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Automotive Test Systems

Emissions Testing Solutions for Hybrid Vehicles

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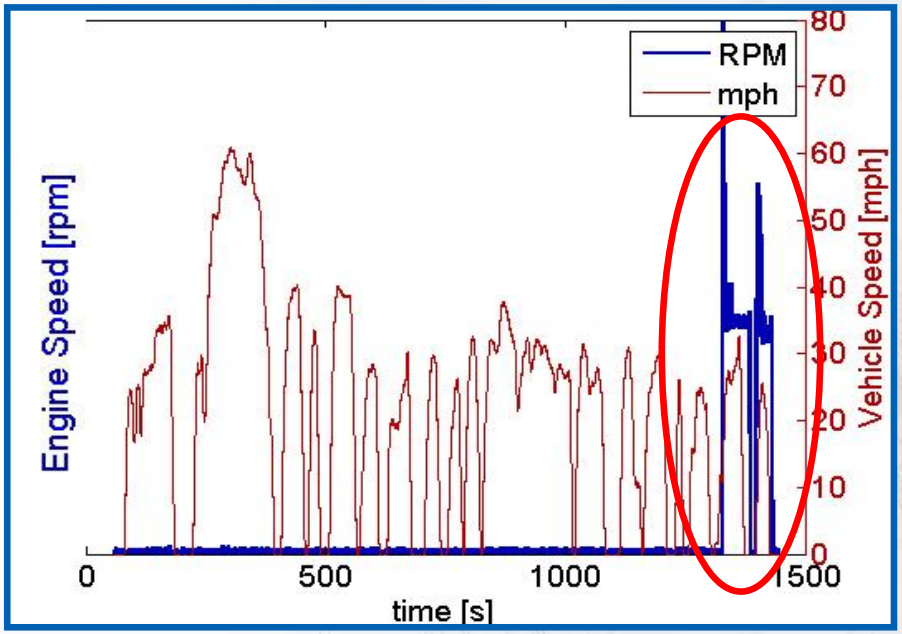
Horiba Automotive Test Systems

CVS & BMD Performance

- **HEV Vehicles respond like Standard Vehicle. (achieve charge balance during a standard FTP test)**
- **PHEV Emission Measurement has significant limitations in a Chassis Dynamometer Test Cell.**
- **First PHEV engine start occurs at very end of UDDS test cycle**



DOE/ANL PHEV tests with a CVS

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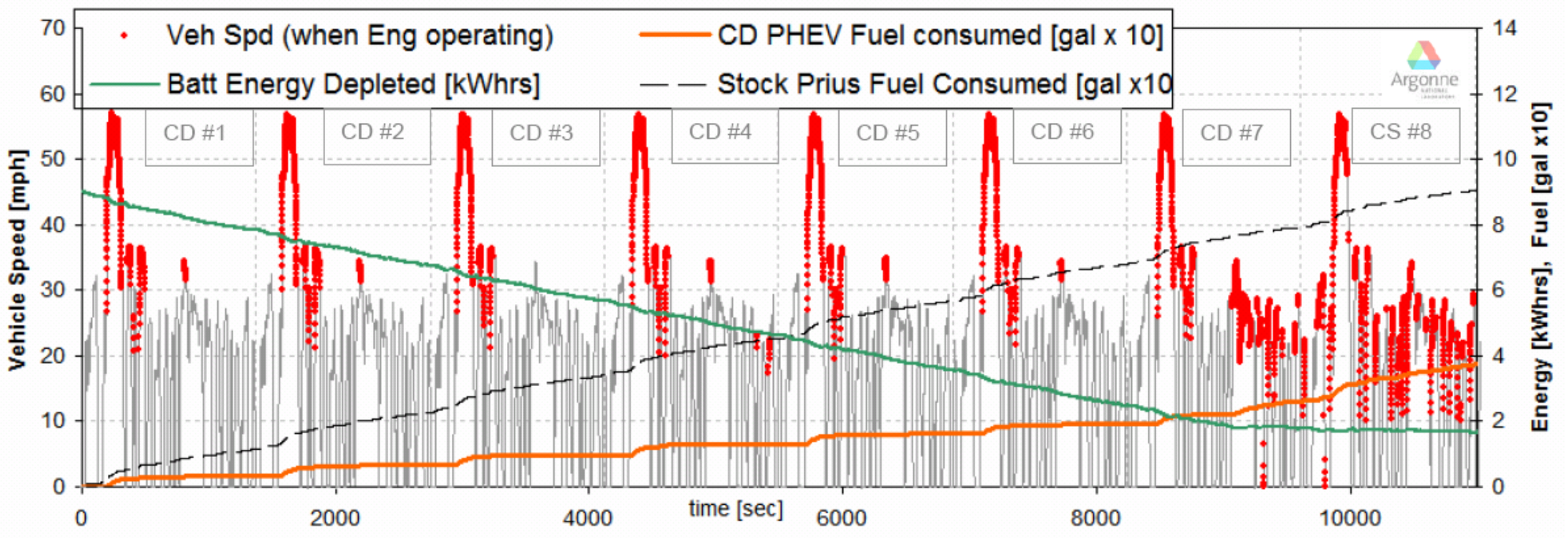
PHEV Fuel Economy measured with a standard CVS is 215 mpg to 240 mpg during CD UDDS.

SAE 2007-01-0283 Carlson, et al.



UDDS	#1	#2	#3	#4	#5	#6	#7	#8
Fuel Economy [mpg]	215	221	242	223	240	239	104	69.7
Elec Consump [DC Wh/mi]	159	147	146	143	145	147	92.4	16.6

