Approach for Modeling Evaporative Emissions in MOVES

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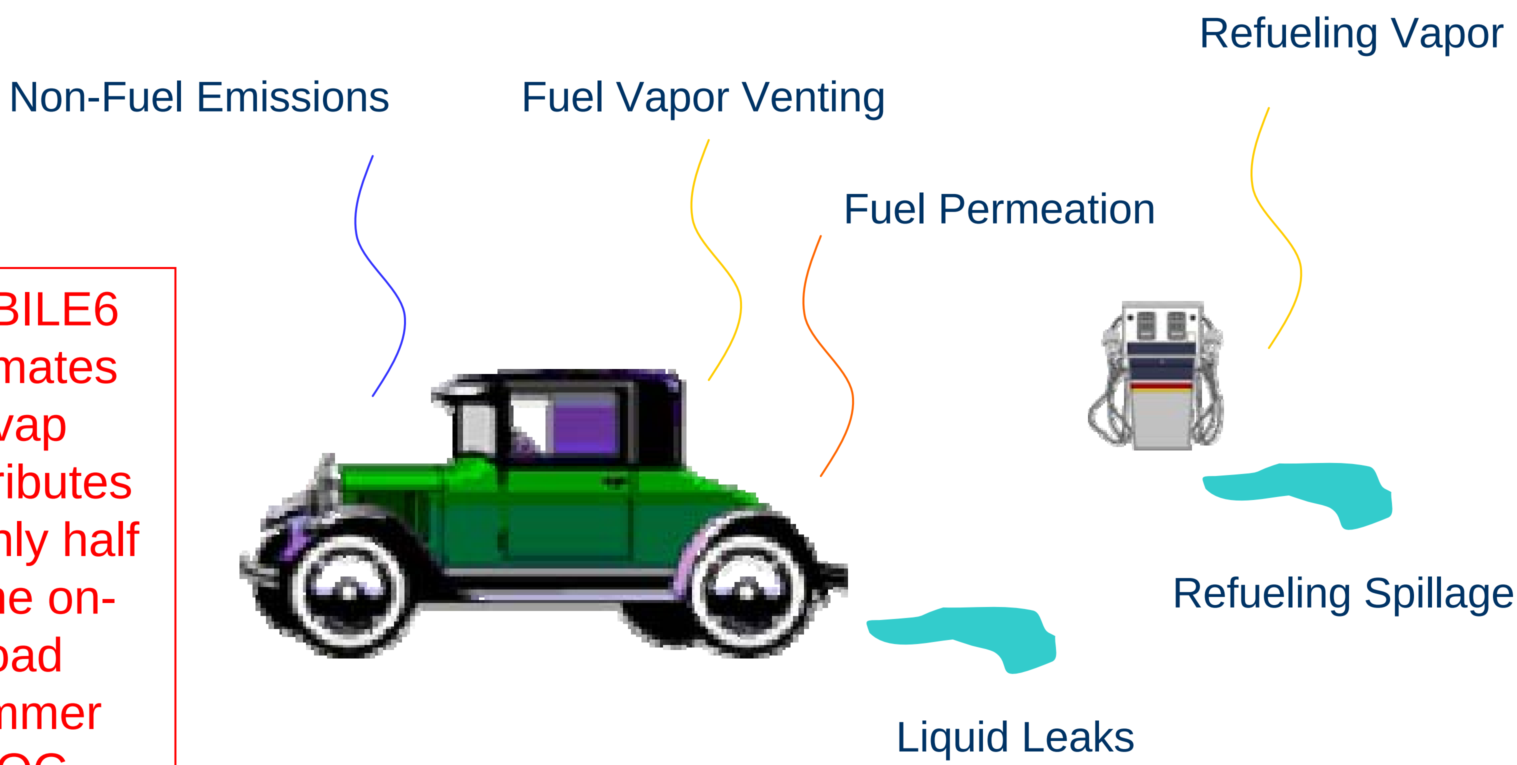
Evaporative emissions a combination of many processes



MOBILE6 estimates evap contributes roughly half of the on-road summer VOC inventory

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Objectives for MOVES evaporative component

- **Use most recent data**
- **Better allocation of evaporative emissions by space and time**
  - Evaporative emissions no longer coupled to VMT
- **Dynamically consistent activity information**
  - Trip starts, trip ends, soak times, trip times by hour
- **Explicit treatment of EtOH permeation**
  - Improve inventory
  - Energy Policy Act analysis

