



Evaporative Emissions Research Overview

MSTRS MOVES Review Work group
November 27, 2012

Evaporative Emissions Plan for MOVES

- Report from Harold Haskew in 2005 recommended a new approach for MOVES different from the MOBILE models which was based on test types.



In the creation of MOVES we wanted to re-think evaporative emissions. We contracted with Harold Haskew, an expert in evap emissions development, to develop a framework that would represent the real world rather than the test types that were created for certification. He provided a new paradigm in which emissions were classified by the way in which emissions escaped from the fuel system to the atmosphere.

In his report he proposed new test procedures which separated these mechanisms. The “Permeation” test procedure which routed the canister to the outside of the SHED on a scale to measure any breakthrough separately. Another procedure is called the “Static Test” which is able to determine whether the vehicle has a vapor or a liquid leak by activating the vapor space and fuel pump from outside of the SHED and looking for a change in the slope.

This is now how MOVES evap emissions are structured.

Vehicle Evaporative HC Sources

- Vapor – generated by fuel tank heating, due to increasing ambient temps and/or vehicle operation



- **Breakthrough** – carbon canister cannot contain all of the generated vapor; can result in large increase in HC emissions

- “Enhanced Evap” rule required canisters sized for 3 days at 9 RVP, 72-96 degrees, 40% fill level



- Breakthrough happens with higher temperatures, higher RVP, less fuel in tank, and/or > 3 days

- **Vapor Leaks** - e.g., gas caps, compromised vent lines, connections, fittings

- **Refueling** – Except for HDGVs, Onboard Refueling Vapor Recovery (ORVR) now drives canister size



- **Permeation** - emissions through polymer walls, worsened by ethanol and controlled by changing fuel system materials

- Liquid leaks - fuel tank/fuel line holes

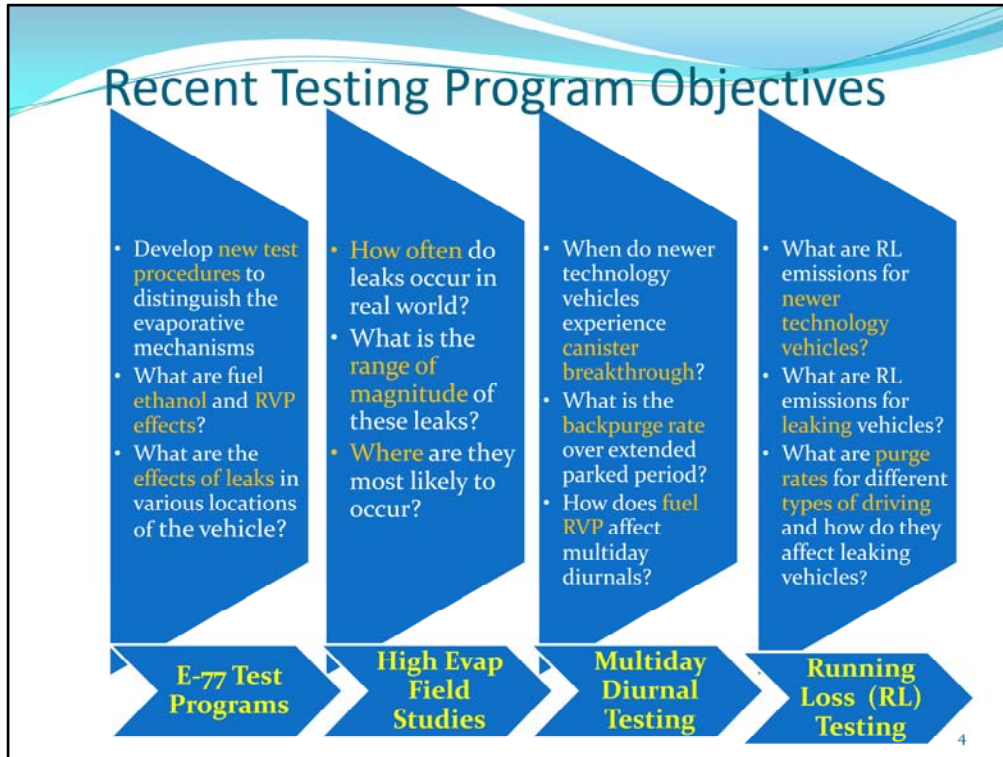
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The evap emissions control system on the newer, enhanced technology, uses a carbon canister to collect the vapor generated in the fuel system from rising temperatures and higher Reid Vapor Pressure (RVP) in the fuel. The certification test required a three day test which was a significant improvement over one day of rising and falling temperatures, cycling between 72 and 96 degrees F, with a fuel tank at 40% fill level. The lower the fuel level the more vapor is in the tank which pushes the canister to hold more vapor for the full three day duration.

The fuel system contains many connections and fittings which are vulnerable to the development of tiny leaks as the system ages. With the decreasing standards these “leaks” are becoming a more significant source of emissions.

Liquid Leaks tend to be in the system where the fuel sits, and develop through use. These emissions are less frequent but can be extremely high – raw fuel evaporating straight into the atmosphere.



With our new paradigm for evap emissions we found ourselves without data specific to these processes and without data on any aging newer technology vehicles – enhanced or CA PZEVs (partially zero emissions vehicles).

We worked with the Coordinating Research Council to set up the E-77 pilot program to develop the test procedures on actual vehicles which Harold had proposed in the report to us. Further testing, in E-77-2 programs we explored fuel effects from different ethanol and RVP levels.

There was also no specific data on “leaking” vehicles so we implanted tiny leaks – 0.02” diameter, which is the lowest leak level which the on-board diagnostics (OBD) was required to detect in CA (0.04” in US), to see what kind of effect they would have on the emission levels.

The findings were orders of magnitude higher than the low levels of the “non-leaking” vehicles. The missing piece of information led to field studies to find out how often these leaks were occurring and also what was the range of magnitude of these leaks in the real world? We also wanted to know where were the leaks most likely to occur.


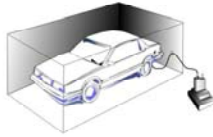

On the vapor venting side, we knew that many vehicles were sitting much longer than 3 days which they were designed for. A GA Tech activity study with 300 vehicles over two years said that 16% of the vehicles drove less than 3000 miles in a year. They did not instrument these vehicles, but that means they either drove seasonally, sporadically or only a few miles a day. Either way that was not enough driving to purge a canister – which requires FTP like driving to “suck” the fuel back to the engine, and empty the canister. For our vapor generation modeling we also needed to know what the backpurge rate was – overnight when the temperature goes down, fresh air is sucked into the canister vent and pushes the hydro carbons back into the vapor space. Info on the RVP of the fuel was also needed to calibrate our model.