Simulated PHEV

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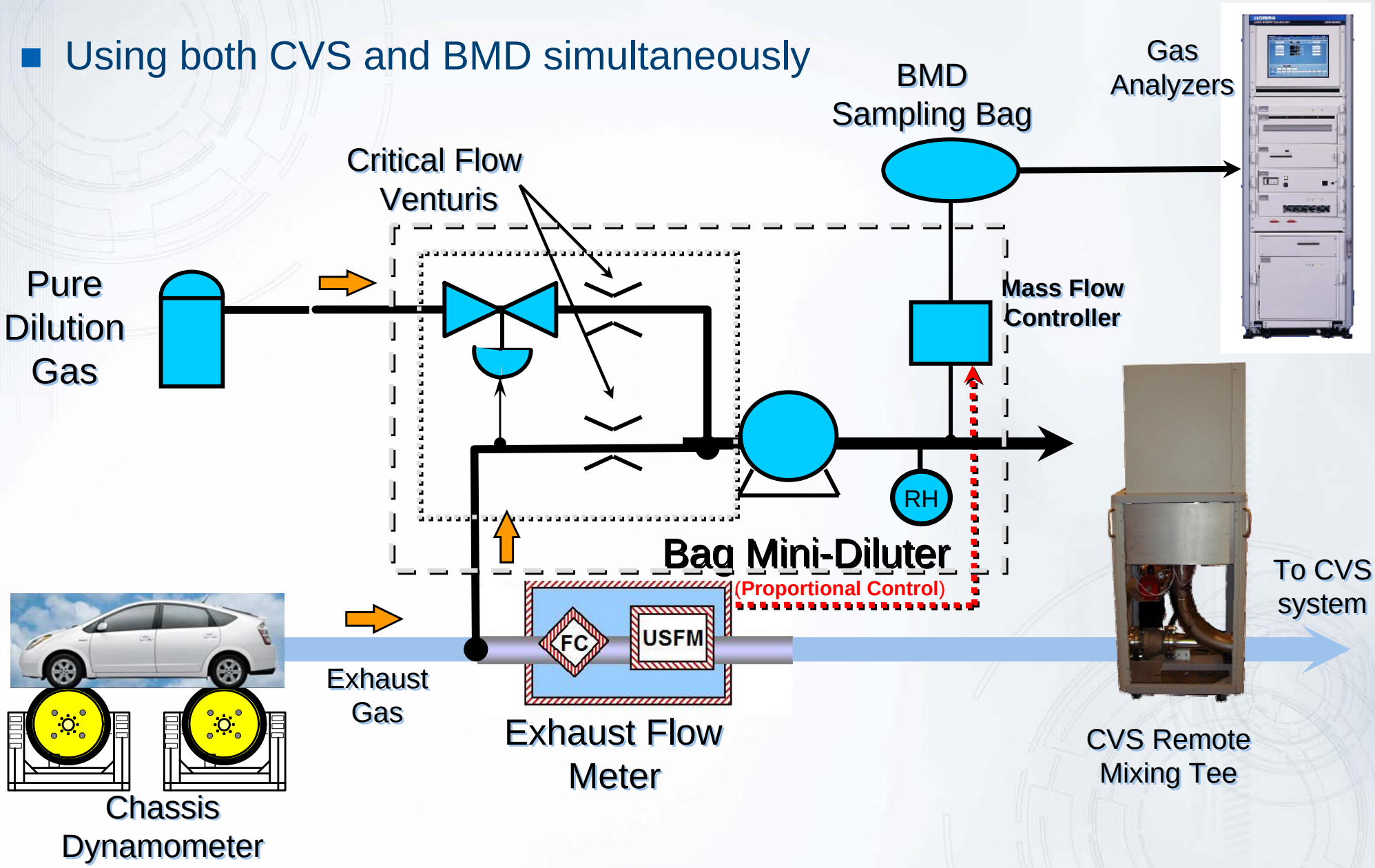
Initial Investigation

- 3.8L conventional vehicle on chassis dynamometer
- FTP 505 test procedure
- BMD operated in series with CVS
- Simulated PHEV ICE operation.
  - Manually start and stop engine: 15 seconds
- Compare BMD and CVS emissions

PHEV Testing

- Using both CVS and BMD simultaneously



CVS Test Data

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CVS bag data						
	THC	CO	NOx	CO2	Fuel Economy	
grams/phase	0.768	3.595	0.052	48.930	64.308	mile/gal
grams/mi	1.822	8.532	0.124	116.128	3.658	L/100km
grams/km	1.132	5.301	0.077	72.159		

CO2 data		
Range	3.0	%
Sample	0.081	%
Ambient	0.051	%
Net	0.030	%

BMD/CVS data		
CVS DF	154.757	
V mix	74.880	m3
Md Exh Vol	0.261	m3
WCF	1.020	

CO2 = 0.03% net
On 3% range

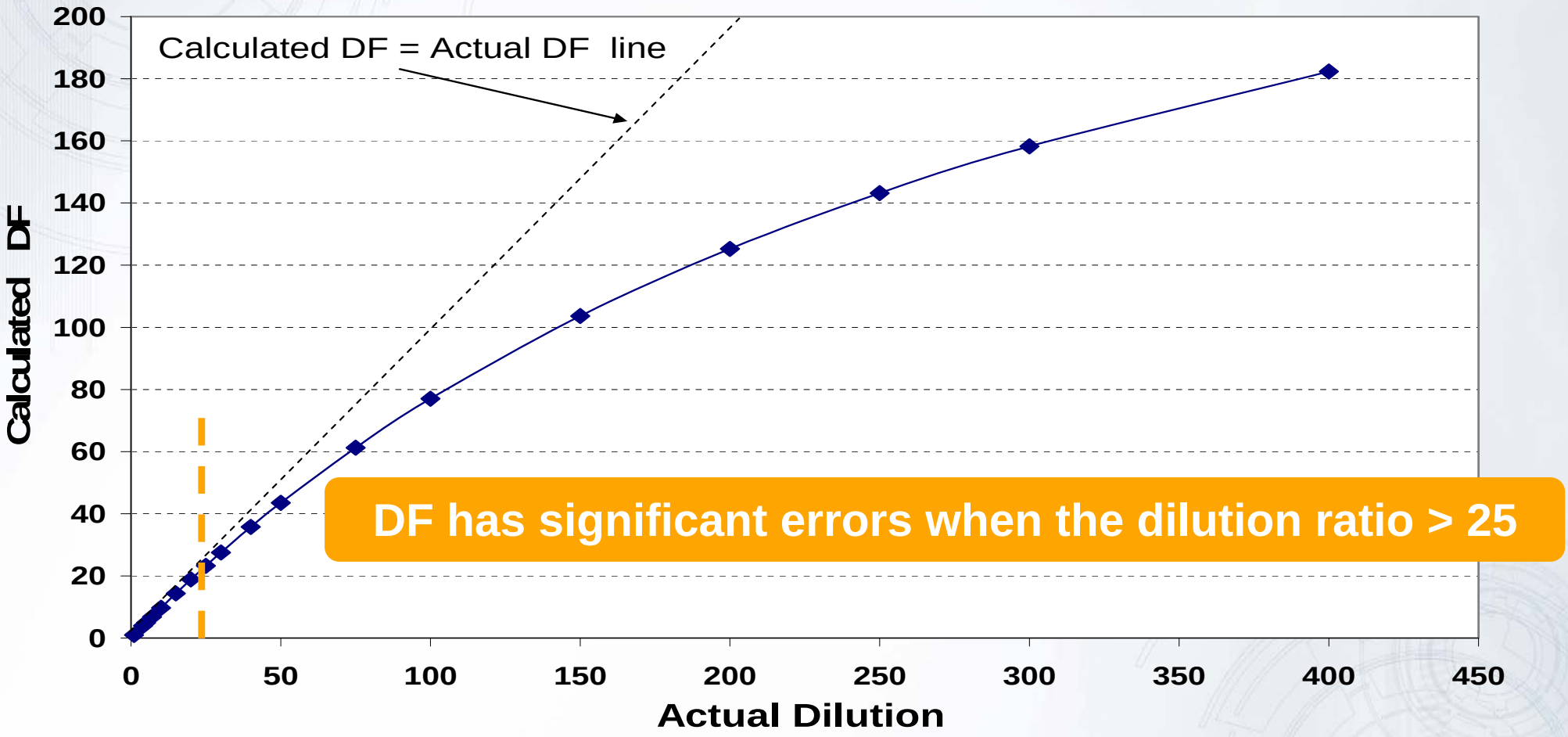
DF = 154.76
Calculated according to CFR

Actual DF= (V mix /Md Exh Vol) +1 = (74.88/0.2605)+1 = 288.4

SAE 2010-01-1295 Nevius, et al.