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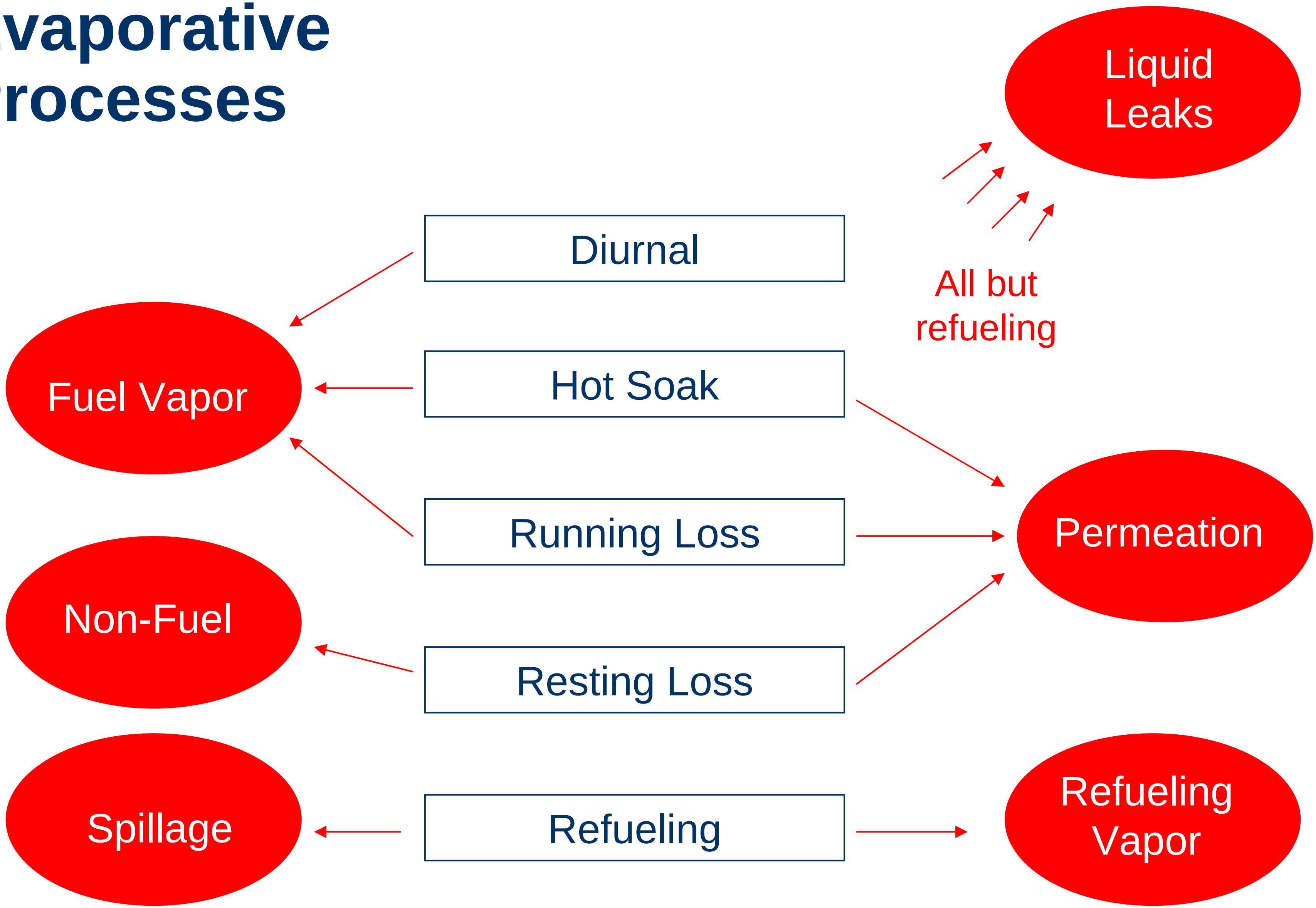
Scope of MOVES evaporative component

- **Fleet average fuel tank temperature and emissions grouped by:**
  - Hour of the day
  - Vehicle classes (LDV, LDT, HDV>14K, HDV>14K)
  - Model year
- **Not attempting to model**
  - Individual vehicles
  - Real-time emissions
  - Canister loading and purge cycles

Design Scoping

- **Contracted HH&A to recommend new approach**
  - "A New Approach to Modeling Vehicle On-Road Vehicle Evaporative Emissions", June 2005
- **Key recommendations**
  - Redefine evaporative breakdowns to match physical processes
    - Increased focus on permeation
  - Use time-based emission rates instead of mile-based
  - Do more testing
    - New permeation test procedure
    - Better define the shape of the EtOH "curve"
    - Liquid leak rates
    - Non-fuel emissions (e.g. upholstery)

