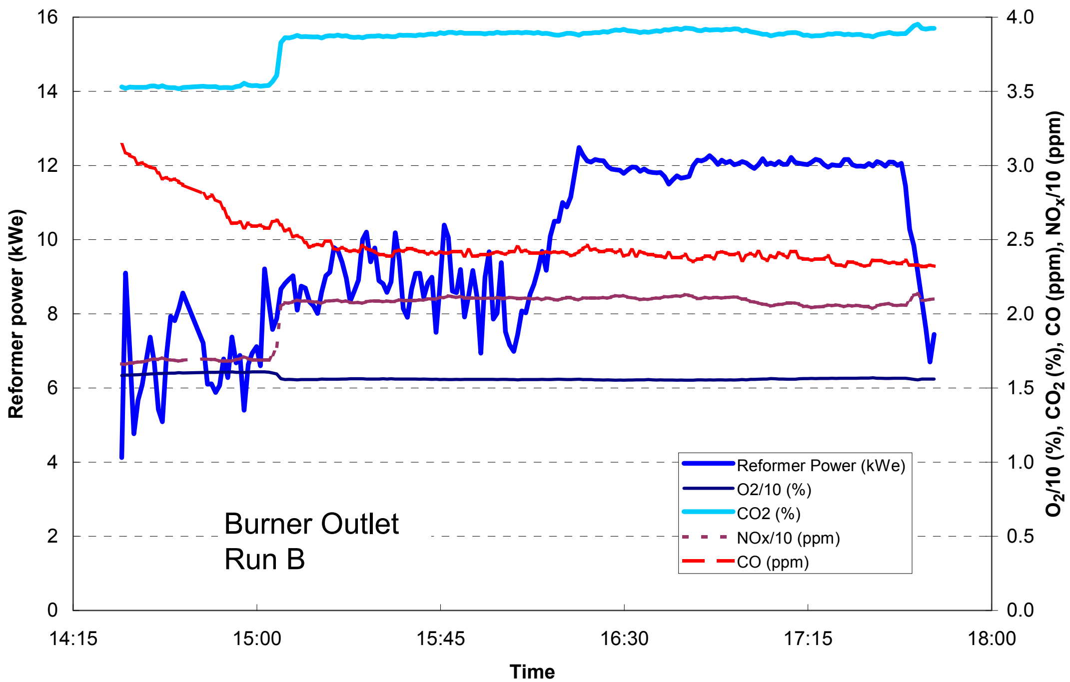
The MTI fuel process was tested at the PrOx exit. The AGB burned gasoline which provides data that reflects startup conditions.



MTI Test Results AGB Outlet Run B

AGB Emissions

- After 15:00
  - O_2 steady at 15.5%
  - CO_2 steady at 3.9%
  - NO_x steady at 20 ppm
  - CO steady at 2.4 ppm
  - THC less than the monitor detection limit of 0.2 ppm



On-road emissions will be modeled based on driving cycle energy requirements and start up energy.

