ASSESSMENT OF AMMONIA EMISSIONS FROM GASOLINE VEHICLES USING ON-ROAD EMISSION TESTS

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RESEARCH MOTIVATION

The Wasatch front is known to have high concentrations of $PM_{2.5}$, for instance, in January of 2004, $PM_{2.5}$ was measured at 132.5 μg/m^3. According to (Malek et al., 2006), this incident is considered the "worst ever" PM pollution episode in the country

On a bad winter day, up to 70 percent of the airborne particulates, called $PM_{2.5}$ because they measure less than 2.5 microns, are ammonium nitrate (NH_4NO_3).

(The WaFACO study)

$$NH_3\ (gas) + HNO_3\ (gas) \rightarrow NH_4NO_3\ (Solid)$$

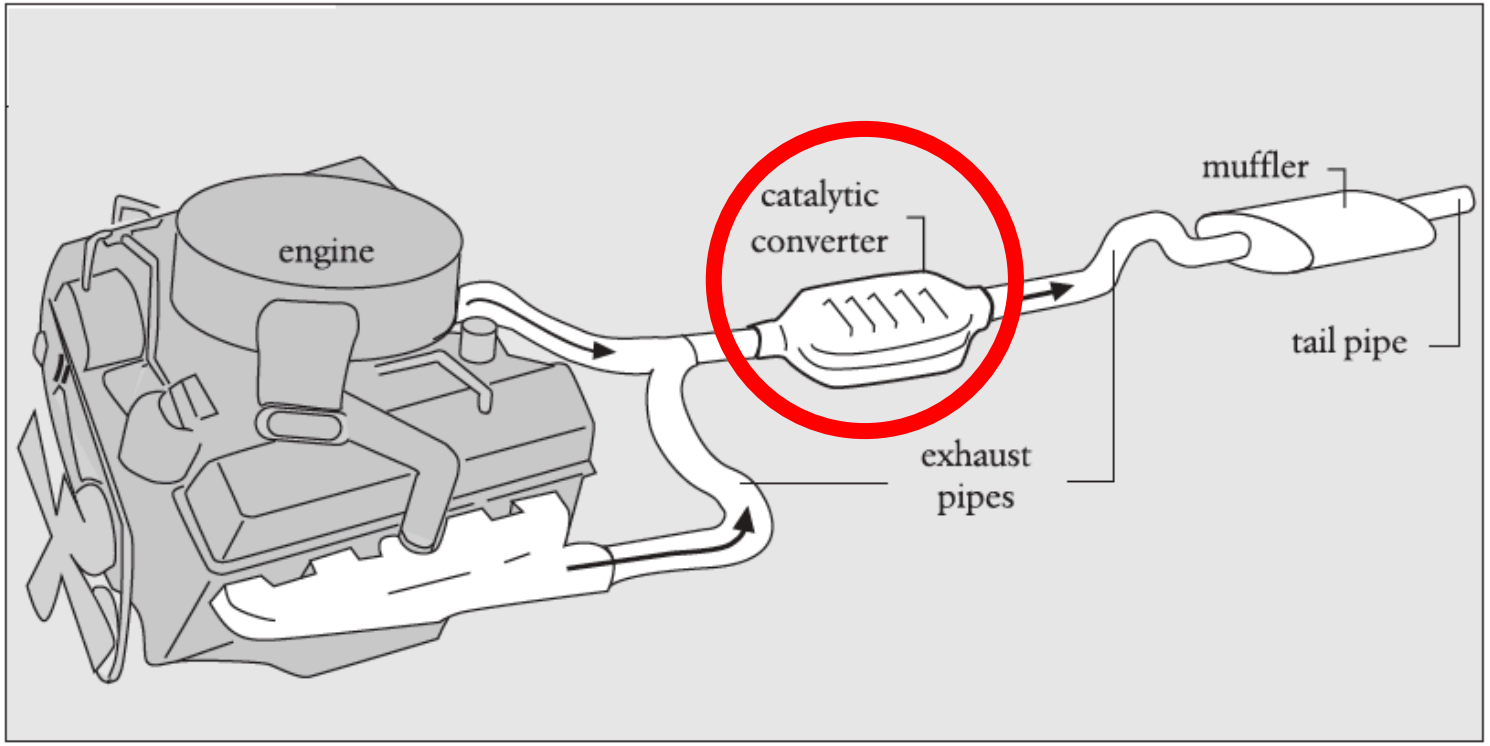
$$2NH_4OH\ (gas) + H_2SO_4\ (gas) \rightarrow (NH_4)_2SO_4\ (Solid) + 2H_2O$$

$$2NH_3\ (gas) + H_2SO_4\ (gas) \rightarrow (NH_4)_2SO_4\ (Solid)$$

INTRODUCTION

- Catalytic convertors are small canister of a series of ceramic screens coated with rare metals platinum (Pt), palladium (Pd) and rhodium (Rh)

- Aside from their ability to control exhaust CO, unburned HC and NOx emissions, catalytic convertors have been causing unintended substantial increase in emissions of exhaust ammonia.