CVS DF Calculation error

SAE 2010-01-1295 Nevius, et al.



Actual Dilution ratio as measured with ultrasonic flowmeter

BMD Test Data

BMD bag data							CO2 data		
	THC	CO	NOx	CO2	Fuel Economy		Range	3.0	%
grams/phase	0.212	1.502	0.002	21.109	156.375	mile/gal	Sample	0.669	%
grams/mi	0.503	3.565	0.006	50.098	1.504	L/100km	Ambient	n/a	
grams/km	0.313	2.215	0.004	31.129			Net	0.669	%

BMD/CVS data		
CVS DF	154.757	
V mix	74.880	m3
Md Exh Vol	0.261	m3
WCF	1.020	

Bag volume = 1 liter

Not Enough Sample to read the Bag !

(16 Liter minimum)

SAE 2010-01-1295 Nevius, et al.

Emission Measurement: Issues

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- Both CVS and BMD need major countermeasures to be applied to PHEV measurement

	CVS	BMD
Bag Sample Gas Volume	**Good:** **But mostly filled with ambient air that can be a big source of error**	**Too little:** **16 liters minimum required but BMD sample can be as small as zero**
Dilution	**Too much:** **Analyzer range being too high?** **DF calculation has intrinsic error.**	**Good:** **Because it is always constant**

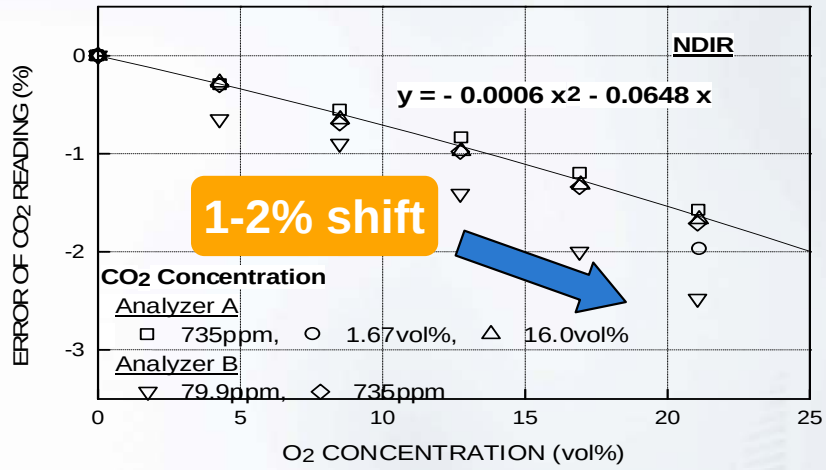
- Other issues:
  - Analyzer ranges, accuracy, quenching
  - Water condensation (many cold-starts)
  - “Leftover” CO2 in the vehicle exhaust system
  - Catalytic converter temperature

Dilution Ratio Effect on NDIR Analyzer

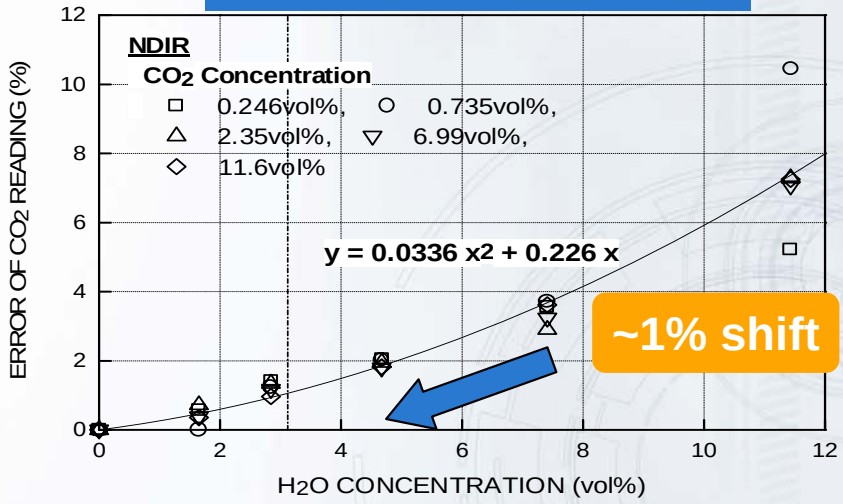
SAE 2010-01-1295 Nevius, et al.

- **Dilution Ratio in the sample bag is different from a conventional ICE vehicle**
  - Mostly Ambient Air
  - Lower Water concentration
  - Higher Oxygen concentration
- **Higher DF results in lower CO_2 concentration reading**
  - Approx 3% shift possible from conventional vehicle CO_2 concentration