Real World Evaporative Emissions Studies

- Coordinating Research Council (CRC)
 - Studies in 90's on older vehicles
 - E-65 Fuel Permeation studies
 - E-77 suite of programs
- Three years of High Evap Field Studies
 - RSD used as a screening tool
 - Portable SHED and other tools
 - Evap OBD
- Multi-day diurnal testing
- Current and Future Work
 - Running Loss with implanted leaks
 - Canister Degredation Study
 - Real World Evap Procedure
 - Activity

MOVES_{2010b}

*Potential
MOVES₂₀₁₃*

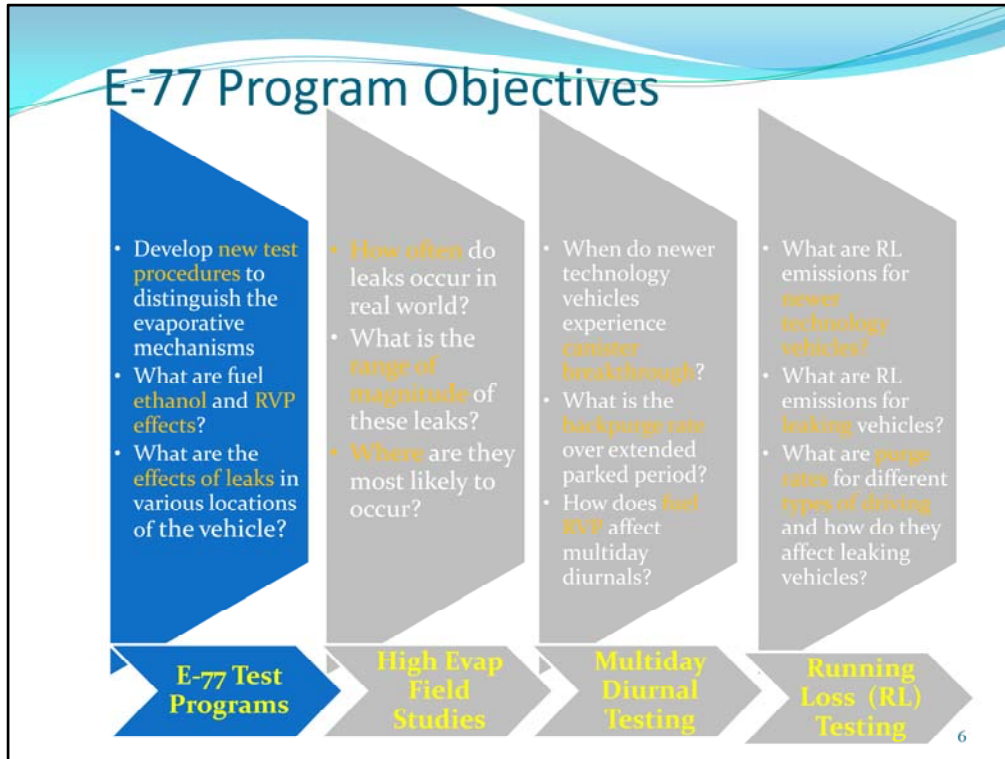
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So, recapping the available data and what is used in which model. MOVES2010b is based on the CRC studies in the 1990's which are on in-use, now older technology vehicles. E-65 was the first permeation study and was done on in-use vehicle fuel systems. The study actually cut the in-use vehicle off of its fuel system, which was then placed on a rig (top right picture) in a SHED for testing.

E-77 permeation data was used in MOVES2010b along with E-65 and E-65-3 for fuel effects – ethanol and RVP levels.

Our proposal for MOVES2013 will utilize all of the data from these CRC studies along with the other programs I will show you in more detail – the High Evap field studies in Colorado and the Multiday diurnal testing.

Then I will let you know about our current testing and plans for future work.



The first step was to develop some new test procedures and get some data on the aging fleet of new technology vehicles, along with the fuel effects – ethanol and RVP.

Summary of E-77 Laboratory Evaporative Testing Programs			
	E-77-2	E-77-2b	E-77-2c
Objective	Assess effects of ethanol and vapor pressure on evaporative emissions from aging enhanced and newer technology vehicles Collaboration with EPA, CRC, DOE (NREL)		
Vehicles	Pre-Enhanced: 1 Enhanced: 5 Near-Zero: 2	Tier 1: 5 Near-Zero: 2 Zero Evap: 1	<i>10 Vehicles selected from E-77-2 and E-77-2b Fleets</i>
Fuels	E0 (7 & 9 psi) E10 (7 & 10 psi) E20 (9 psi)	E0 (7 & 9 psi) E10 (7 & 10 psi)	E20 (7 & 9 psi)
Tests performed	-Static (85°F) -Running Loss/Hot Soak -72h Diurnal (65-105°F)	-Static (85°F & 105°F) -Running Loss/Hot Soak -72h Diurnal (65-105°F)	-Static (85°F & 105°F) -Running Loss/Hot Soak -72h Diurnal (65-105°F)
Key Features	1 "Enhanced" & 1 "Near-Zero" have implanted leaks (.020" dia. Hole in special tank gas cap)		New implanted leaks on same vehicles as in E-77-2: -Top of fuel tank -Hose connection to canister ⁷

This slide has a lot of information. The objective is to find the fuel effects for ethanol and RVP in evaporative emissions, with the new test procedures developed in the E-77 Pilot program, and also to determine leak effects in different locations on the vehicle.

The project was a multi-year collaboration between CRC, EPA, and DOE/NREL – Department of Energy, National Renewable Energy Laboratory.

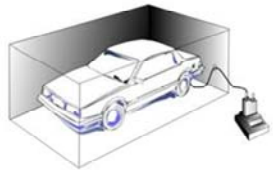
There were a total of sixteen vehicles, eight in the first set and the next eight in 2b/2c. They were tested over E0, E10 and E20 fuel with 7 and 9 or 10 RVP.

The new Permeation procedure was used for Running Loss, Hot Soak and 3 Day Diurnal tests over the CA cycle 65-105 deg F, which is considered “off-cycle” for the Federal (72-96 deg), with these fuels of high RVP.

The new Static test was also used at 85 deg F which pressurized the fuel vapor space from outside of the SHED to see if there was a difference in Permeation rate, would indicate a vapor leak. Then the fuel pump was activated from outside the SHED and liquid leaks could be seen with a change in the permeation rate.

Leaks were implanted on two vehicles. At first in the gas cap. When we realized that ORVR actually dealt with this and the emissions were much lower than the non-ORVR vehicle which was tested in the pilot program, we implanted leaks at the top of the tank and at the canister connection. Both of these locations were found to be high rate of occurrence in the field studies which I’ll talk about next.

CRC E-77 Testing Programs



- Separated the evaporative emissions mechanisms
 - Permeation
 - Canister breakthrough measured outside of SHED
- Reports on CRC website:
 - www.crcao.com/publications/emissions

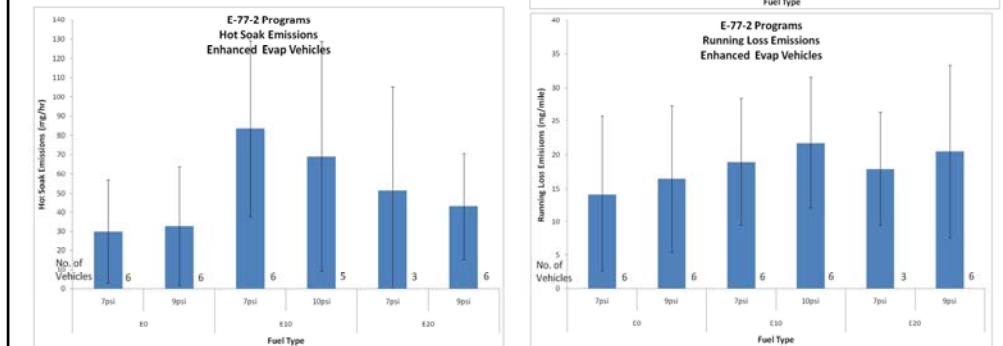
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The big take-aways from this program are the new test procedures which separated Permeation from canister breakthrough which was measured outside of the SHED.