Catalytic converter (Source Kidd & Kidd, Air pollution, problems and solutions, 2006)

INTRODUCTION

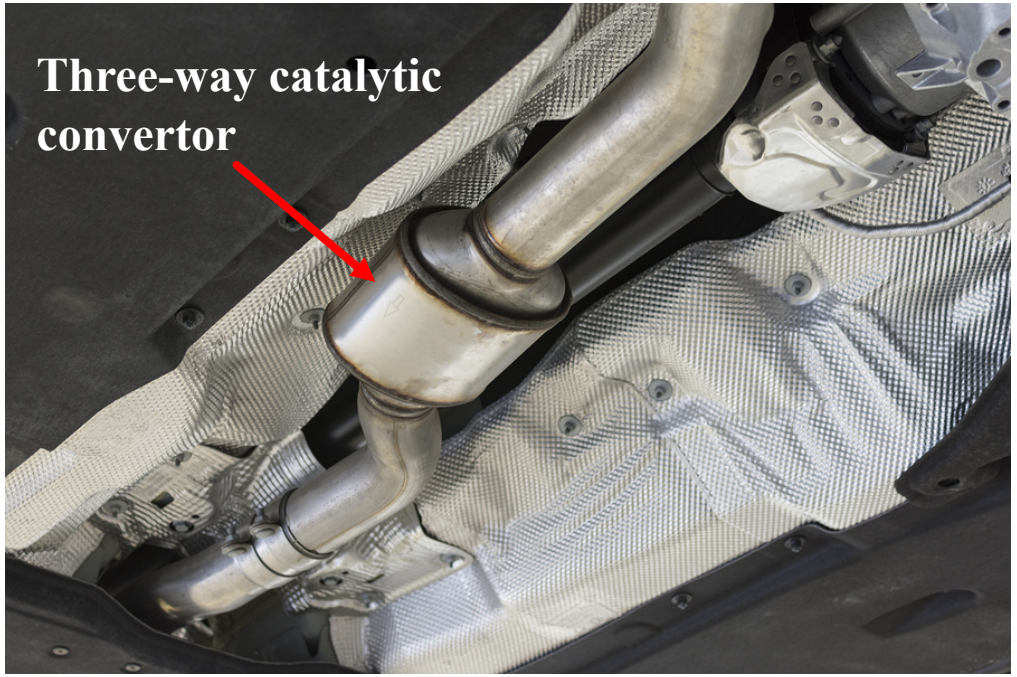
- **Oxidation catalytic convertors**

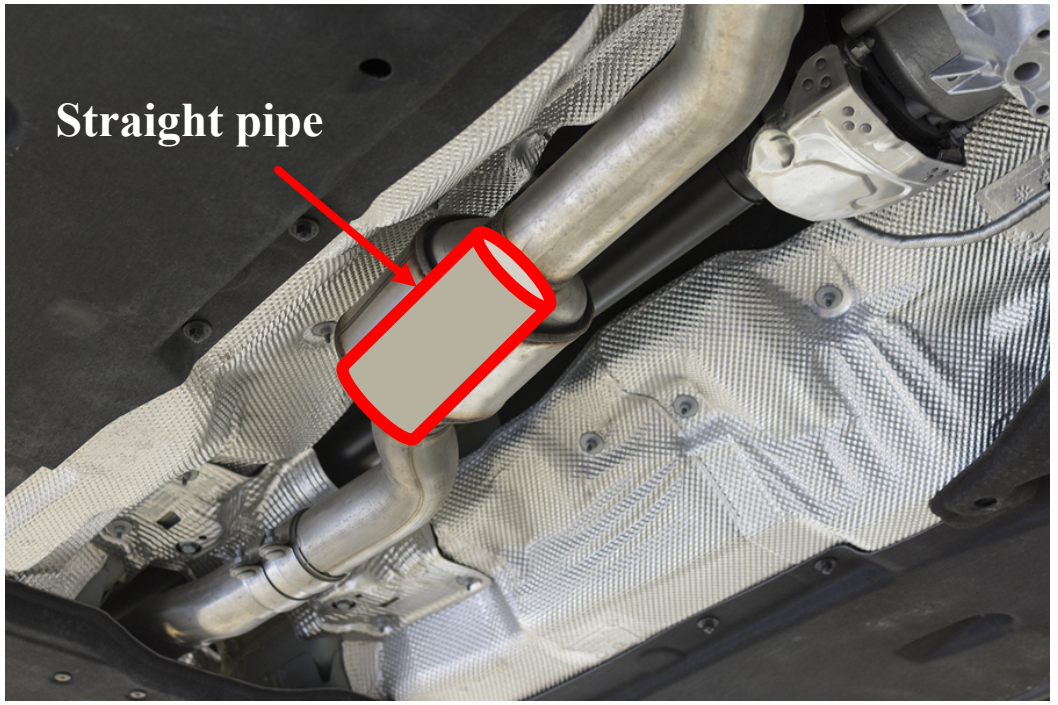
1. Used on diesel motor vehicles
2. Control CO and HC exhaust emissions
3. Consist of one ceramic block coated with platinum (Pt) and palladium (Pd).