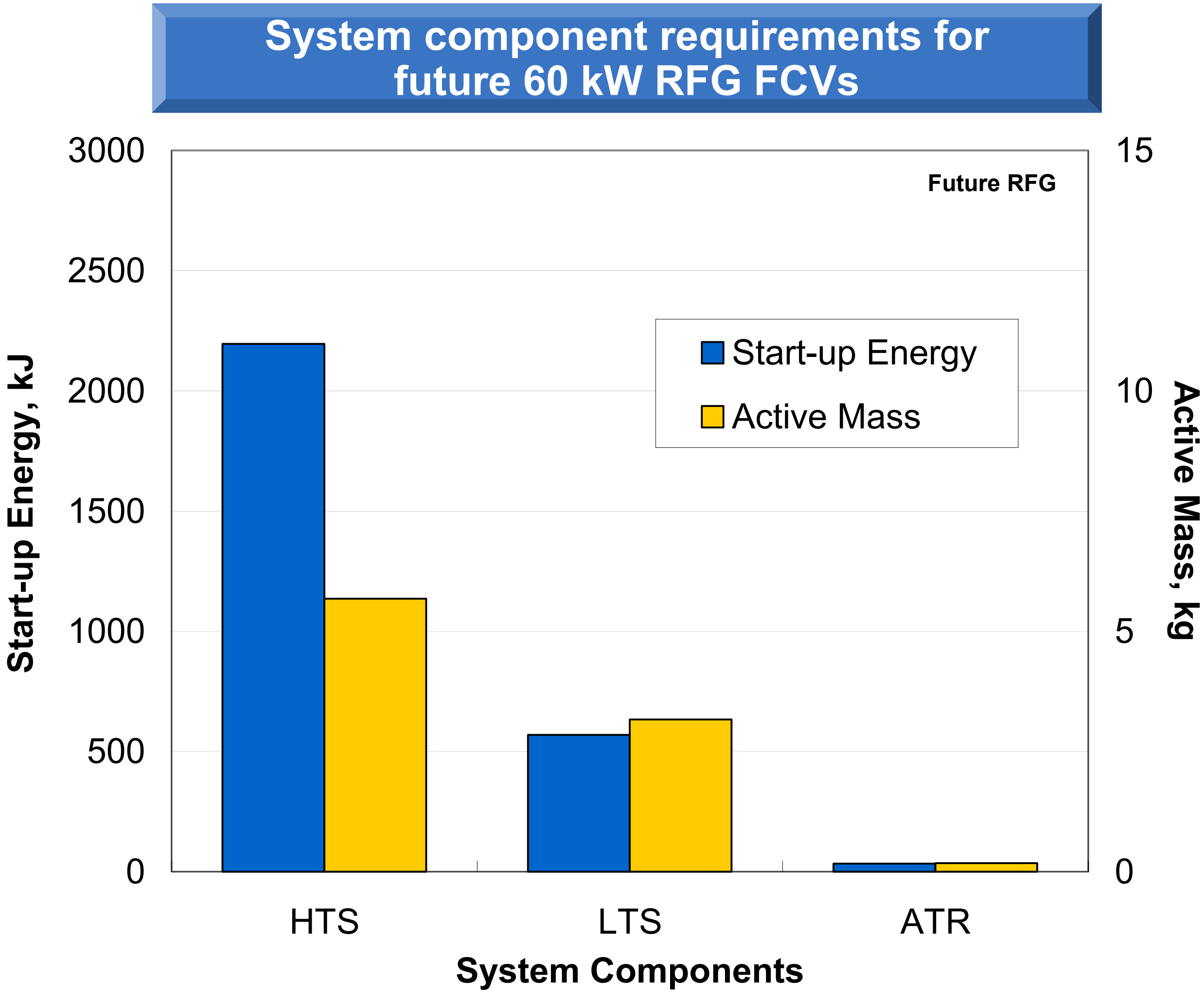
- NOx and CO should meet the lowest emission standards
- A key target should be the CA PZEV NMOG standard for NMOG of 0.01 g/mi and NOx standard of 0.02 g/mi
  - Depends on start up energy and start up emissions
  - Some emission control during reforming may also be required
- A quick emissions example
  - During reforming
  - 5 ng/J x 1,800,000 J/mi = 0.009 g/mi
  - During startup
  - 500 ng/J x 1,700,000J/25 mi = 0.03 g/mi
  - Total = 0.039 g/mi
- **Calculations are illustrative only**

Start-up energy demand represents a significant portion of the energy for FCVs with on-board reformers.