Oxygen Quench Effects



H2O Quench Effects



Horiba PHV Solutions for BMD and CVS

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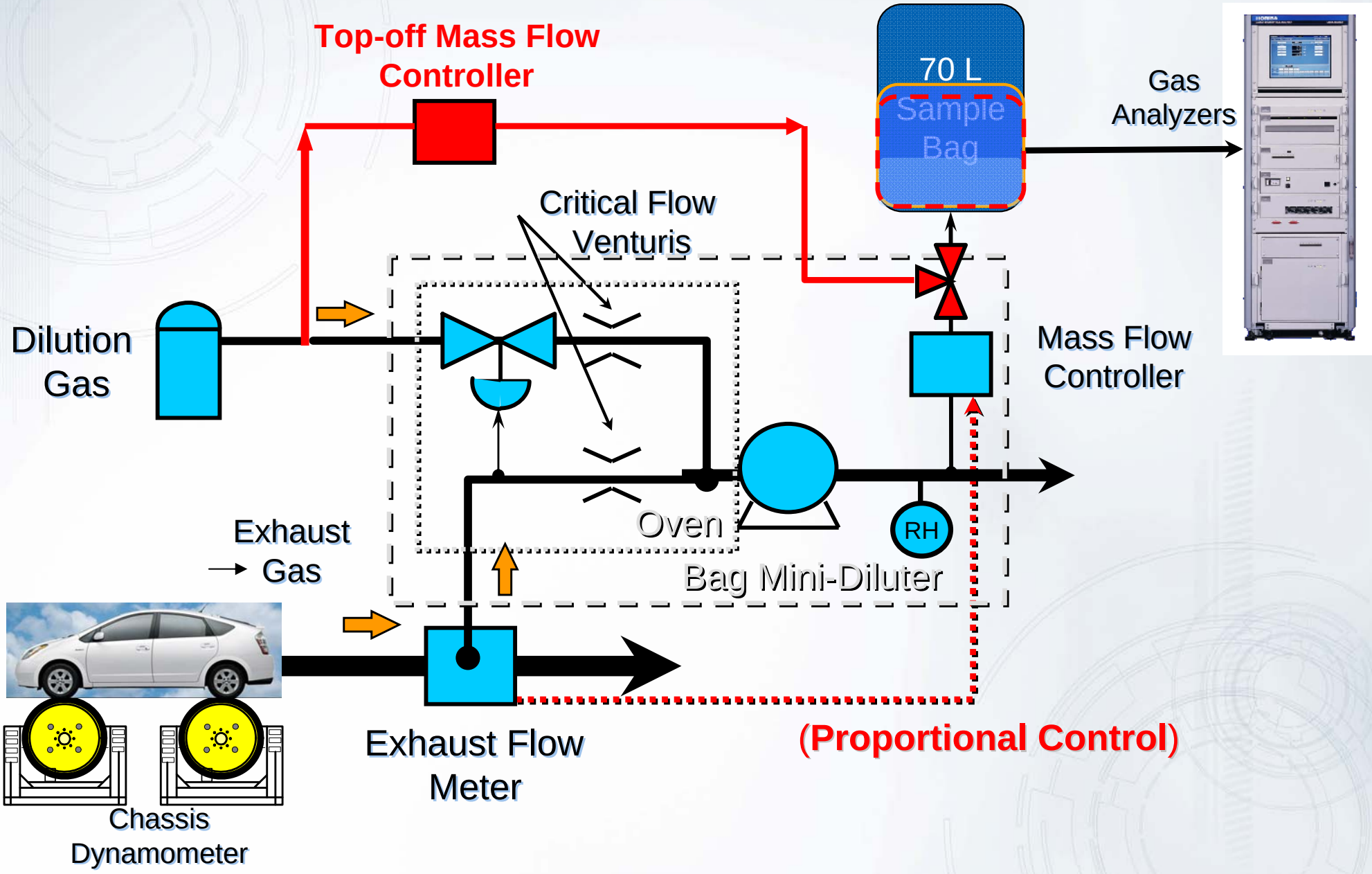
- **PHEV Testing**
  - Verification with a PHEV
    - performed testing with Prius modified to be a PHEV.
    - Horiba SULEV Test cell with CVS and BMD
  - Verification of current PHEV testing practices
  - Modifications to BMD hardware and software
  - Modifications to CVS hardware and software
  - Exhaust Flowmeter specifications for low-flow accuracy.

- **Based upon tests, developed joint-patent concept with Ford Motor Company to overcome potential low bag volumes and excessive PHEV exhaust dilution**

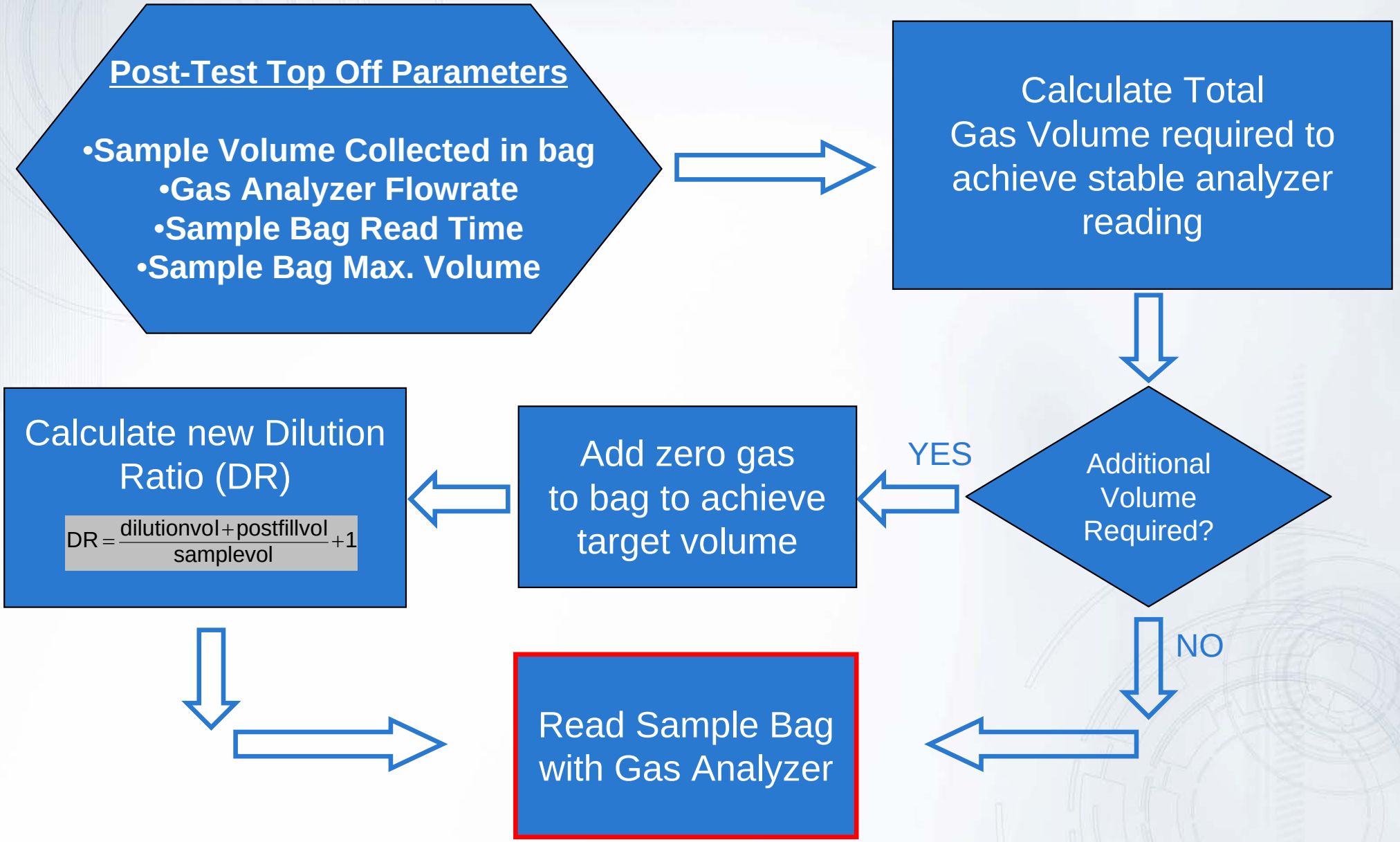
‘Top-off’ Patent Concept



PHEV Patent Concepts

- **Benefits of the patent concept:**
  - Optimizes bag DR
  - Provides sufficient bag sample volume for stable and accurate reading
- **Utilizes MFC to add pure zero air to sample bag … AFTER the test phase is complete**
- **Referred to as “Post-Test Top-Off”**
- **Concept can be applied to CVS or BMD**