The reports have all been posted on the CRC website.

Permeation Results by Test Type

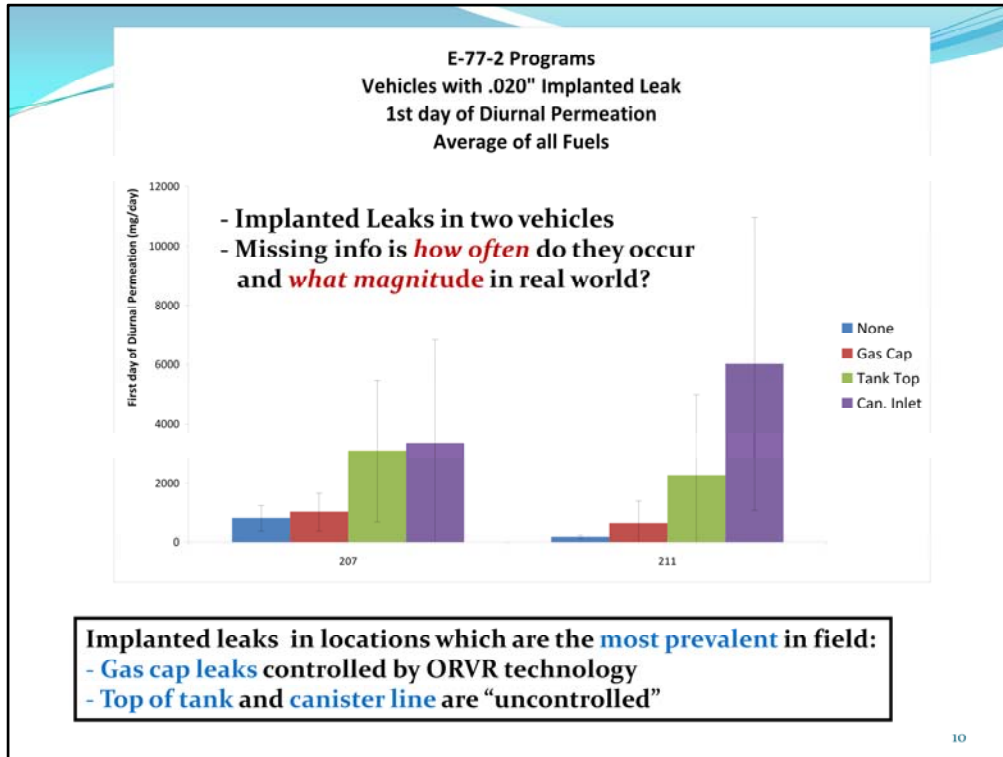
- E-77 Programs compared Ethanol and RVP
- Only Hot Soak permeation data was used in MOVES2010b
- For MOVES2013 analyzing all data including implanted leak emissions



This is a sampling of the data from this program – permeation by test types. Each bar is a different fuel ethanol and RVP level.

Only Hot Soak permeation data was used in MOVES for the fuel effects.

We have since analyzed all of the data including the implanted leak emissions, and would like to use in MOVES2013.



Here is an idea of the leak data for the different locations on two different vehicles. As you can see there is potential here for significant impact on the inventory.

What we don't know at this point is how often these leaks occur in the real world or what the range of magnitude is.

MOVES2010b Estimates for Liquid Leaks

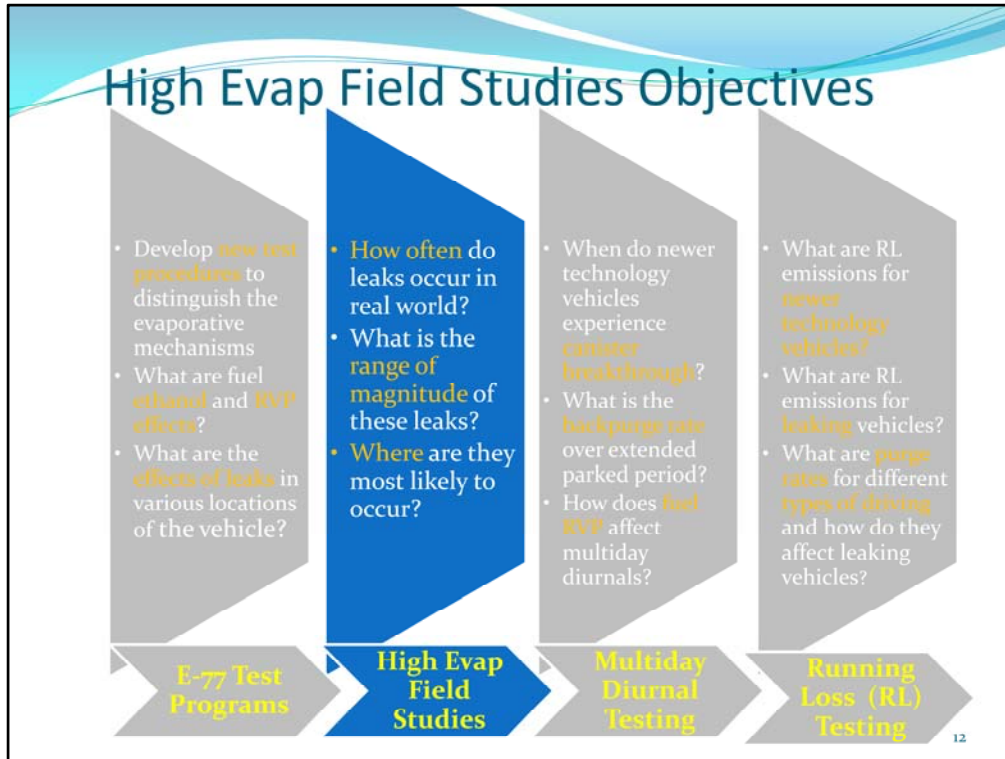
- API “Raw Fuel Leak Survey in I/M Lanes”, 1998
- CA BAR “Evaporative Emission Smog Check”, 2001, Gas Cap Study

- Nothing for aging Enhanced Vehicles
- Vapor leaks are included in base emission rates

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In MOVES2010b these were the studies which our rates are based on for liquid leaks.

There was no data for aging enhanced or newer evap technology vehicles. Vapor leaks were not separate – they were included in the base rates as part of the average for the randomly recruited vehicles.



Moving on the Field studies where we sought to answer the questions of how often and how much are these leaks really in the world.

We also wanted to know where on the vehicle they were more likely to come from.

High Evaporative Emissions Field Studies in Denver, CO

- Lipan IM Station, 2008
- Ken Caryl IM Station, 2009
- Repair Effectiveness, 2010



Handheld HC detector



Portable SHED set up in IM Station

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When we were designing this study, we found out that Colorado Department of Public Health and Environment (CDPHE) were also doing some preliminary work and interested in this area. They were finding that you could differentiate exhaust and evap HCs with the newer version of their Remote Sensing Device (RSD) instrument.

We partnered with them through a CRADA – Cooperative Research and Development Agreement to study this. We did a pilot study in 2008, setting up shop at the Lipan IM Station in Denver. These are pictures of our portable SHEDs, we call PSHEs. For a few hundred dollars and a lot of duct tape we were able to get pretty good snapshots of the hot soak emissions for a limited time.