Mapping Evaporative Processes



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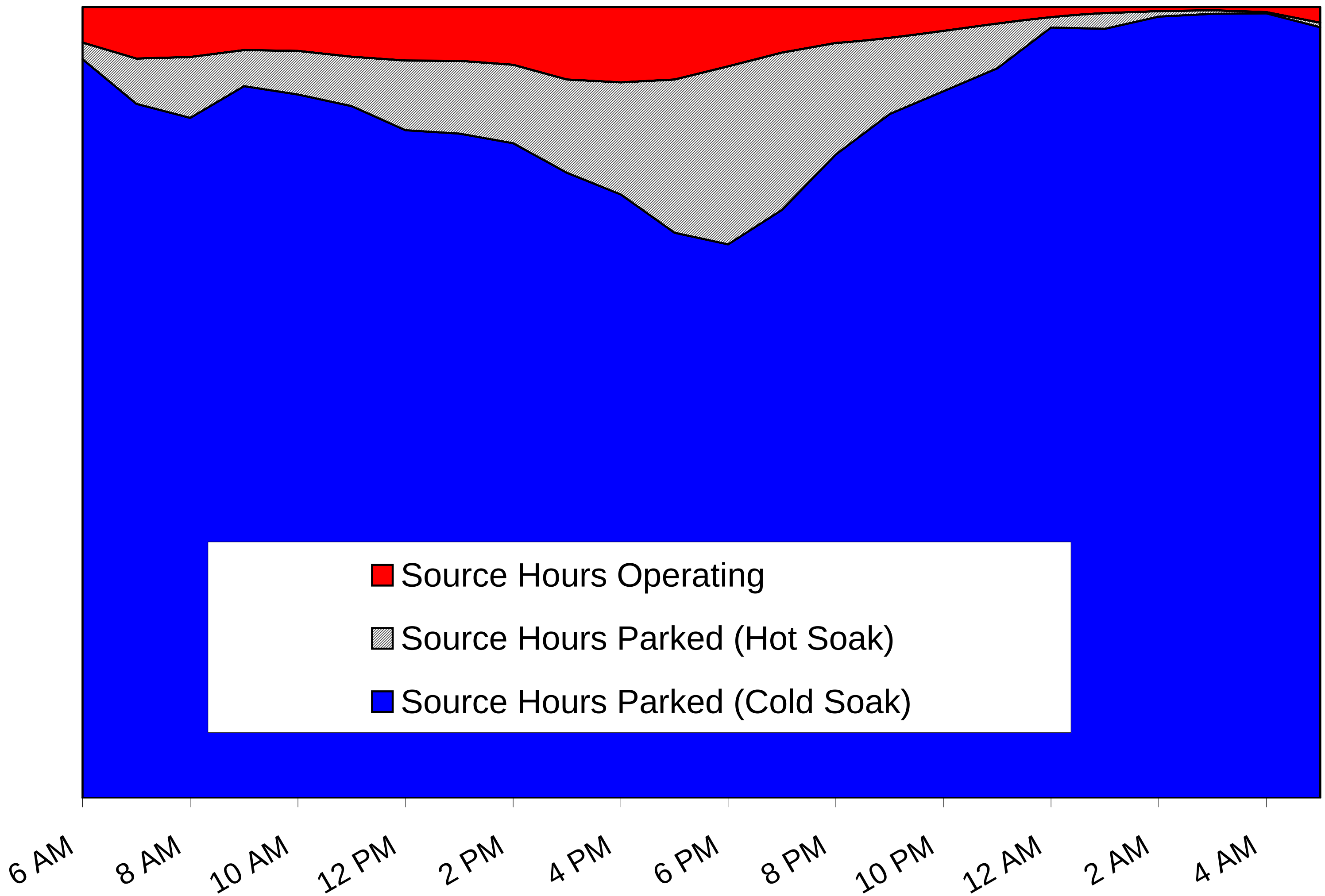
Activity Approach

- **Time basis for activity**
  - Source hours parked (SHP)
    - Split into "cold soak", "hot soak" modes
  - Source hours operating (SHO)
    - For "running" mode
- **Allocated independently of VMT**
  - Distribution of hours parked (when, how long) calculated within MOVES via sample trip data
  - Geographic allocation factor can account for commute and parking patterns

Breakdown of Evaporative Mode Based on Sample Trips

Maricopa County, AZ Typical September Day
Enhanced Evap Vehicles



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Fuel Tank Temperature is Central

- Fuel temperature main driver for permeation and vapor venting emissions
- Depends on day-to-day vehicle operating pattern
- MOVES will estimate real-world fuel temperature based on sample trips
- Hourly averages by mode (cold soak, hot soak, operating) will be used to calculate emissions

Fuel Tank Temperature Algorithm

- **Permeation and Fuel Vapor Venting calculations will use estimated fuel tank temperatures averaged by:**
  - Hour of the day
  - Mode: Cold Soak, Hot Soak, Operating
  - Tank Temp Group: pre-enhanced LDV, pre-enhanced LDT, enhanced and later
- **To produce these averages first requires estimating temperature over individual trip patterns**
  - “Sample Vehicle Trip” input table contains summary information on individual vehicle trips from instrumented data (trip start time and end time)

Cold Soak Fuel Tank Temperature

In theory:

$$\frac{dT_{Tank}}{dt} = k(T_{air} - T_{Tank})$$

- Newton's law of cooling: Rate of tank temperature change is directly proportional to difference between ambient and tank temperatures
- Ambient temperature changes in a non-linear fashion
- Used computational programs (Matlab® and Simulink®) to validate and find *k* to match MSOD data
- Allows us to model any temperature cycle

Cold Soak Fuel Tank Temperature

MOVES must integrate numerically, quickly…

Euler integration: $$(T_{Tank})_{n+1} = T_{Tank_n} + k(T_{air} - T_{Tank})_n \Delta t$$

- *Initial tank temp = ambient temp*

- *k=1.4*

-*MOVES uses 15' time increments (Δt = 15') for this calculation, then averages by hour*