- **Three-way catalytic convertors**

1. Used on gasoline motor vehicles
2. Control CO, HC and NOx exhaust emissions
3. Consist of two ceramic blocks. First block is coated with platinum and rhodium metals, whereas the second block is coated with platinum and palladium.

INTRODUCTION





- $CO + H_2O \rightarrow H_2 + CO_2$
- $2NO + 2CO + 3H_2 \rightarrow 2NH_3 + 2CO_2$
- $2NO + 5H_2 \rightarrow 2NH_3 + 2H_2O$

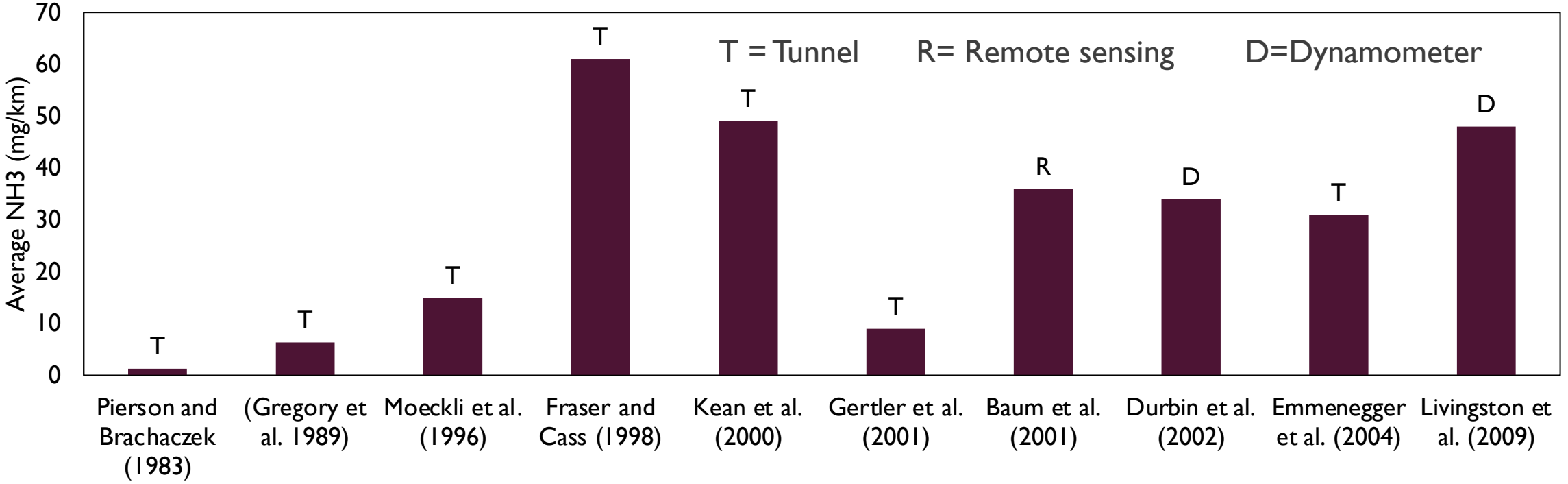
NH_3 : 19-24 mg/mile

NH_3 : 0.3-8 mg/mile

Cadle, Steven H. and Patricia A. Mulawa. 1980. "Low-Molecular-Weight Aliphatic Amines in Exhaust from Catalyst-Equipped Cars." *Environmental Science & Technology* 14(6):718–23.

INTRODUCTION

- Previous tunnel, dynamometer and remote sensing studies have also shown that after ammonia emission rates increased after the introduction of catalytic convertors.