With lessons learned CDPHE set up a similar study at the Ken Caryl IM Station also in Denver in 2009. They were able to collect some good data during this time which we were able to use to find out some answers on how often these higher evap emission vehicles exist in the fleet.

We also used a handheld HC detector, or “sniffer” by going over the vehicle when it had just driven, to locate the source of the higher HCs. We were not always able to find the source, but in many cases we did, which gave us an indication on where the most problems were occurring.

In 2010 CDPHE took it even further and specifically recruited vehicles through their RSD program into their lab and Tech Center to test, and repair and then retest. They were able to get some valuable data from this summer as well.

Screening and Sampling

- Obtained Remote Sensing (RS) measurement as vehicle entered station
- Selected vehicle based on RS value
 - “Probability Proportional to RS” – the higher the evap emissions the more we wanted to recruit the vehicle
- Assigned “sampling weight” to each vehicle
 - The number of vehicles in fleet are represented by each sample vehicle
- In analysis, applied sampling weights to estimate leak frequencies.

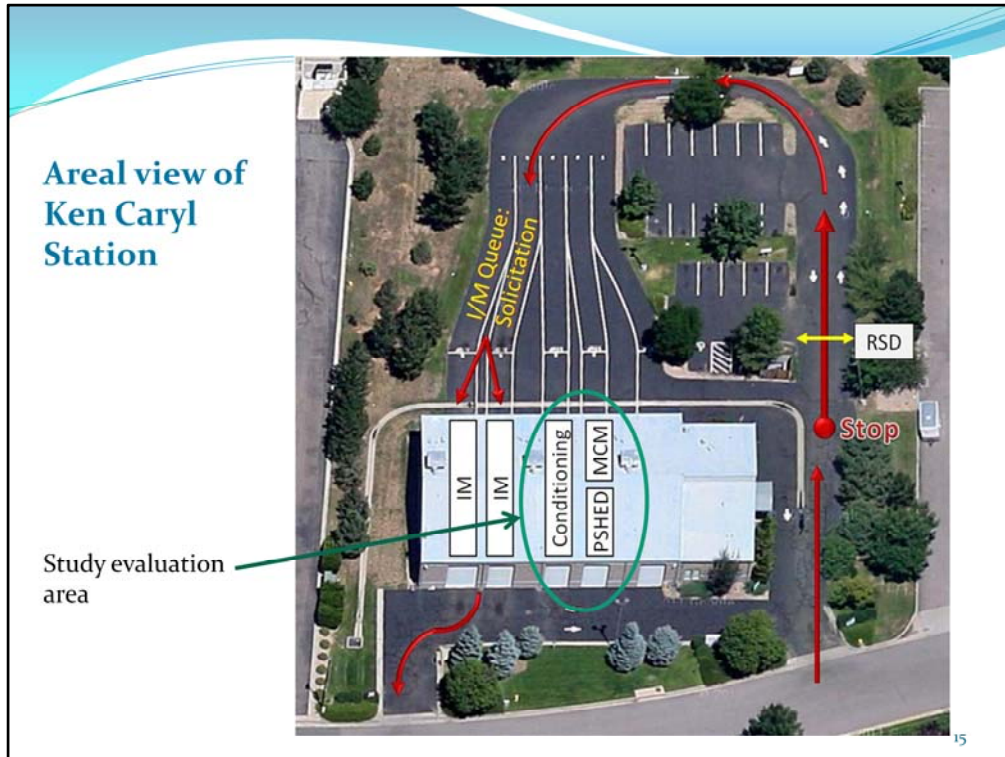
Selection RSM EI23 Bin	Sampling Fraction
1	0.06
2	0.06
3	0.06
4	0.3
5	1
6	1
7	1

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We were able to identify the higher evap vehicles and recruit based on emission level of the bins. Basically if it was a high emitting evap emissions vehicle we worked hard at obtaining the vehicle for the study.

Many of the vehicles were difficult to recruit from the owners, but we ended up with roughly half of the vehicles with higher evap emissions rather than a much smaller sample if we just randomly recruited them. In this way RSD was a useful tool.

In the analysis, we were able to weight the recruitment bins back together so they actually represent the percentages found in the fleet at the Ken Caryl Station.




The red arrows indicate the flow of the vehicles into the IM Station, past the RSD, when the technician in the van running the computer with the algorithm for sampling, was able to alert the recruiters to approach the “tagged” vehicles for participation in the study. After their IM test if they were willing to participate, we had a driver take the vehicle around a predetermined route which represented the FTP. This route consisted of some highway driving, and took the vehicle past a few different RSD monitors to get a “hot” reading at 3 different speeds. They then drove the vehicle back and stopped the engine in front of the PSHED while technicians pushed the vehicle in for a 15 minute hot soak.




Portable SHED (PSHED) and other Field Tools

PSHED Statistics:

Average Recovery	97.6%
Recovery Std. Dev.	3.3%
Average Retention	95.7%
Retention Std. Dev.	2.3%



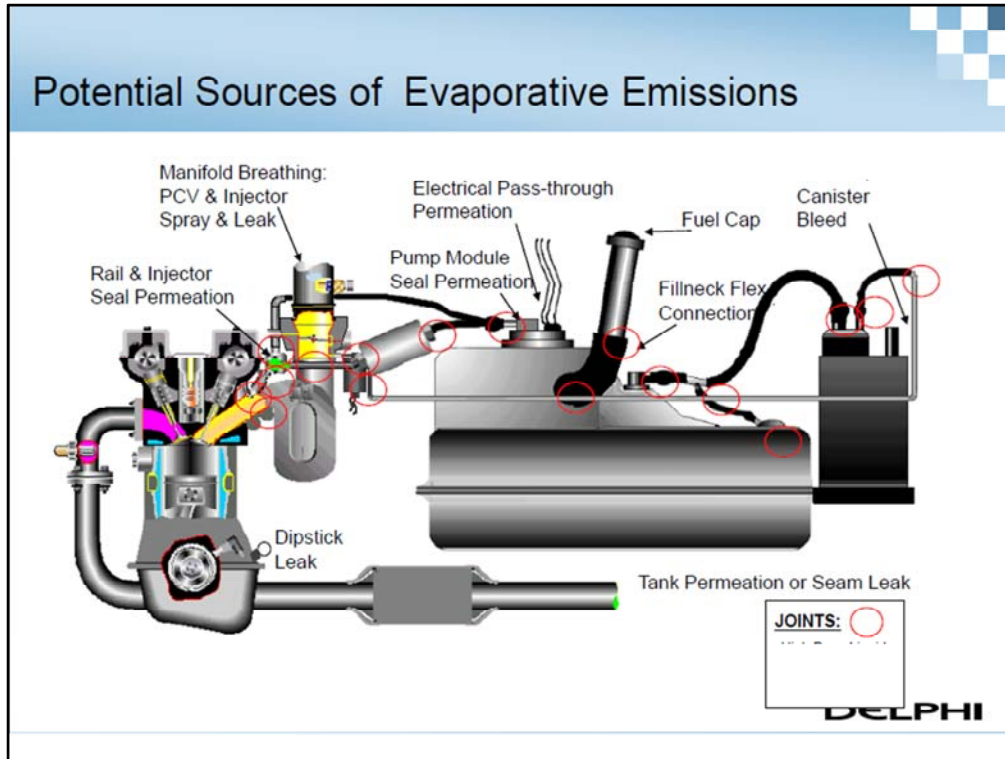
- **PSHED was a very effective means for testing large number of vehicles in the field**
 - **Significant savings over laboratory SHED testing**
- **Handheld HC Detector (Sniffer)**
 - **Effective when can reach the source of emissions**
 - **Many newer vehicles packed very tightly, difficult to reach to determine the source without dropping tank and fuel lines**
- **Snap-On device for leak detection**
 - **Can determine if leak in system and cumulative size**



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Our PSHED was very effective for the 15 minute period.