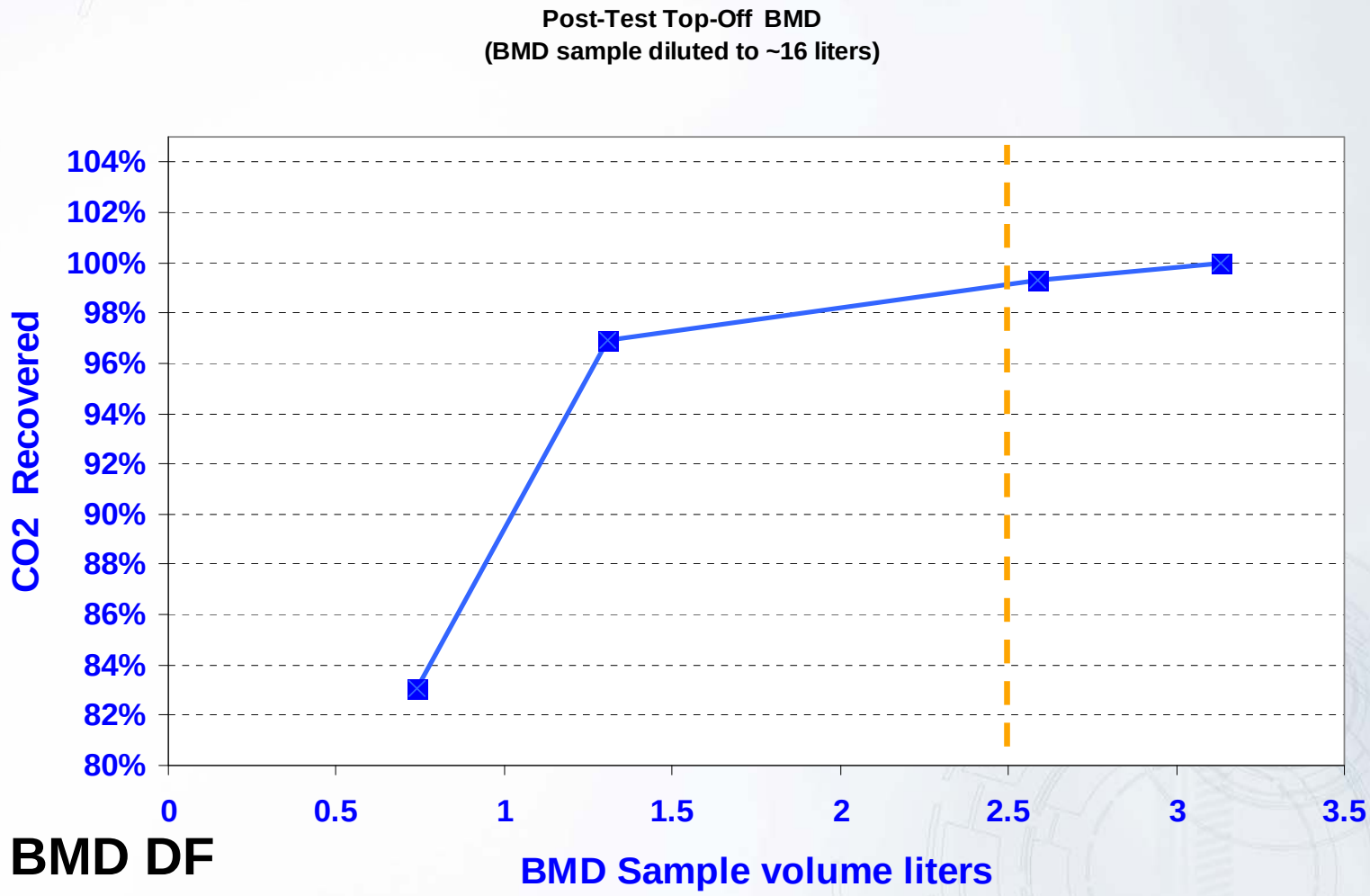
BMD Post-Test Top-Off



Optimizing the BMD for PHEV

- **Post-Test Top-Off (99% recovery @ 2.5liter)**

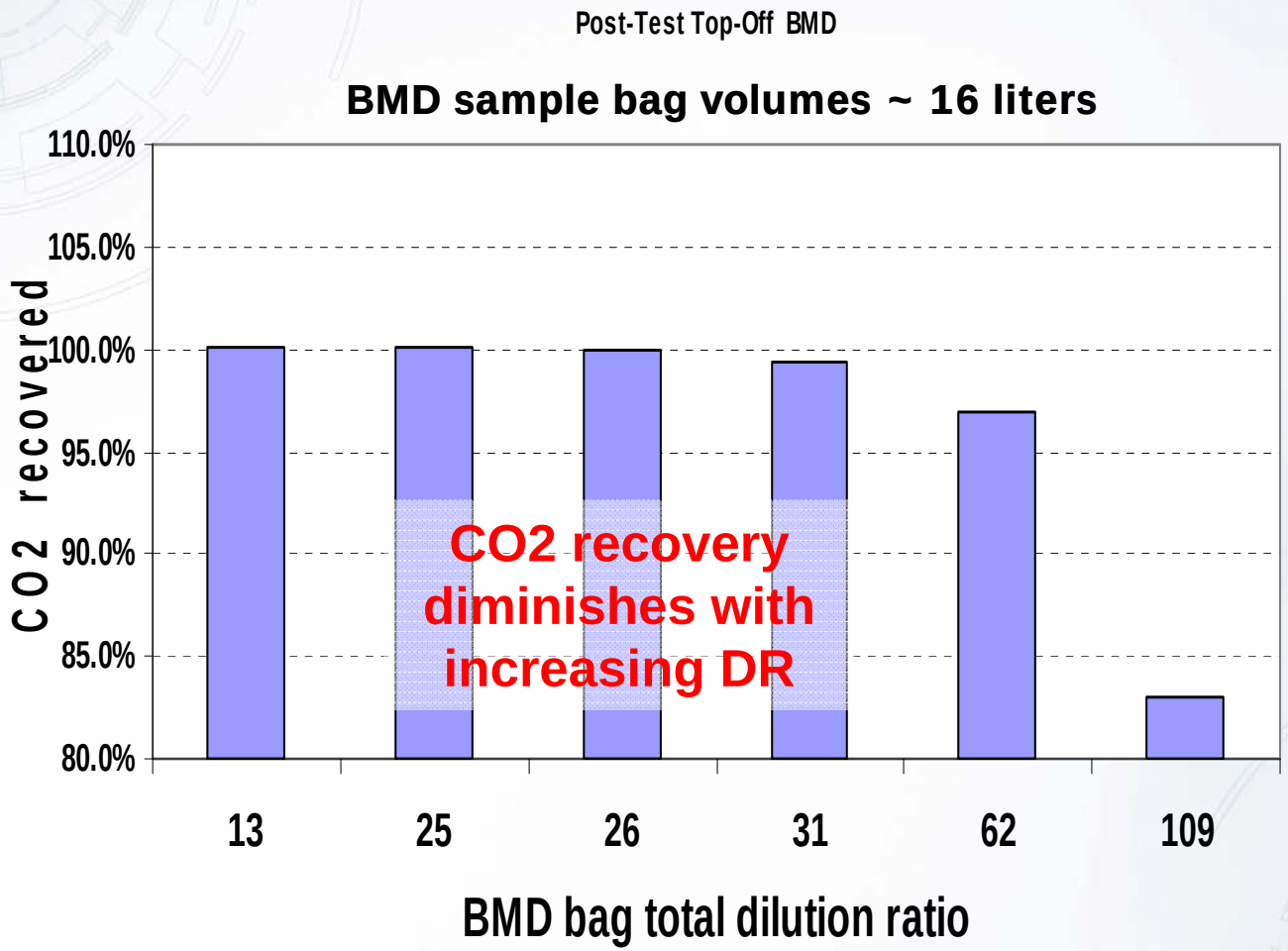
- second dilution step increases the sample volume (sufficient for gas analyzers).