- TIAX modeled energy inputs based on catalyst volume, heat capacity, system mass, and operating temperature
  - Start-up energy requirements are dictated by the energy input to the catalyst beds
  - Fuel cell generates power with hydrogen feed, even at low temperatures, so no start-up energy input is required
- Start-up energy inputs may need to occur twice a day for typical driving and represents up to 10 percent of the drive-cycle energy
  - Significant mass reductions in the fuel processor catalyst beds are projected

Energy requirements for future RFG ATR and Methanol SR FCVs					
Fuel Processor, power unit size		Active Mass, kg	Start-up Energy, kJ	City Drive-cycle, kJ	Hywy Drive-cycle, kJ
RFG ATR	60 kW	9.0	2,800	17,700	21,900
	38 kW	5.7	1,770	15,600	20,600

The start-up energy requirement for system components decreases with active mass.



Starting the entire ATR represents a large fraction of the energy on a typical drive-cycle. Partial start-up of hybrids will reduce energy use.

- Partitioning the catalyst beds into 4 independent systems can improve turndown and cold start
  - Partial start-up on 25% of the HTS reduces start-up energy (with a partitioned reformer)
  - Applicable to hybrid configurations where batteries can power the vehicle
- Waste heat from the ATR system and anode gas can be used to warm up the remainder of the HTS

Energy requirements for future RFG ATR FCVs					CAFÉ Fuel Economy mpg
Fuel Processor, start-up fraction		Start-up Energy, kJ	City Drive-cycle, kJ	Hywy Drive-cycle, kJ	
RFG ATR, 60 kW	100%	2,800	17,700	21,900	45.6
RFG ATR, 38 kW Large Battery Hybrid	100%	1,770	15,600	20,600	52.2
	25%	440	15,600	20,600	56.1