The snap-on device is used for diagnosis in many dealerships and was an effective tool to determine the actual size of the cumulative leak – all tiny leaks added together in the system. We added this partway through the study so do not have the info on all of the vehicles.



There are many possible locations for potential leaks when you look at the fuel system, even though manufacturers have been trying to minimize connections over the years, they are still part of the system.

High Evap Emissions by Component (g/Qhr) All Model Years in Study

Row Labels	Count of Location_One	Max of Before Repair (g/Qhr)	Average of Before Repair (g/Qhr)	Min of Before Repair (g/Qhr)
⊕ Nothing Found	57	55.86	5.65	0.30
⊕ Tank	24	58.96	10.22	0.39
⊕ Fill pipe	13	18.47	7.30	0.89
⊕ Canister	11	26.61	11.73	1.29
⊕ Cap	9	28.36	6.18	0.38
⊕ Injector	5	89.62	27.85	2.20
⊕ Fuel lines	4	23.46	11.73	0.47
⊕ Purge line	4	19.78	7.29	0.85
⊕ Tank line	4	12.62	6.76	0.80
⊕ Fuel rail	4	15.84	7.85	0.71
⊕ Fuel pump	4	13.18	8.24	2.44
⊕ Purge solenoid	3	70.93	33.12	12.20
⊕ Fuel filter	2	1.47	1.26	1.05
⊕ Underbody	2	3.12	1.72	0.31
⊕ Carburetor	2	16.27	12.25	8.22
⊕ PCV	1	16.81	16.81	16.81
⊕ Intake manifold gasket	1	8.65	8.65	8.65
⊕ Other	1	2.35	2.35	2.35
Total	151			



Used hand-wand “sniffer” to detect source of “leak”

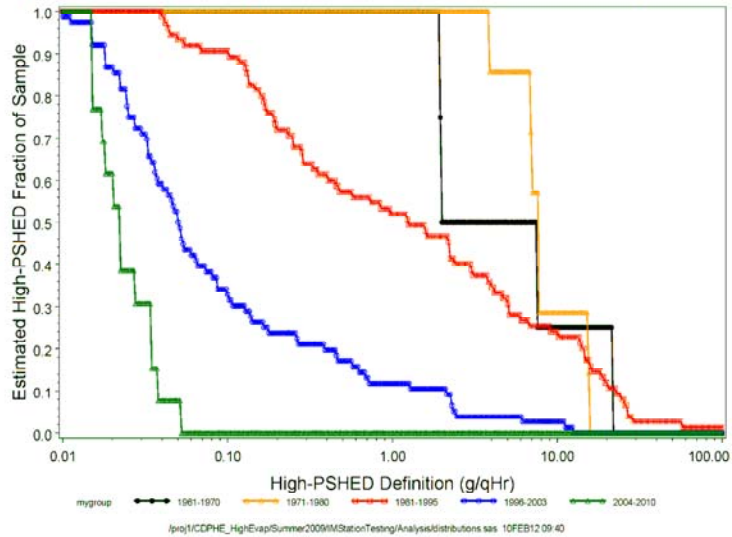
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ALL MODEL YEARS (>0.3g/Qhr)

This is a summary list of the sources of the leaks along with the magnitude spreads from these sources. As you can see almost a third of the problems were not able to be diagnosed (“Nothing Found”).

The fill pipe is near the gas cap and is mostly taken care of through ORVR, so the other top percentage of occurrences were the top of the tank and the connection near the canister. This is likely because of maintenance – changing the fuel filter and when working under the vehicle everything is packed tightly, you have to move things around and lines can easily get compromised with tiny leaks and not realize it.

Prevalence Rates for High Evap Emissions by Model Year, Ken Caryl IM Station, Denver



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Our contractor, ERG, did the analysis to re-weight the sample back into the fleet and were able to deliver Prevalence Rates – for how often the high evap emissions occur in the fleet.

This chart is set up by model year group – each color line is defined.

The emissions cutpoint is across the bottom in a log scale.

Prevalence Rates for High Evap Emissions by Model Year and Cutpoint, Ken Caryl IM Station, Denver

Model Year Group	Number of Observations Used to Determine Fraction	Ken Caryl Fleet Fraction Exceeding Various PSHED Hot-Soak (g/Qhr) Values							
		0.3	1	2	5	10	20	50	100
1961 – 1970	4	1.0	1.0	0.68	0.68	0.53	0.53	0.0	0.0
1971 – 1980	7	1.0	1.0	1.0	0.85	0.30	0.0	0.0	0.0
1981 – 1995	75	0.392	0.258	0.222	0.086	0.049	0.032	0.003	0.001
1996 – 2003	76	0.064	0.043	0.038	0.029	0.028	0.00	0.00	0.00
2004 - 2010	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Overall	175	0.142	0.099	0.086	0.044	0.031	0.010	0.001	0.000

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This table shows the same rates by model year group and percentages by cutpoint.

The 2004 -2010 model year group has zero percentages because we were not able to recruit the vehicles that did get flagged as high, so we actually have good reason to know they exist.

We will discuss how this would get modeled at another FACA meeting when we have more time.

Multiday Diurnal Program Objectives

- Develop **new test procedures** to distinguish the evaporative mechanisms
- What are fuel **ethanol** and **RVP effects**?
- What are the **effects of leaks** in various locations of the vehicle?

E-77 Test Programs

- **How often** do leaks occur in real world?
- What is the **range of magnitude** of these leaks?
- **Where** are they most likely to occur?

High Evap Field Studies

- When do newer technology vehicles experience **canister breakthrough**?
- What is the **backpurge rate** over extended parked period?
- How does **fuel RVP** affect multiday diurnals?

Multiday Diurnal Testing

- What are RL emissions for **newer technology vehicles**?
- What are RL emissions for **leaking** vehicles?
- What are **purge rates** for different **types of driving** and how do they affect leaking vehicles?