Operating Fuel Tank Temperature

- **Estimates temperature at beginning and end of each sample trip (or hour breakpoint if trip spans top of the hour)**
  - ΔTemperature from Fuel Tank Temperature Profiles @ 95 deg
    - Pre-enhanced: CRC E-35; Enhanced: Certification FTTPs (thank you)
    - Pre-enhanced LDV = 35°, Pre-enhanced LDT = 29°; enhanced all = 24°
  - Need to scale ΔTemperature to actual key-on temperature

$$\Delta T_{Tank} = 0.352(95 - T_{Tank,KeyON}) + \Delta T_{Tank95}$$

SAE 930078

    - The higher the starting temperature, the lower the temperature increase
  - Calculate key-off temperature assuming linear increase in temperature during trip (includes scaling back ΔTemperature to 1 hour)

$$T_{Tank} = \frac{\Delta T_{Tank}}{4300/3600}(t - t_{keyON}) + T_{Tank,KeyON}$$

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Capped @ 140°

- **Hourly average = average of key on & key off times weighted by sample trip length**

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Hot Soak Fuel Tank Temperature

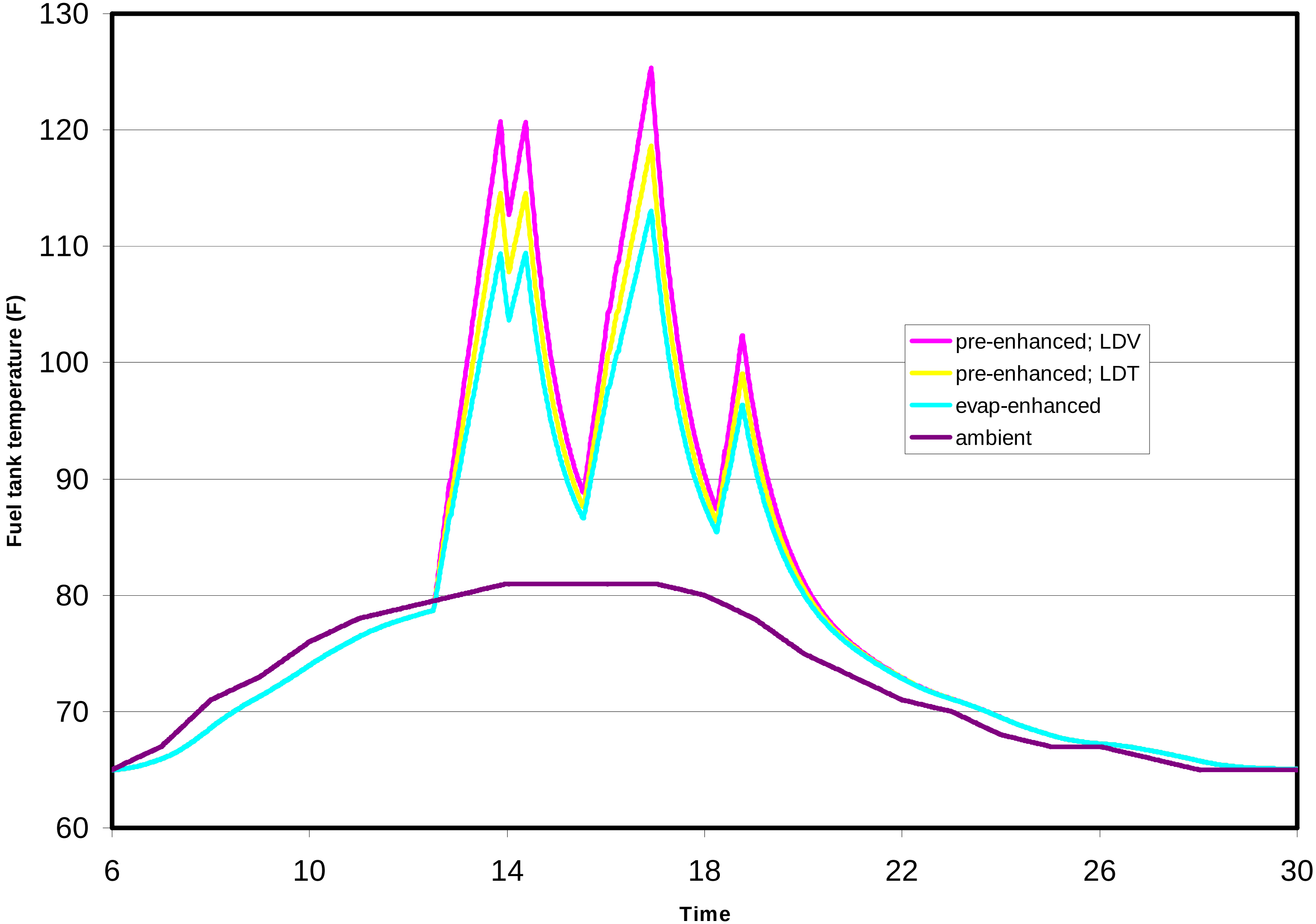
Euler integration, same method as cold soak:

$$(T_{Tank})_{n+1} = T_{Tank_n} + k(T_{air} - T_{Tank})_n \Delta t$$

- *k=1.4*
- *Initial temp = key-off temp from previous trip*
- *MOVES uses 1' time increments for this calculation, then averages across each hour*
- *1' used since temperature drops rapidly during hot soak*