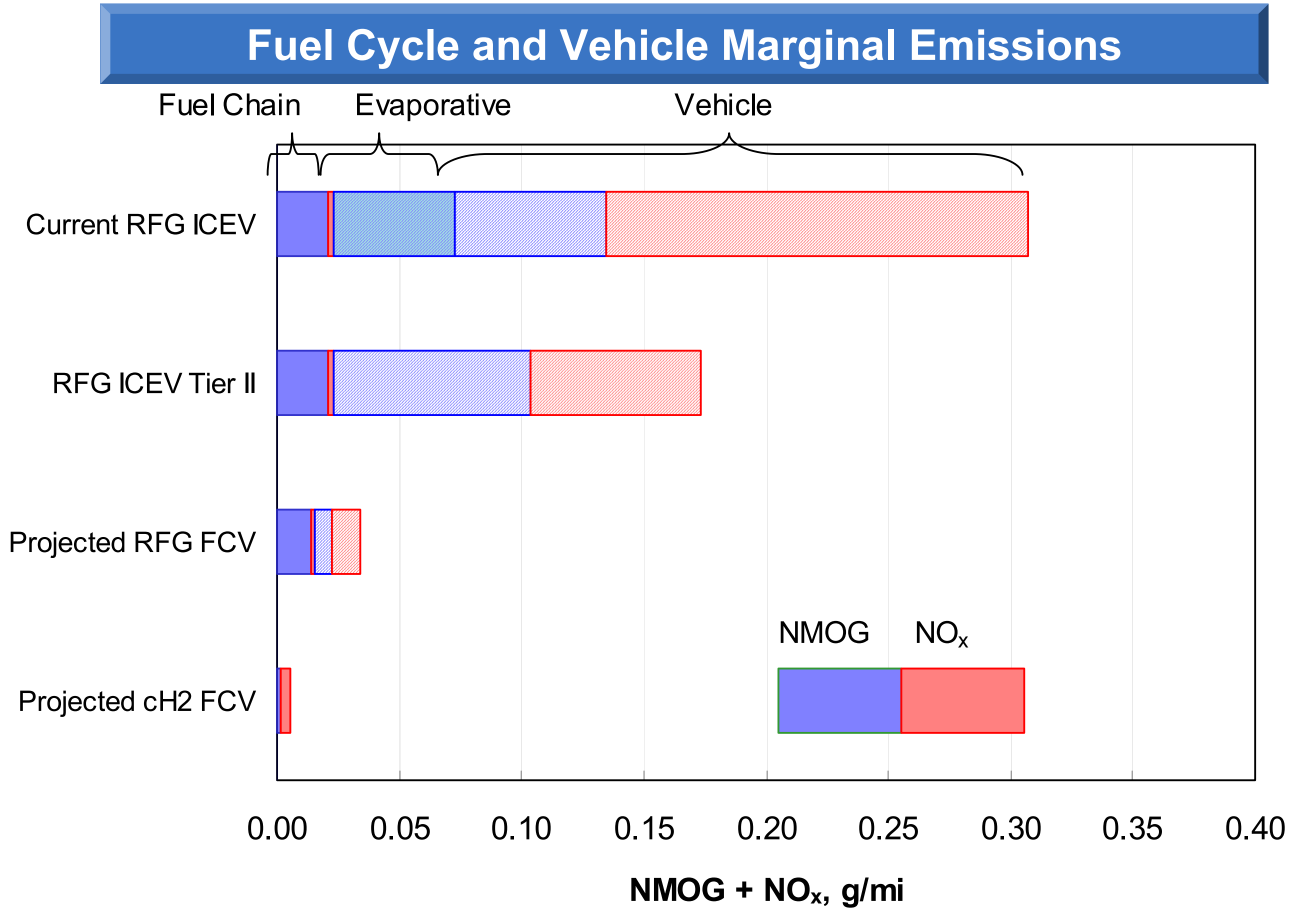
Partitioned start-up saves fuel

ICEV emissions are projected to meet aggressive new standards. FCVs can also meet these standards if start-up emissions are controlled.

Vehicle	NMOG, g/mi		NO_x, g/mi	PM, g/mi
	Tailpipe	Evaporative	Tailpipe	Tailpipe
PNGV Goal/ CA LEV Standard[1]	0.08	2 g/test	0.07	0.01
PZEV Standard	0.01	0.0	0.02	0.01
CA MY 2002 On-road[2]	0.062	0.049	0.173	❾0.01
PZEV On-road	0.0065	0.0164[3]	0.024	❾0.01
RFG ATR FCV[4]	0.0065	0.0164[3]	0.012	❾0.01
cH2 NG SR FCV	0	0	0	0

[1] Emission standards represent maximum emission levels over the vehicle life. Tailpipe emissions are tested over the FUDS cycle. For PZEVs, the emission standards apply for 150,000 miles.
[2] On-road projections take into account reduced levels needed to meet in-use compliance, deterioration, as well as a mix of hot and cold start events and driving conditions.
[3] Inventory values are based on detection limits for certification testing. Actual levels may be lower.
[4] ATR FCV emissions are projections based on the assumption that cold-start emissions can be controlled to similar levels as ICEVs. Operating NMOG and NO_X emissions from reformer tests are near PZEV levels.

FCVs could provide the lowest overall criteria pollutant emissions, especially direct hydrogen.



"Current RFG ICEV" results are based on the inventory for California 2002 model year vehicle inventory values and fueling station requirements.

If development goals are met, next generation fuel processor/fuel cell systems should be tested. Emissions from APUs and stationary hydrogen systems should also be characterized.

Future Work	Challenges
Measure emissions from stationary hydrogen generation systems	• Find developers interested in quantifying both start up and continuous emissions and assessing operational profiles
Measure emissions from promising APU technologies	• Few small scale APUs which reflect future commercial products are available
Characterize N_2O and other pollutant emissions	• Low detection levels and background emissions
Measure emissions from next generation fuel cell/fuel processor systems	• Limited availability of developed systems

Inputs from regulatory agencies and other stakeholders have been solicited as input to the project.

Outreach Efforts

- Participated in International Energy Agency Annex XV
- Made presentations on environmental impacts to CA Air Resources Board
- Submitted Paper to Dec '03 Fuel Cell Seminar