Running Loss (RL) Testing

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Multi-Day Diurnal Testing

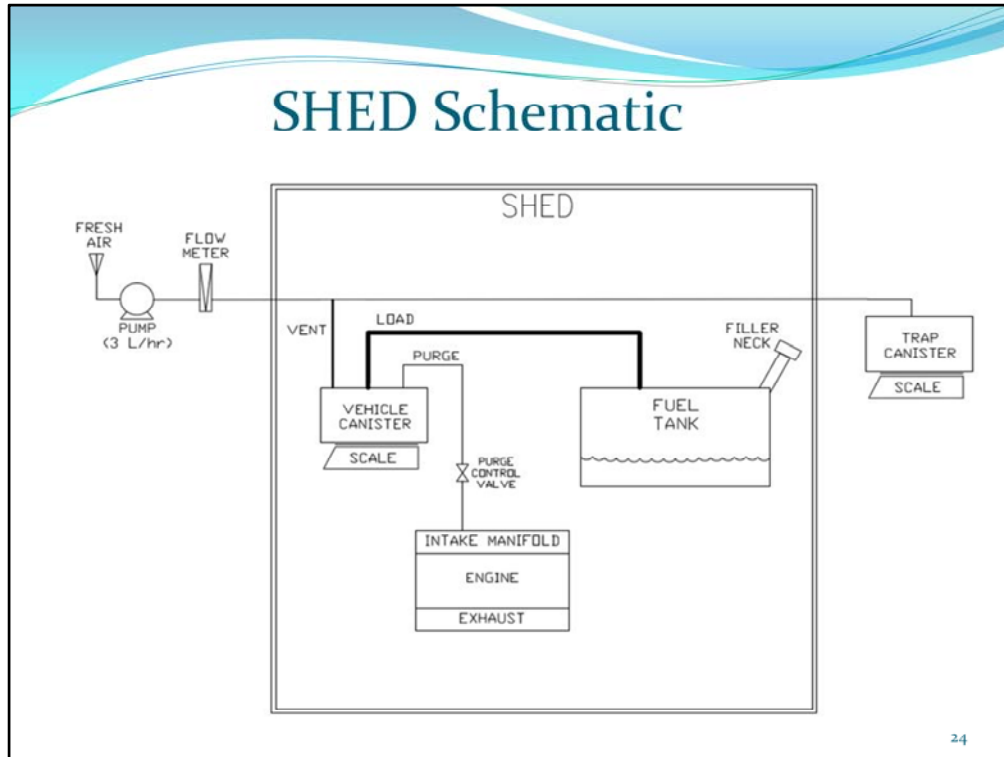
- *Developed test procedure* to monitor evaporative emissions, canister loading profiles and breakthrough emissions
- Tested **9 vehicles** at Environmental Testing Corporation (ETC, now a part of SGS), Summer 2011
- **14 days** of Federal Diurnal Cycle **72° – 96°F**
- Each vehicle tested on 2 fuels:
 - Represent **9.0 RVP at Sea Level**, used 8.0 in Denver
 - Represent **10.0 RVP at Sea Level**, used 9.0 in Denver

Test Procedure

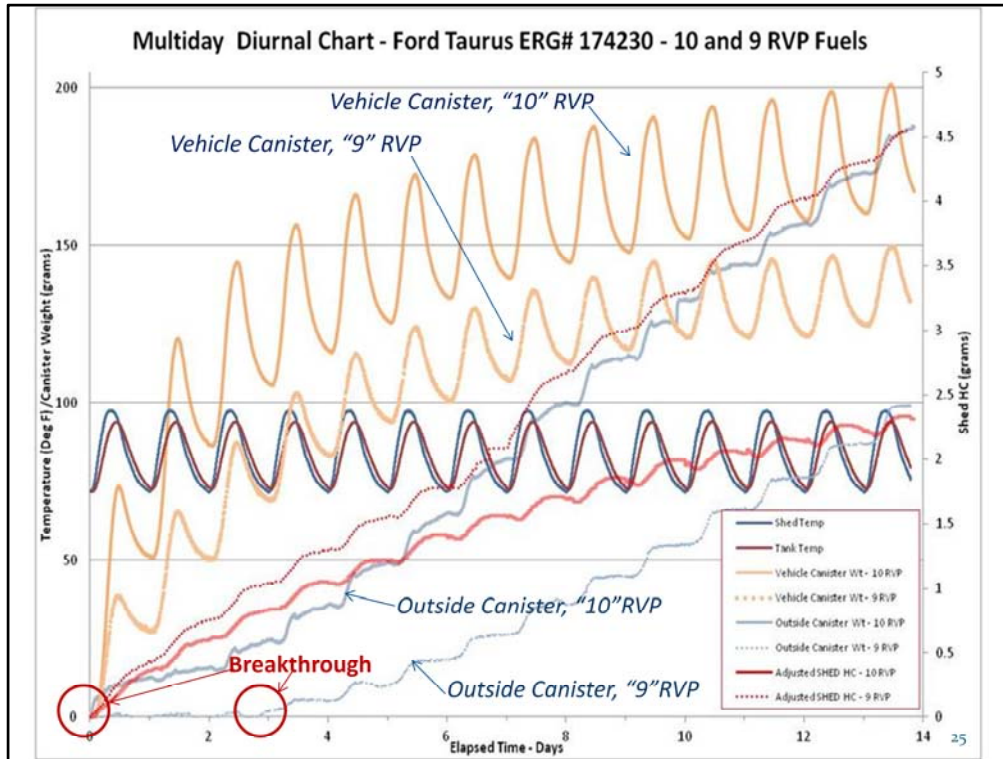
- Drain and Refuel
- 6-36 Hour Soak
- Precondition - 3 Phase FTP With Hot Soak
- Drain and Refuel
- Canister Load to 2 Gram Breakthrough
- Emissions Test - 3 Phase FTP With Hot Soak
- Vehicle Soak Cool Down
- 14 Day VT SHED



SHED Schematic



This slide shows the test layout, how we extended the canister off from the vehicle onto a scale in the SHED. We were able to keep it at the same orientation and level it was on the vehicle to have less interference to real world performance. It shows how we had the fresh air lines available to the canister vent so backpurge could occur naturally, and then a trap canister outside of the SHED to measure any breakthrough or bleed.

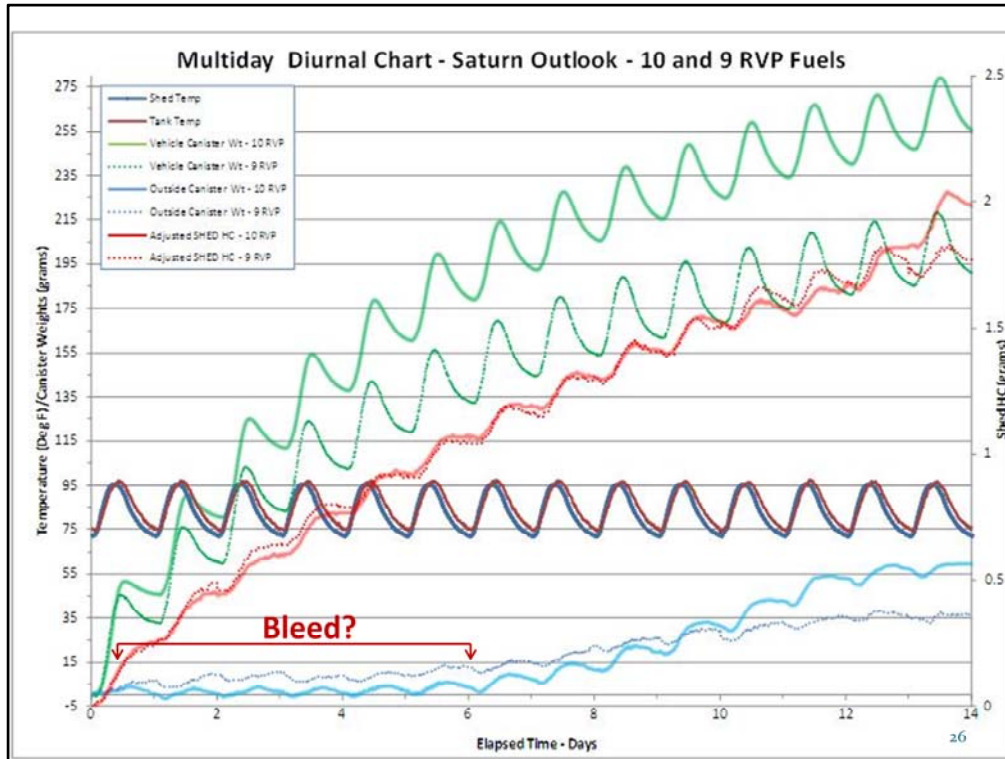


There is a lot on this slide, because we were able to separate so many parts, or “mechanisms” with this test procedure. The bottom is the time in number of days the vehicle was in the SHED.