Average ammonia emissions rates measured from previous studies

MAIN OBJECTIVE

Assessment of ammonia emissions from gasoline vehicles using on-road emission tests

- **Portable pollution emissions monitoring system**

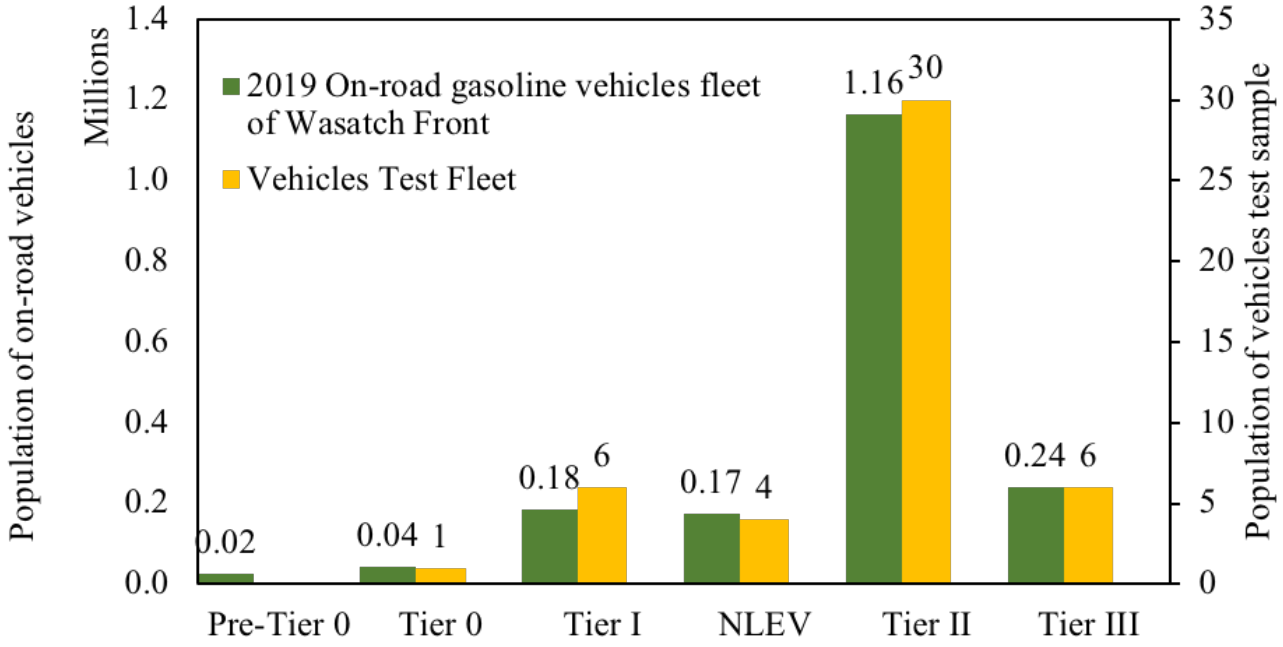
Tailpipe ammonia emissions are estimated over real on-road driving emission tests using a potable pollution emissions monitoring system carried on tested vehicles.

METHODOLOGY

- **Vehicles Recruiting (Desire to replicate local distribution**

Populations and tier standard of gasoline vehicles in the Wasatch Front, U.S. State of Utah

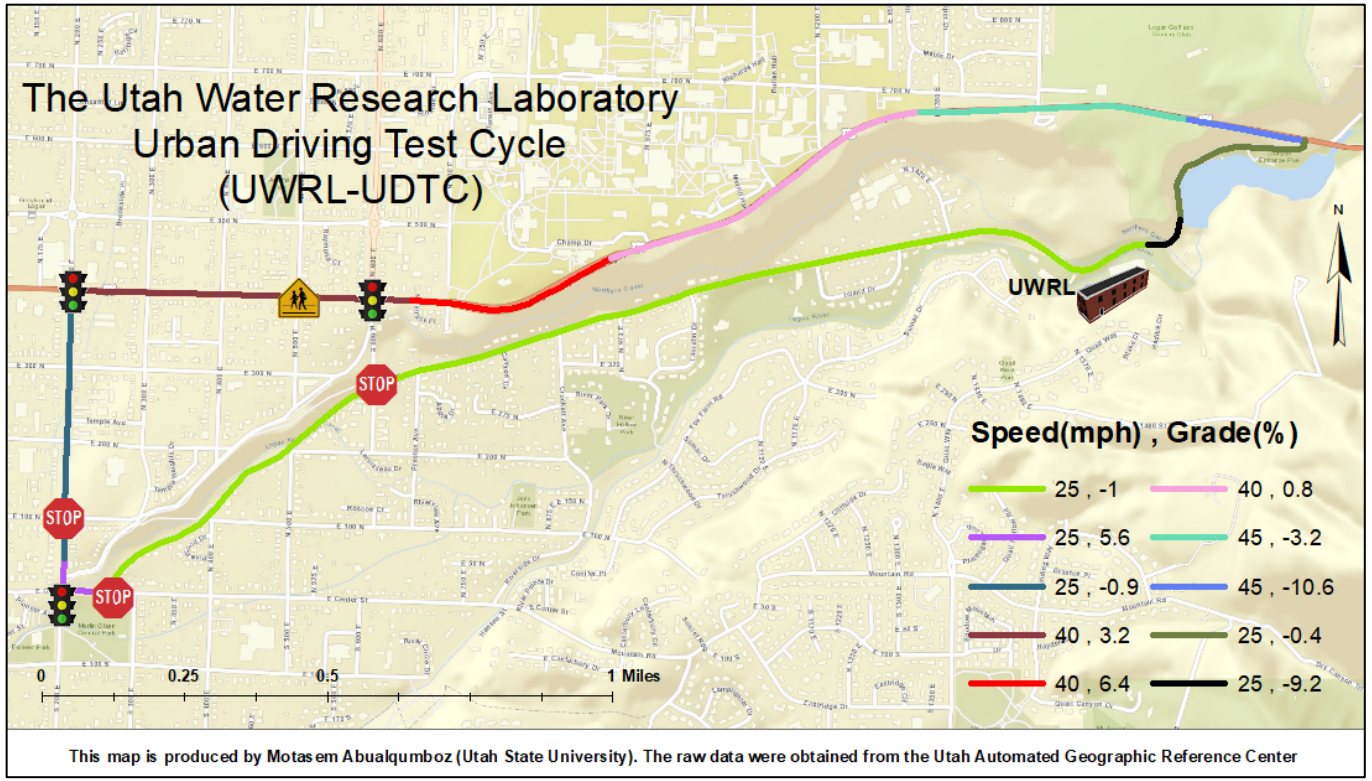
Model Year (MY)	Tier Standard	Population
< 1981	Pre-Tier 0	24,667
1981 -1993	Tier 0	42,304
1994 - 2000	Tier 1	183,726
2001 - 2003	NLEV	174,037
2004 - 2016	Tier 2	1,163,123
2017 +	Tier 3	238,728
Total		1,826,584