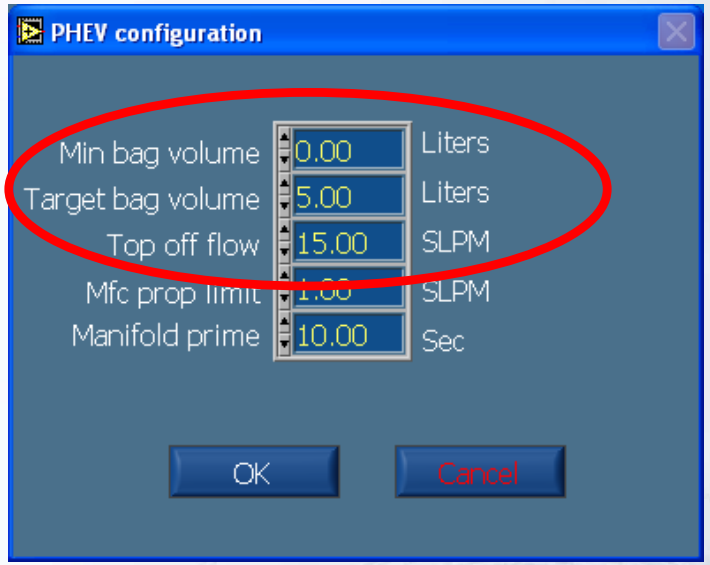
- Recalculate the BMD DF

PHEV Patent Concepts

Optimizing the bag Dilution Ratio



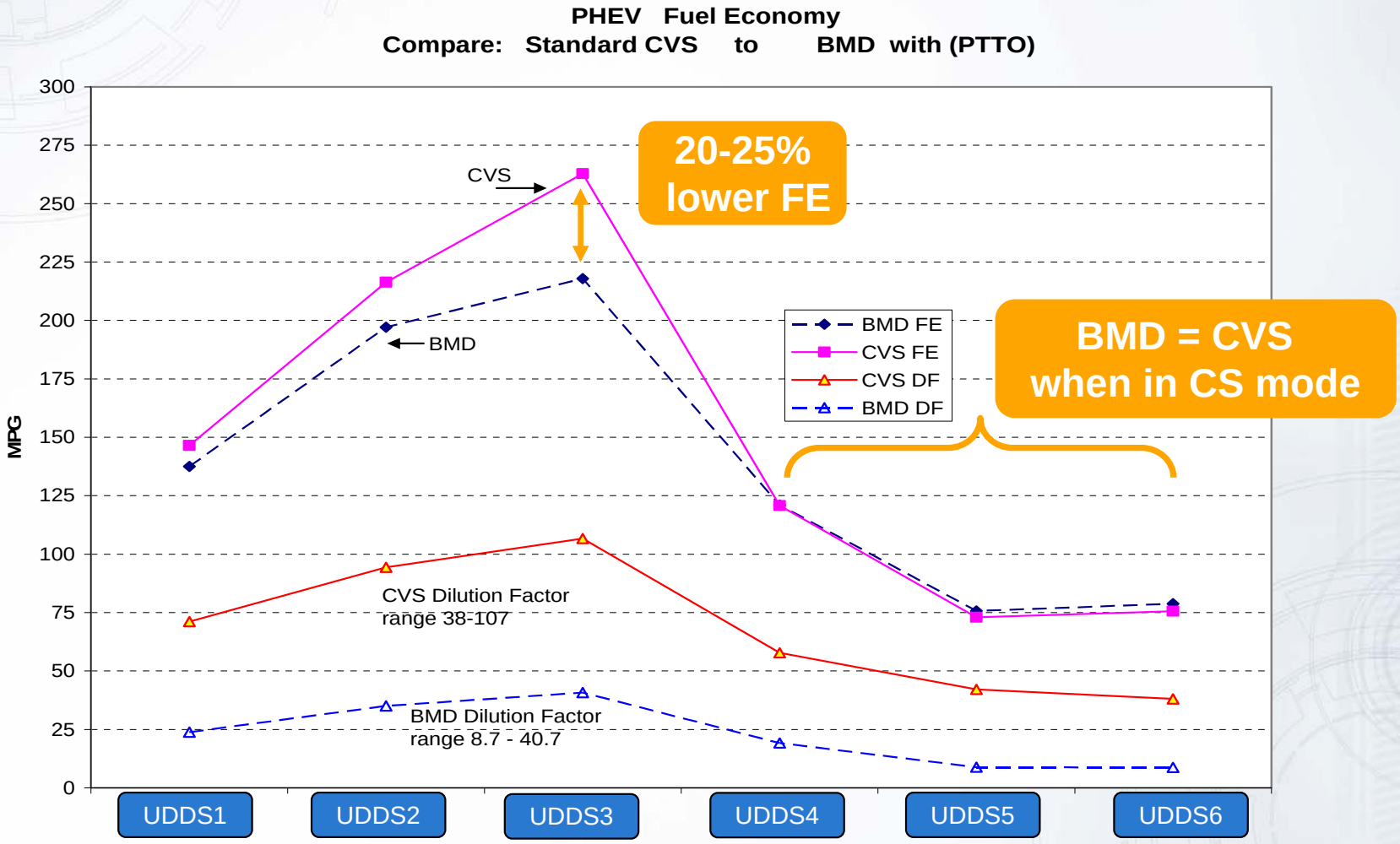
Modified BMD Software for PHEV



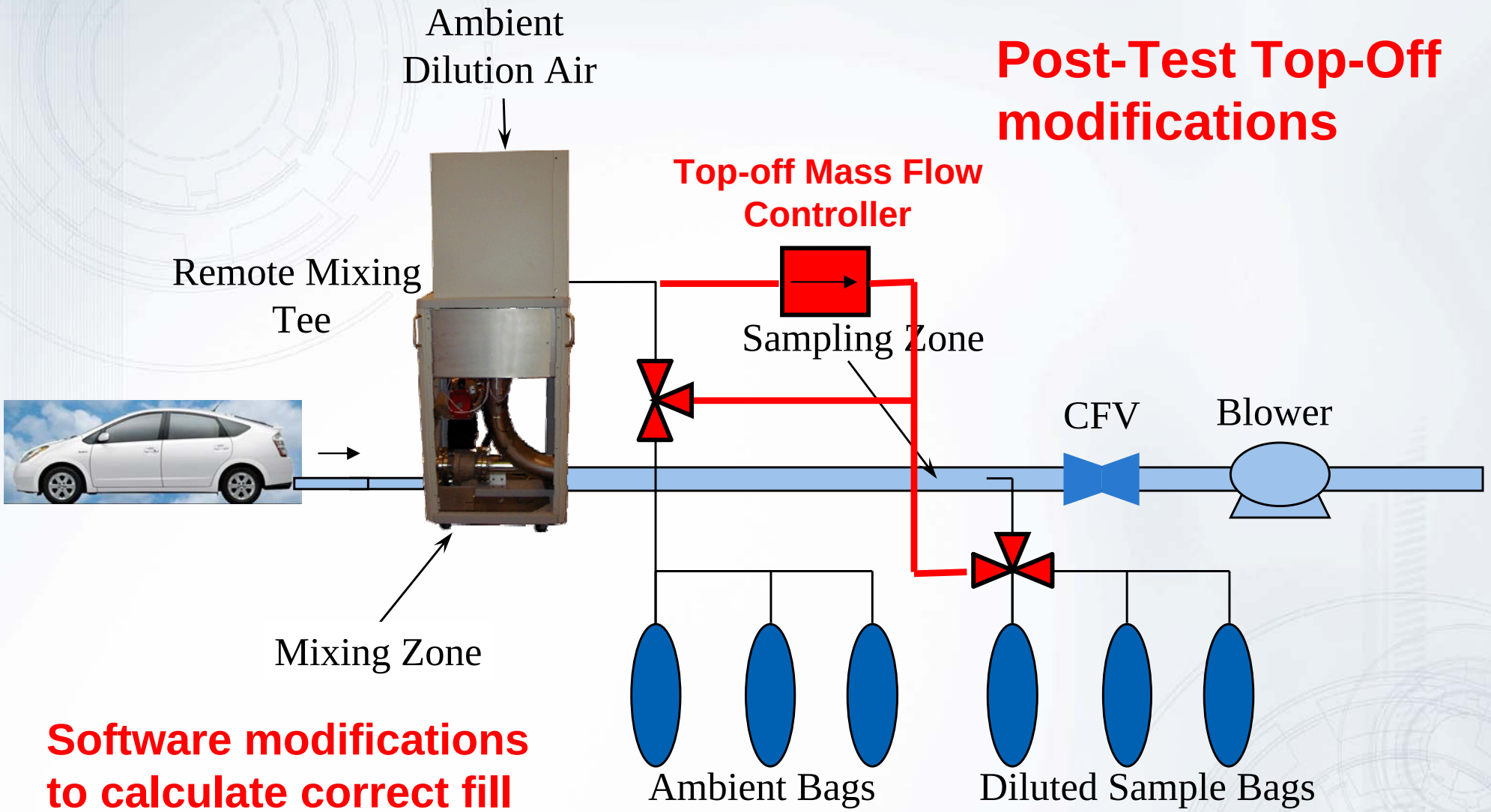
$$DF_{PHEV} = DF_{Std} * \left(\frac{TopOffVolume + BMDBagVolume}{BMDBagVolume} \right)$$

Compare BMD with Post-Test Dilution to CVS

- **Test vehicle:PHEV = 2007 Prius + 5.5 kW-hr plug-in battery**
  - ~Equivalent to EnergyCS Prius