It also shows the difference in Fuel RVPs. The top two yellow are the vehicle canister, you can see how the weight goes up and down with the temperature (left hand scale) and the backpurge. This was important to get the actual backpurge rate for our model, and then also to see how the HC accumulates on the canister – how much it can hold over the 14 days.

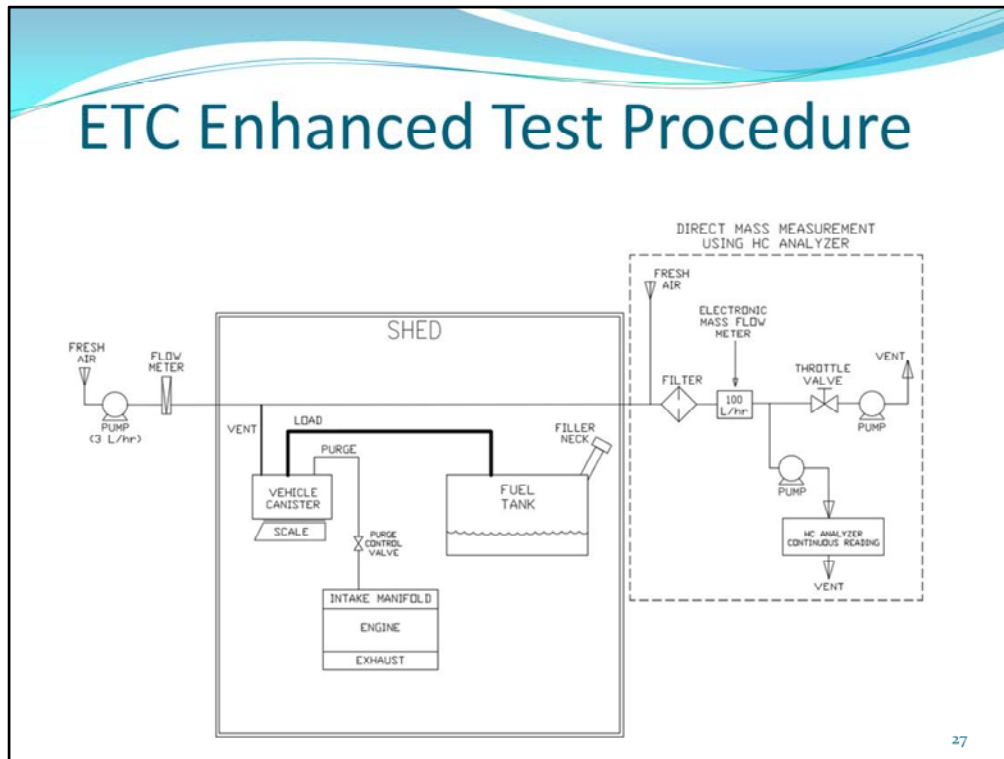
The blue lines show the breakthrough for the two RVPs.

Red lines are Permeation, which is on the right hand scale.



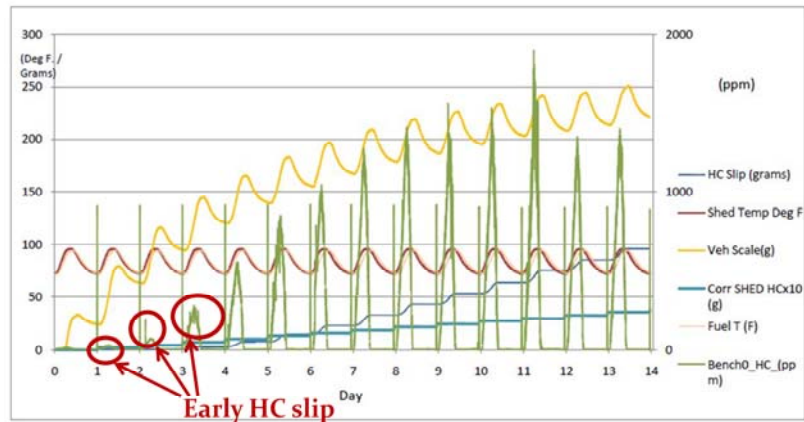
This is similar for a different vehicle. The early ‘bumps’ in the canister breakthrough are unclear, is it “bleed”?

ETC Enhanced Test Procedure



Gerard Glinsky, our contractor at ETC (through ERG), was curious about the previous slide and wanted to better define what was going on. He further refined the test procedure to more accurately measure the “breakthrough”. Instead of weighing a trap canister outside of the SHED, he set up this line to go straight to a FID.

14 Day VT SHED - RVP 10 Fuel SGS Saturn Outlook



Test 4317- Canister was purged before test.

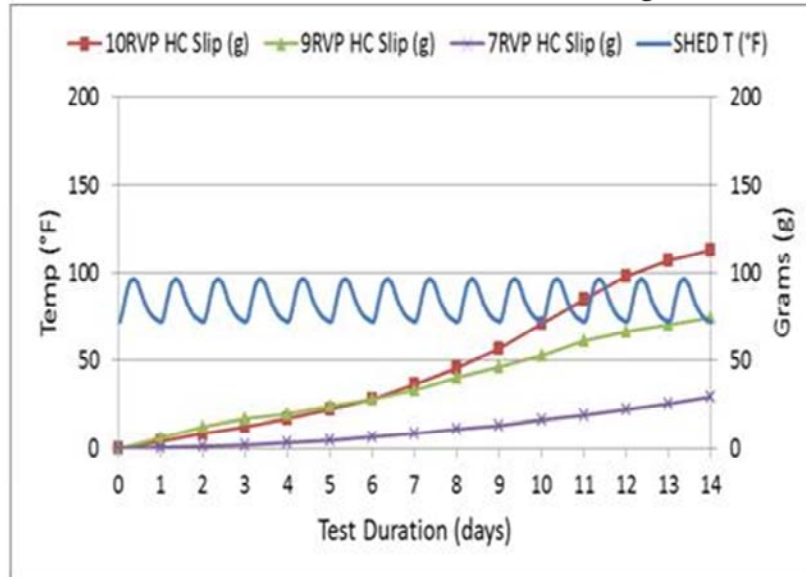
Day	Daily Mass Gains/Losses														Total (g)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
SHED HC (g)	0.212	0.212	0.302	0.278	0.31	0.245	0.277	0.311	0.276	0.266	0.243	0.278	0.312	0.289	3.811
HC Slip (g)	0.076	0.197	0.566	2.101	4.540	6.870	8.160	9.845	10.579	10.211	10.535	11.810	9.918	10.891	96.299
Veh Scale (g)	23.9	39.6	31.9	25.3	19.8	15.4	12.7	11	8	8.4	7.8	5.2	5.2	7.1	221.300

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The results add up to agreement with the previous data, but give much more accuracy in the continuous data. You can now see that what is actually happening is early HC slip events, or “bleed”.