Tier Standard classification of on-road vehicles of the Wasatch Front, Utah and the sample fleet

METHODOLOGY

- **Testing Cycle**

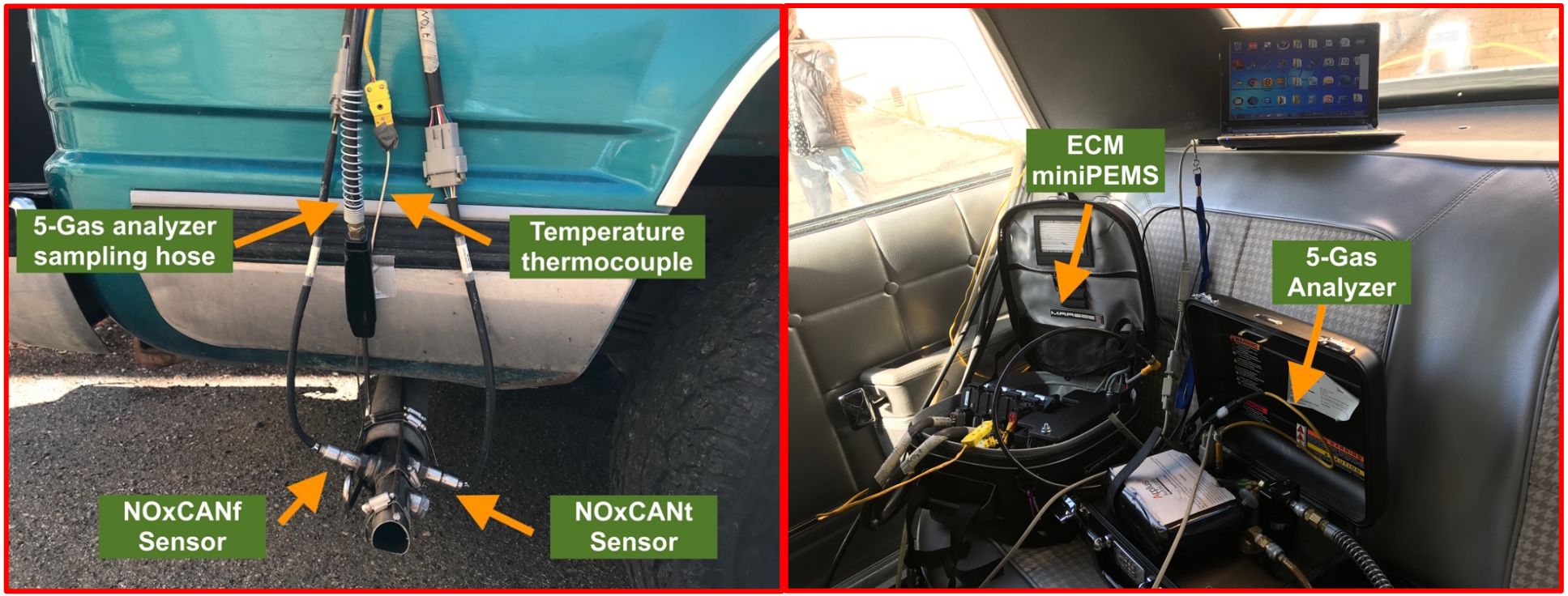


The Utah Water Research Laboratory Urban Driving Test Cycle (UWRL-UDTC)