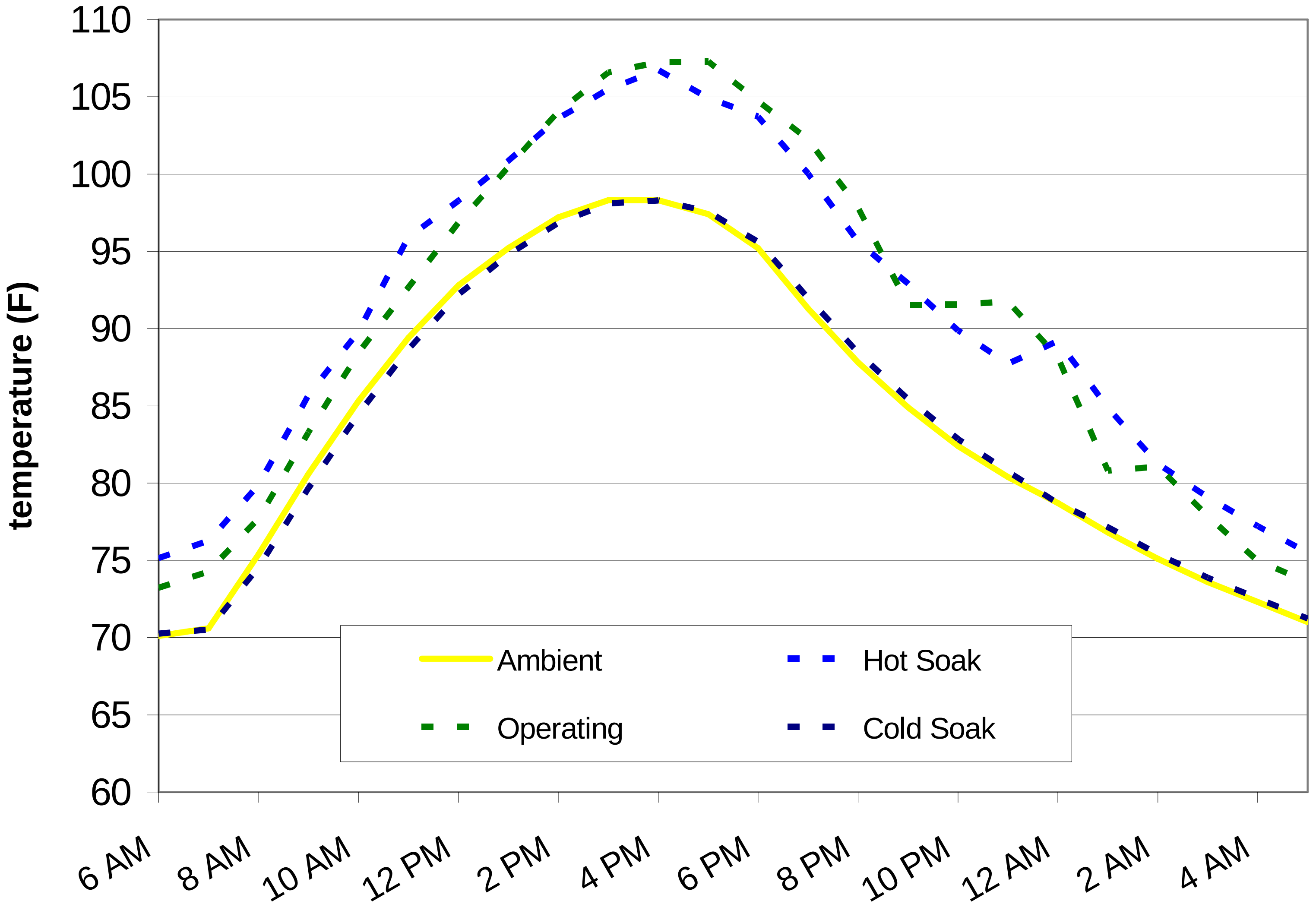
Estimated Fuel Tank Temperature Profile For a Single Vehicle

Washtenaw County Typical July Day



Estimated Average Fuel Tank Temperature Based on Sample Trips

Maricopa County, AZ Typical September Day
Enhanced Evap Vehicles



Evaporative Emission Sources

- **Historical EPA Testing (MSOD)**
- **Recent CRC Programs**
  - E-9, E-35, E-41, E-65
- **EPA Compliance Data (enhanced evap)**
- **E-77 underway**
  - Pilot program to focus on aging enhanced vehicles
  - Includes permeation testing, “off-cycle” diurnal
- **EtOH effects**
  - E-65 & 65.3, EPA sponsored gas can program