Alliance Added 7 RVP Tests on Six Vehicles

Saturn Outlook Canister Breakthrough



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I presented the multiday results at the CRC Real World Emissions Workshop in March of this year for the 9 and 10 RVP fuels. The response from the autos was that we needed 7 RVP fuel to go with this dataset for our modeling. The Auto Alliance contracted directly with SGS/ETC and were able to test 6 vehicles which were still available from the original test program.

Here are the breakthrough results for one vehicle. You can see that the 7 RVP does not breakthrough for three additional days, as expected.

Running Loss Program Objectives

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Running Loss (RL) Testing

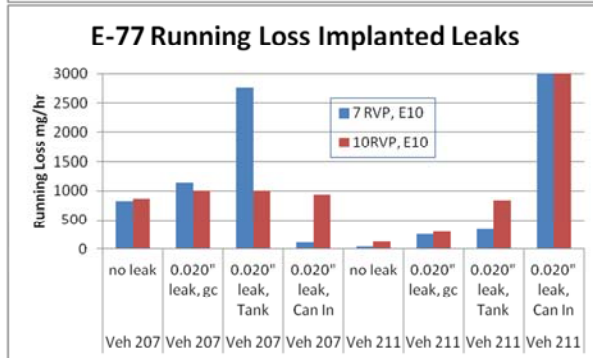
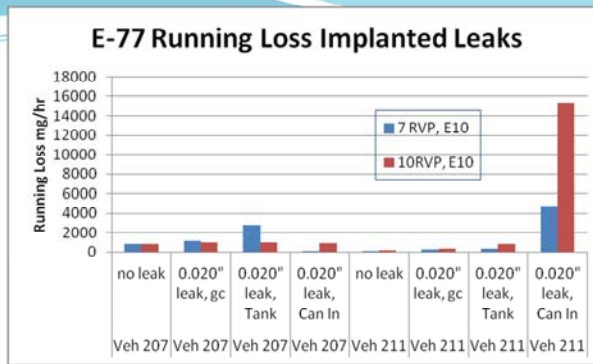
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Need for Running Loss (RL) Data

- We have little to no RL data with leaks for aging enhanced evap vehicles
- E-77 data suggests that implanted and real-world leaks can impact RL emissions
- We need to understand the impacts of different size leaks on RL emissions

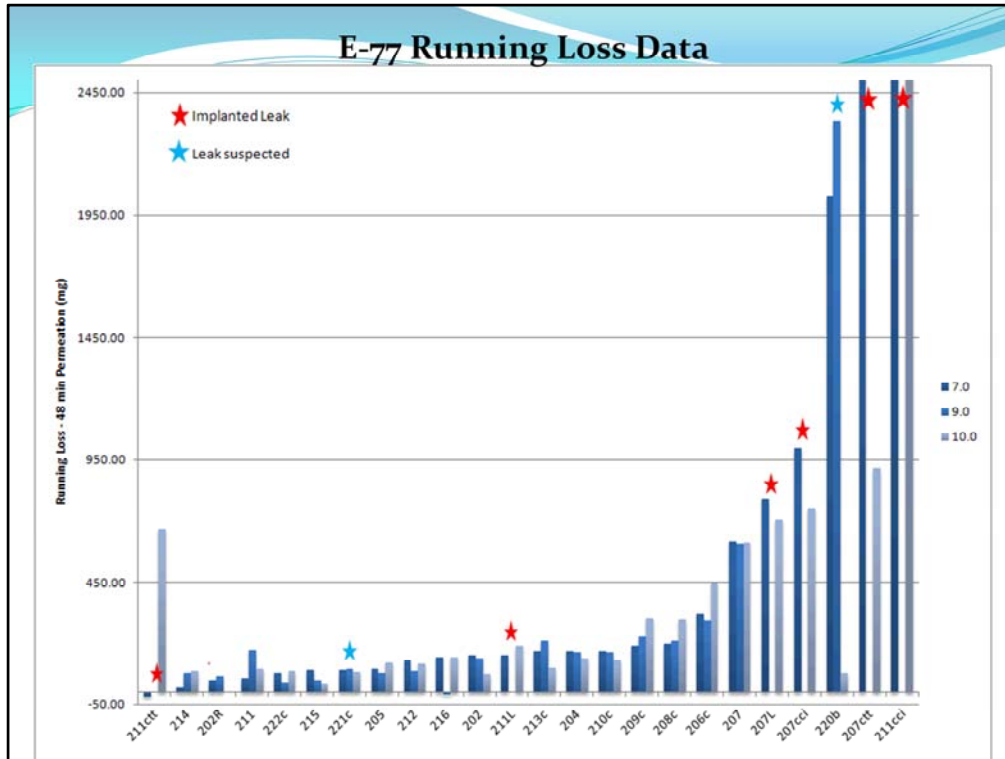
Implanted leaks do show RVP effect.

Location affects quantity of emissions.



This graph shows how the magnitude of emissions can change for the same size leak, but in different locations and different RVPs.

These are both the same picture, bottom is blown up to see more detail.



This is just another look at the RL emissions from E-77 with all of the vehicles. The different blue bars are the varying RVPs, the red stars indicate a leak we implanted, the blue stars are the randomly recruited vehicles that look like they contain a leak based on their Static test.

It highlights even more how the location of the leak can make a difference: “cci” is canister inlet, “tt” is top of tank, “L” was the original implanted leak at the gas cap.

Running Loss Test Program

- Contractor SGS/ETC through ERG
 - Previous experience in Multiday program
 - Flexible with new procedures and “out of the box” thinking
 - Local lab to eliminate altitude issue for purge rates
 - Ford Allen Park Testing Laboratory (APTL)
- Currently in progress
 - Complete early 2013

RL Laboratory Test Program

- **Vehicles:**
 - 5 - 2004-2011 (from EPA fleet)
 - Choosing based on temperature profiles
- **Fuels:**
 - E10 7 RVP
 - E10 10 RVP
- **Initial testing in as received condition**
 - Check vehicle for leaks, Snap-on to find cumulative diameter of all "leaks"
 - FTP prep, Hot Soak, Static Sequence
 - Running Loss test
 - Snap-on leak test
- **Implant 0.020" leak (top of tank / canister connection); repeat sequence**
- **Implant 0.040" leak same location; repeat sequence**
- **Adding new cycle for 2 vehicles, LA92 for highway driving**

*Testing at Ford Lab
In Dearborn*

*- Total of 70 tests
- Currently in process
- Complete early 2013*

What Have We Learned?

- We now know more about:
 - Ethanol and RVP fuel effects
 - Leak emissions
 - Frequency of leak emissions
 - Multiday diurnal emissions
 - canister breakthrough for different fuel RVPs
- Testing will provide a better understanding of RL emissions with leaks.

Future Research

- Canister Degredation Study
 - Look at in-use canisters:
 - different parts of country
 - Weather /temp conditions
 - Dust/salt
- Develop Real World Evap Test Procedure
 - Driving on roadway not same as dynamometer for purging
- Activity Study
 - Dataloggers over 6-12 months
 - Capture whole households, including rarely-used vehicles
 - Capture vacations, other gaps in driving

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- Multi-Day Diurnal Testing
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