Constant Volume Sampling System- Solutions

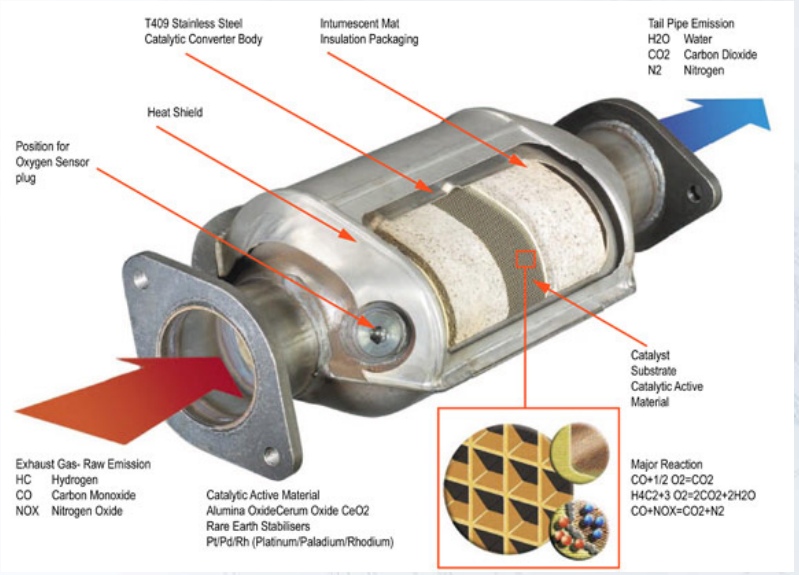


Software modifications to calculate correct fill volume

CVS System

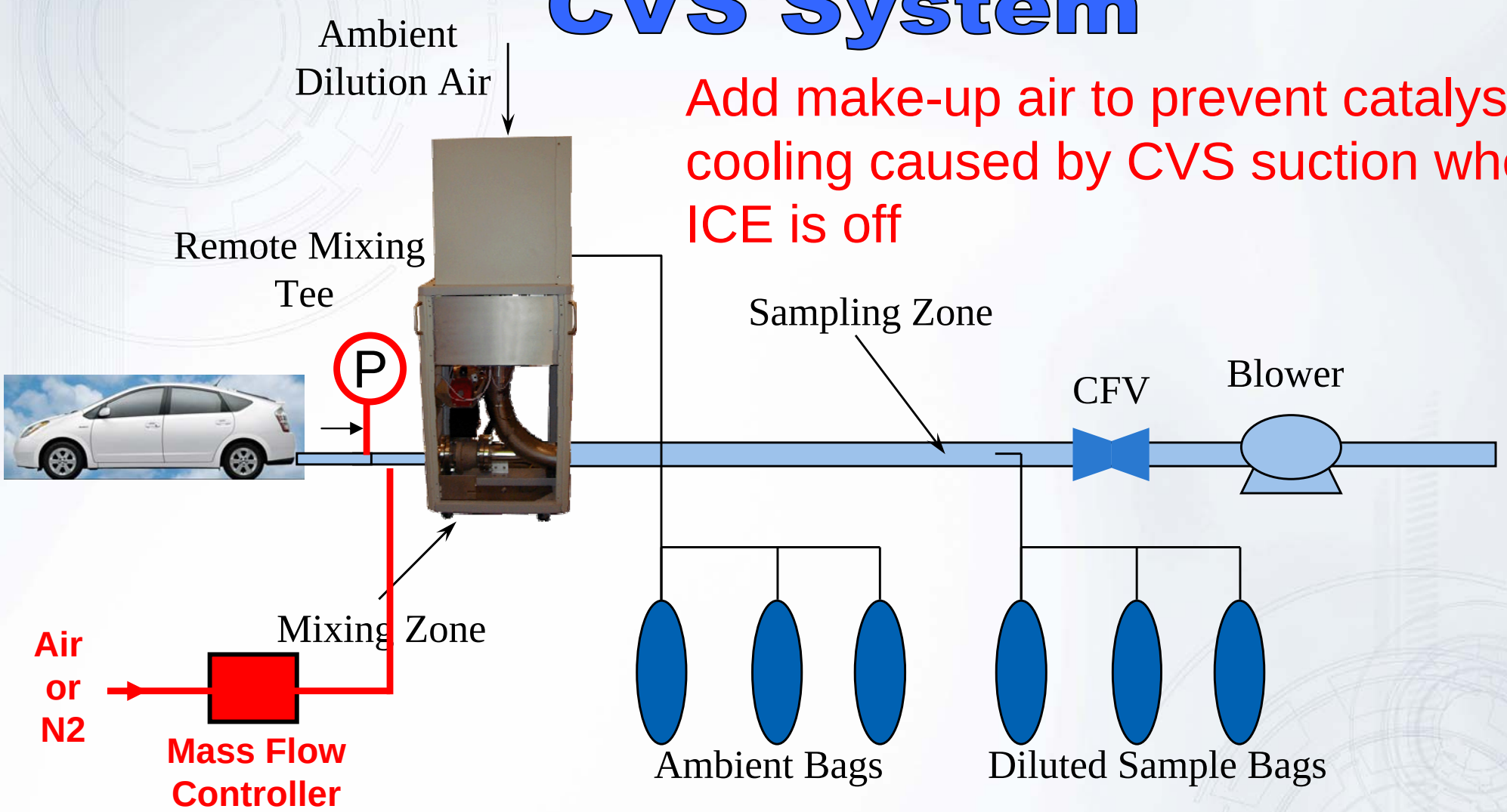
PHEV measurement issues

- **Catalyst temperature management**
  - Many ‘cold starts’ require catalyst temp management strategy
- **CVS method draws small amount of air across the catalyst when ICE inactive**
  - Slightly negative CVS tailpipe pressure
  - Air flow across the catalyst reduces catalyst temperature
  - Impact on emissions upon ICE activation



Constant Volume Sampling System –Solutions

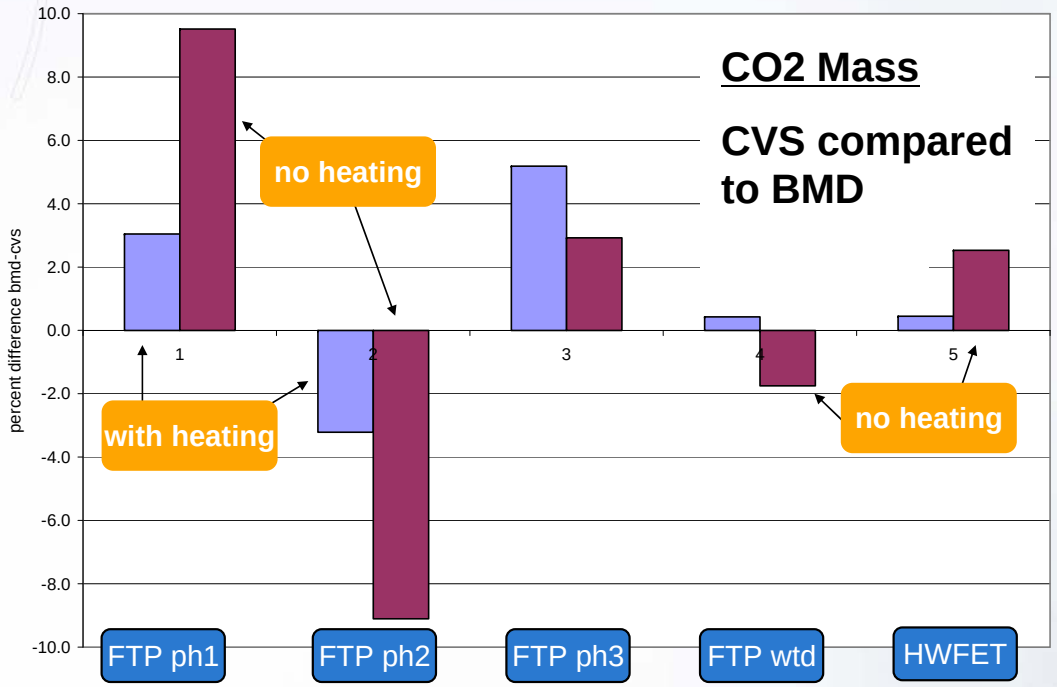
CVS System

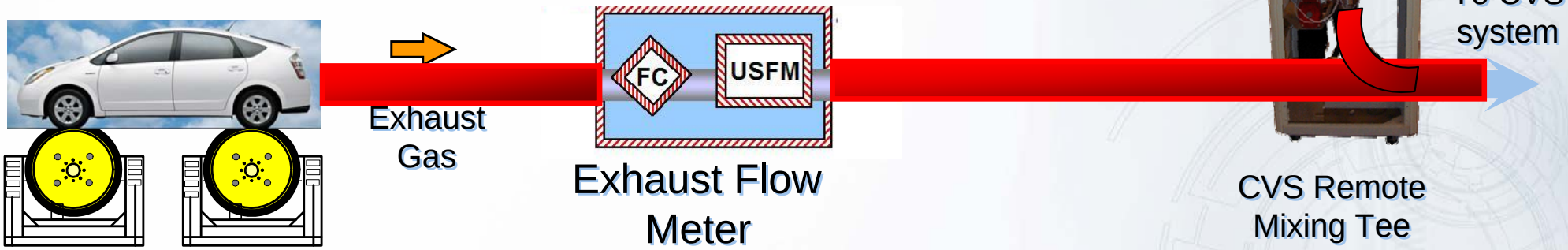


PHEV Testing Solutions

- Heating required to eliminate condensation due to many ‘cold starts’

Add Heating





Summary- PHEV equipment modifications

- **CVS**
  - High dilution factor leads to measurement error
- **BMD**
  - Low sample volume results in measurement error
- **CVS and BMD require hardware and software modifications for maximize measurement accuracy for hybrid vehicle technologies**
  - Optimize bag fill dilution ratios using post-test bag dilution
  - Prevent catalyst cooling
  - Heating of raw transfer tubes

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Thank You for your Attention

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