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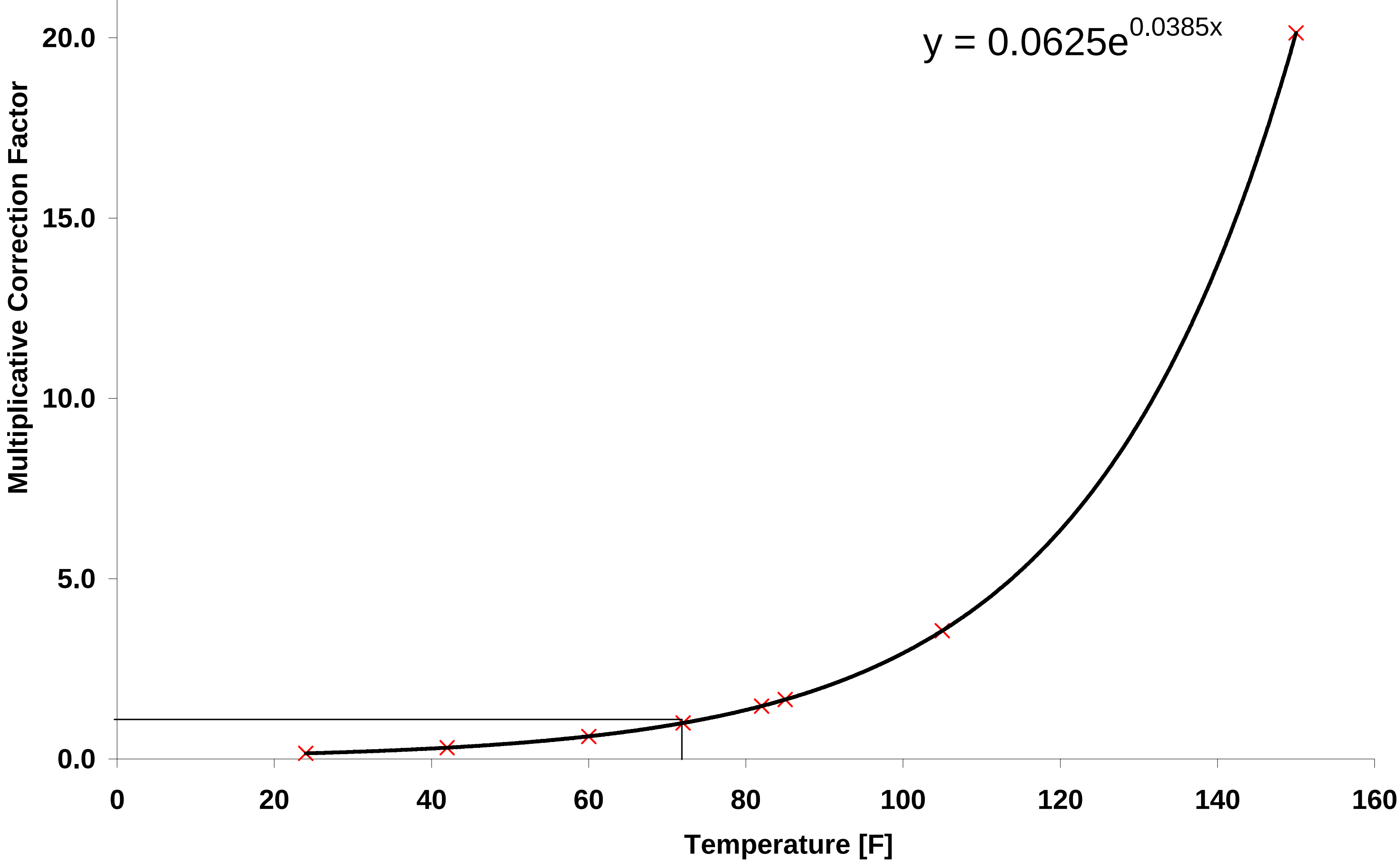
Permeation

- Base rates @ fuel temp = 72°
- Stratified by model year group and age group
- Adjustments: fuel temp, EtOH
- Only difference in emissions over cold soak, hot soak and operating is fuel tank temperature

Permeation Tank Temperature Adjustment

Based on relationship established by Lockhart, et al (SAE 2001-01-0730) – permeation doubles per 10° C

Consistent with E-65 and EPA test results



Future Assumptions - Permeation

- **No deterioration of permeation emissions on enhanced evaporative and later vehicles**
- **No reduction in permeation emissions with Tier 2 / LEV II standards (reduction attributed to fuel vapor venting)**
  - AAM has commented that permeation emissions should be reduced with standard
- **Will re-evaluate as new data becomes available, e.g. E-77**