- Total Length, 5.3 miles
- Speed limits: 25, 40 and 45 mph
- Roads grades : uphill and downhill segments
- Has 3 traffic lights, 2 4-way stop signs and one 2-way stop sign.
- School zone with reduced speed limit from 40 to 25 mph.
- Many pedestrian crossings

METHODOLOGY

- **Instrument- 5 Gas Analyzer**

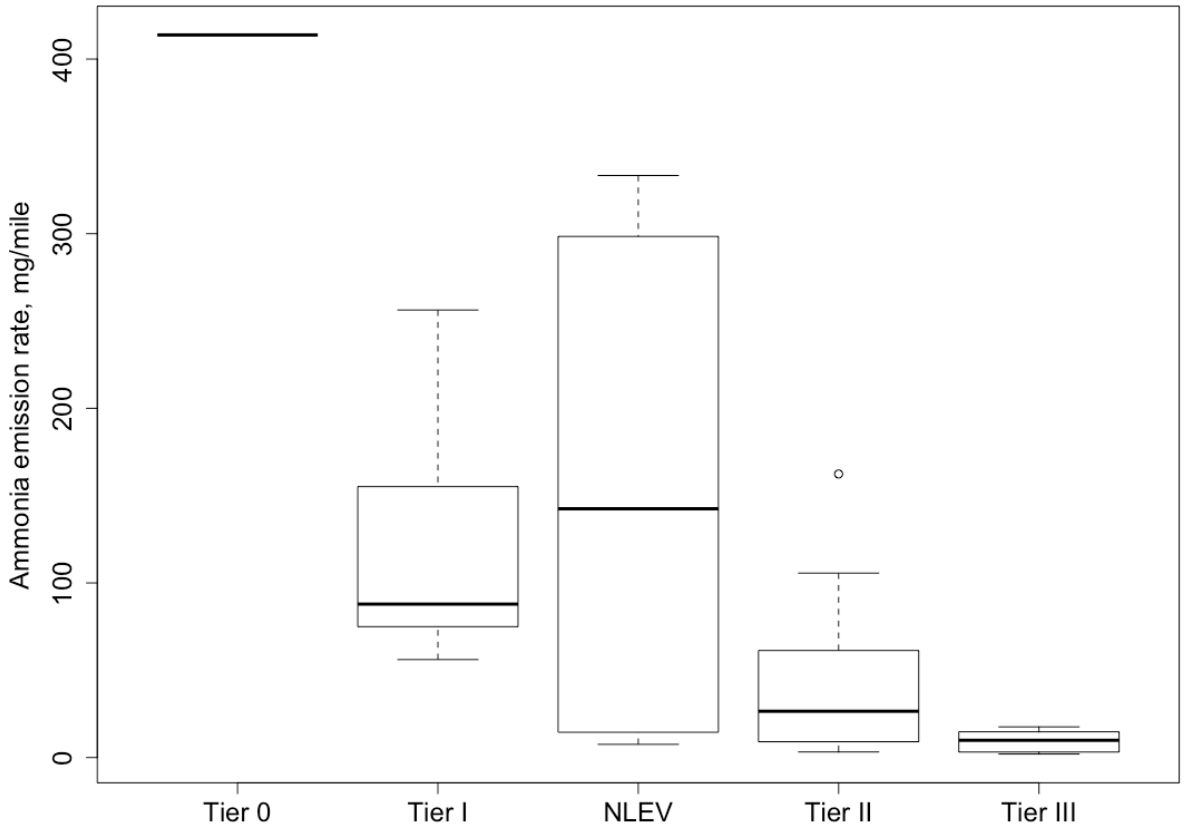


Instruments Setup

- Gases concentrations (CO, NOx and HC)
- Exhaust temperature
- Engine RPM

RESULTS

- **NH_3 emission rates for vehicles of the same tier level**