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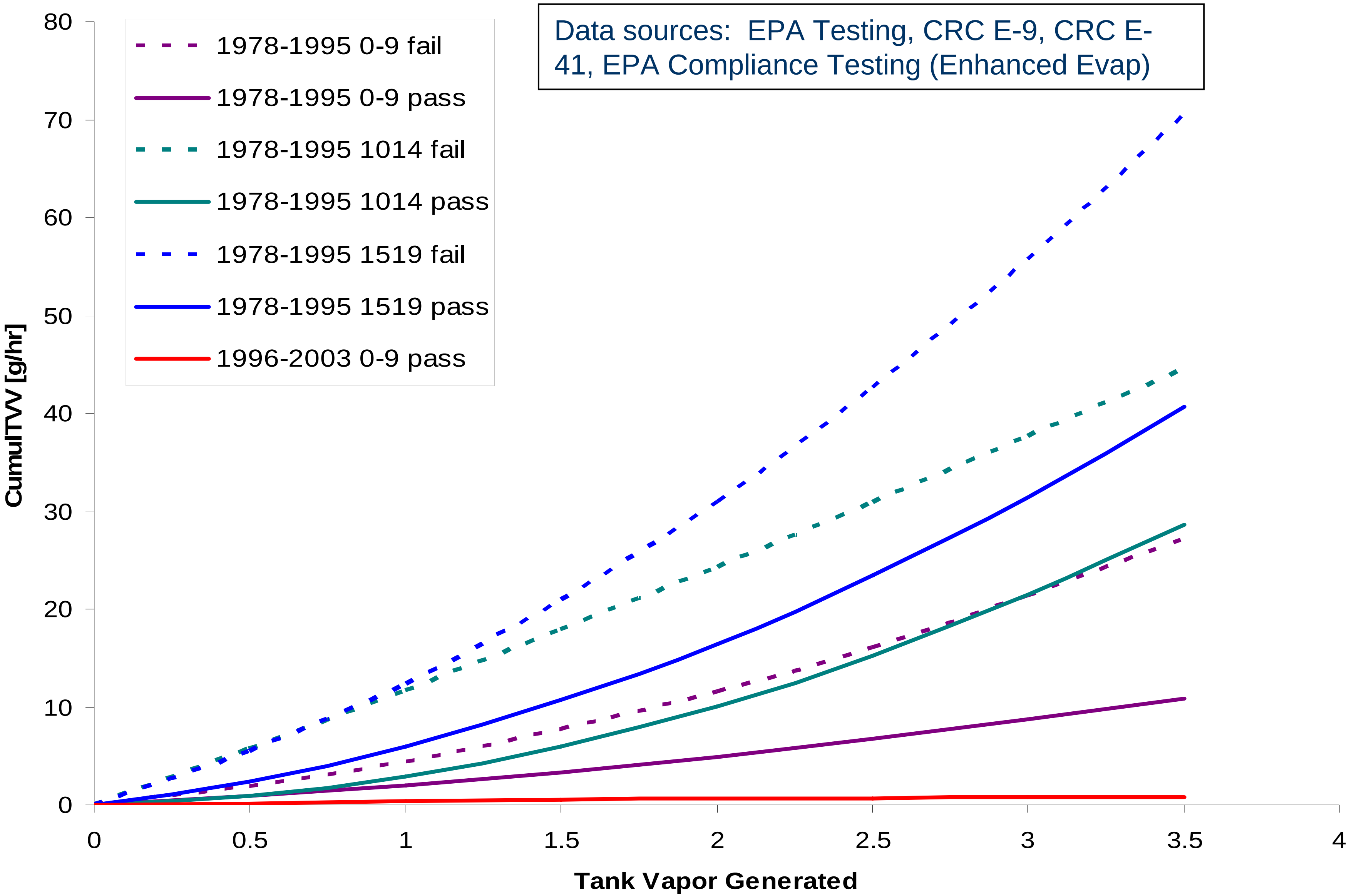
Fuel Vapor Venting

- **Hot Soak & Running**
  - Average available gram/hour emission test results
  - Hot Soak $Emissions_{hour}$ = SHP * hot soak rates
  - Running $Emissions_{hour}$ = SHO * running rates
- **Cold Soak (diurnal)**
  - Tank Vapor Generated ≈ f (Δ temp, RVP, EtOH)
    - Reddy, SAE Paper 892089 ($A\ e^{B(RVP)}\ (e^{CT2} - e^{CT1})$)
    - A,B,C depend on altitude and EtOH volume
  - Cumulative HC emissions ≈ f (TVG)
  - Cold Soak $Emissions_{hour}$ =

$$SHP * \sum^{\text{Initial hour}} (cumHC_{hour} - cumHC_{initial\ hour}) * \text{fraction of soaks starting in initial hour}$$

Cumulative TVV vs. Tank Vapor Generated



Fuel Vapor Venting, cont.

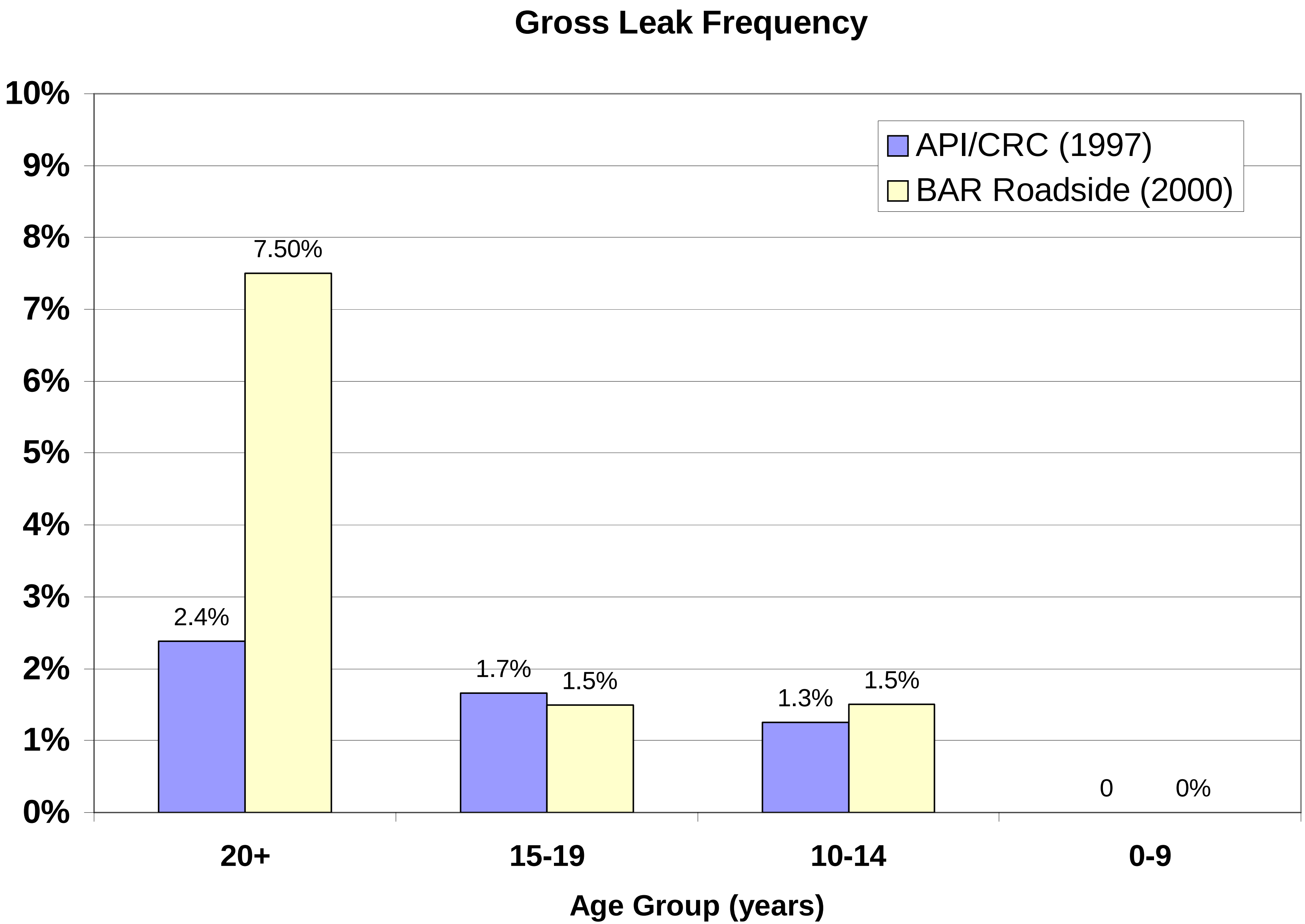
- **Limited data requires weighting pressure test pass/fail strata outside MOVES to approximate representative rates**
- **Develop weightings based on pressure test failure, gas cap failure & non-gross liquid leak rates for pre-OBD vehicles**
  - Sources: BAR roadside studies, CRC E-9/35/41, API/CRC liquid leak survey
- **Develop weightings from OBD Evaporative MIL rates for OBD vehicles**
  - Look at “new” OBD IM programs where there is less chance of learning curve

Future Assumptions – Fuel Vapor Venting

- **Passing vehicles**
  - No deterioration of fuel vapor emissions on “passing” enhanced evap and later vehicles
  - Reduction in fuel vapor emissions from LEV II standards based on ratio to standards
- **Failing vehicles**
  - Emissions on failing vehicles same as pre-enhanced
  - Failure rates based on “new” IM OBD program leak code rates (P0442, P0455, P0456, P0457)
  - For ages for which OBD data doesn’t exist yet, assuming residual failures due to gas caps and non-gross liquid leaks

Liquid Leaks

- **Gross leaks – i.e. dripping fuel**
  - Less severe leaks accounted for in FVV rates
- **Small frequency but very high emissions; could drive evap inventory even if < 1% of fleet**
- **Only data on emissions from 70-80's vehicles**
  - but a drop of fuel is a drop of fuel…?
- **Available data on frequency differs significantly**
  - Would be great to have an update of 1997 API/CRC study
  - Lower frequency of leaks on old fuel injected vehicles? Or will people inadvertently drill holes in fuel tanks at the same rate?
- **Assuming for the future that gross leak emissions and frequency rates are not affected by evap standards or OBD**



Gross Leak Frequency
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
API/CRC (1997)
BAR Roadside (2000)
7.50%
2.4%
1.7%
1.5%
1.3%
1.5%
0
0%
20+
15-19
10-14
0-9
Age Group (years)

Refueling

- **Split into spillage and vapor**
- **g/gallon emission rates * fuel consumption**
  - allows refueling emissions to reflect changes in fuel consumption as estimated by MOVES
- **Varies by model year (ORVR), location (Stage II)**

Non-Fuel Emissions

- **Combination of several things**
  - Fluids (e.g. wiper)
  - Tires
  - A/C refrigerant
  - Upholstery and adhesives
- **Will be encompassed in MOVES2006 permeation and fuel vapor emissions**
- **Will consider breaking out for MOVES2007**

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Possible Inventory Trends vs. MOBILE6

- ⇩ Current data on enhanced evaporative vehicles shows very low permeation and fuel vapor venting emissions; data on aging enhanced evap vehicles is needed

- ⇧ EtOH permeation effects relative large; not included in MOBILE6

- ⬄ Liquid leaks large in MOBILE6, may continue to drive inventory for MOVES