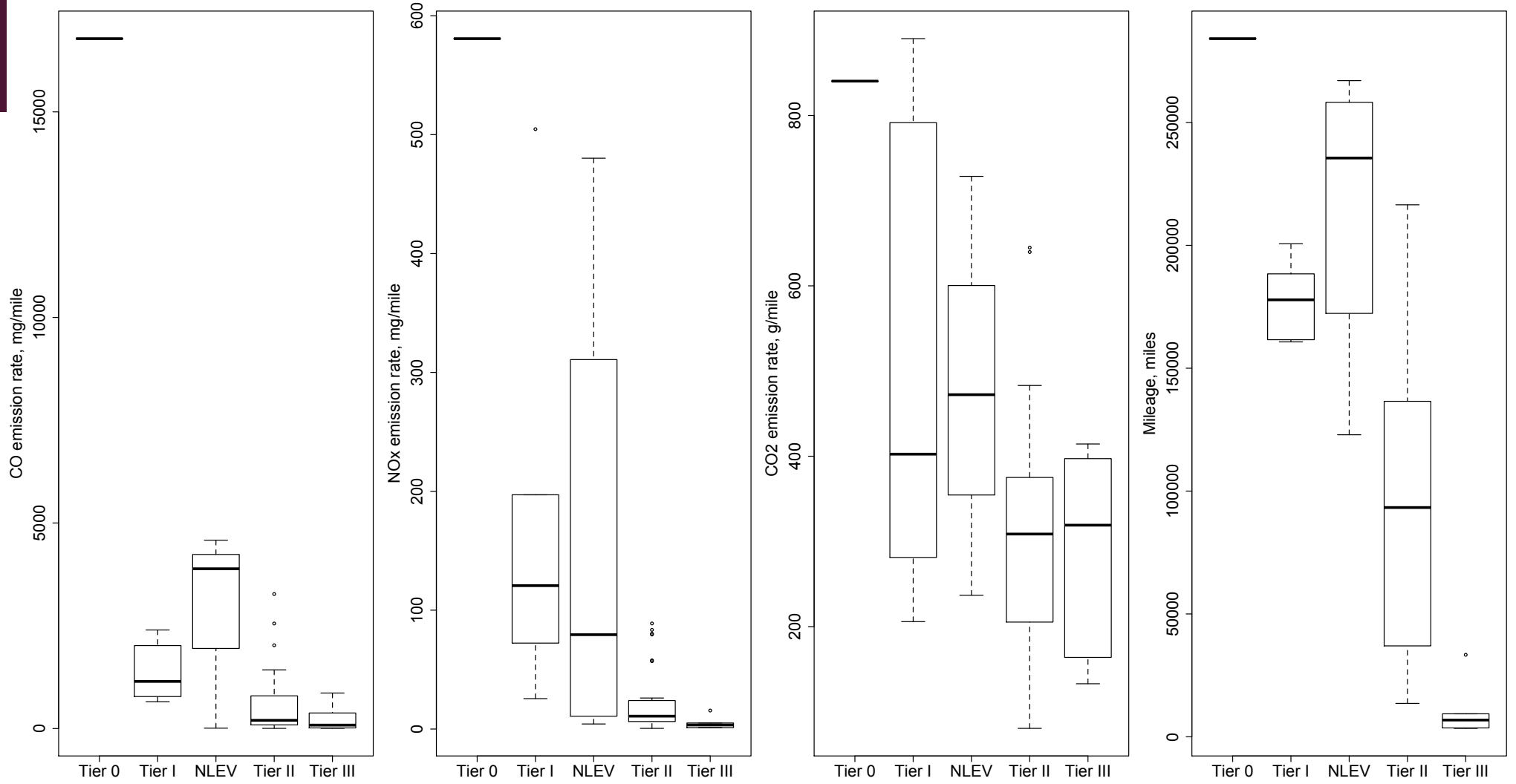
NH_3 emission rates of each tier level vehicles

The mean NH_3 averaged emission rates as a function of vehicle emissions technology were as follows: 414.8 mg/mile for Tier 0 vehicles, 119.7 mg/mile for Tier I vehicles, 156.5 mg/mile for NLEV vehicles, 38.2 mg/mile for Tier II vehicles, and 9.53 mg/mile for Tier III vehicles

ANOVA results for the impact of Tier lever factor

	Df	Sum Sq	Mean Sq	F Value	Pr (>F)	Significance
Tier	4	214083	53521	15.1	7.9×10^{-8}	***
Residuals	44	156463	3556			

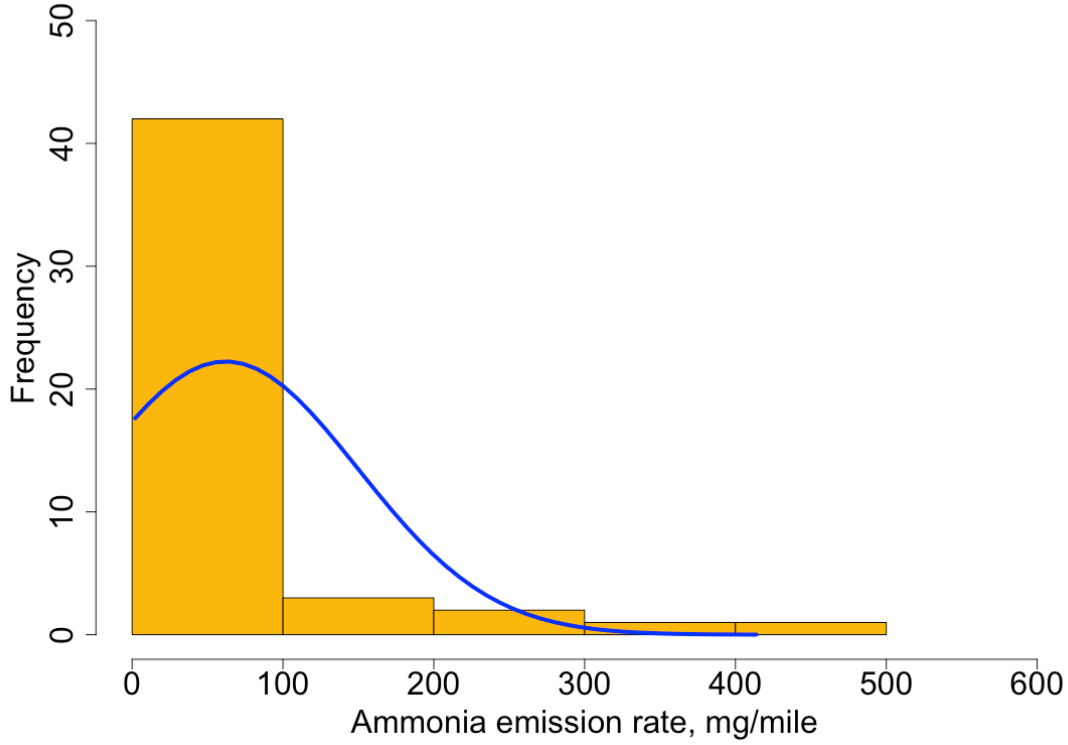
RESULTS



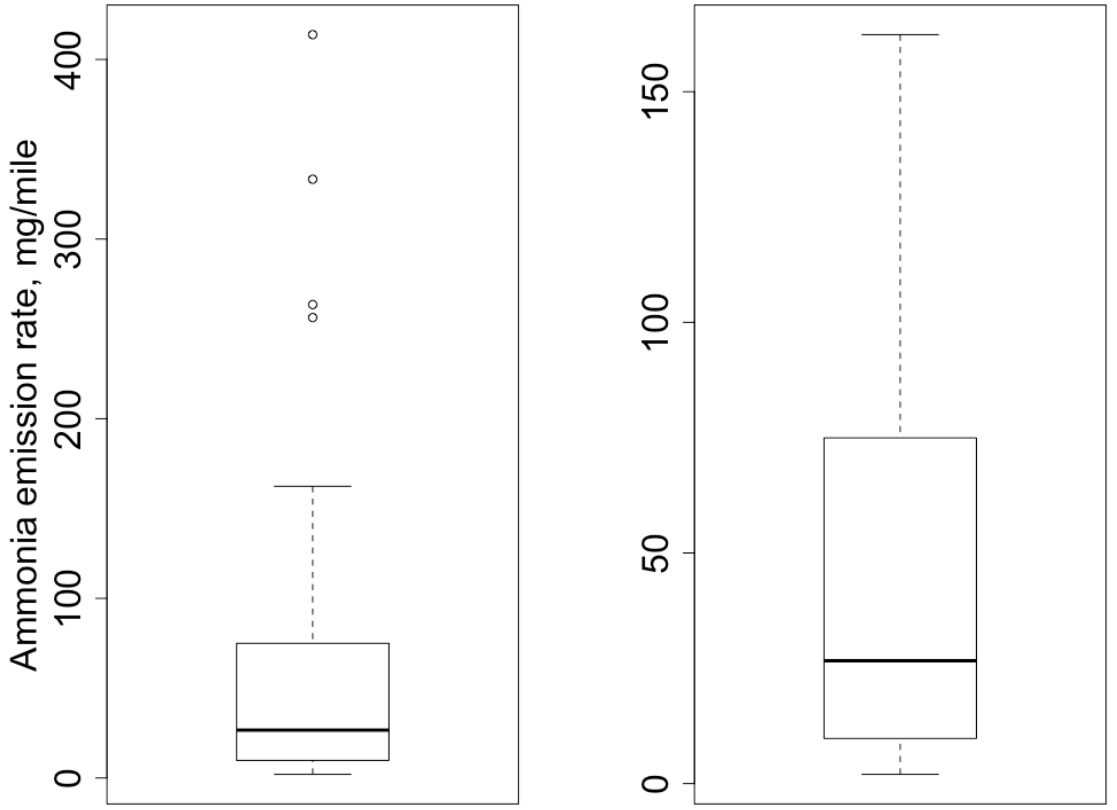
ANOVA results for the impact of emissions technology factor on NH_3 emission rate

RESULTS

- **NH_3 emission rates of the entire vehicles test sample**



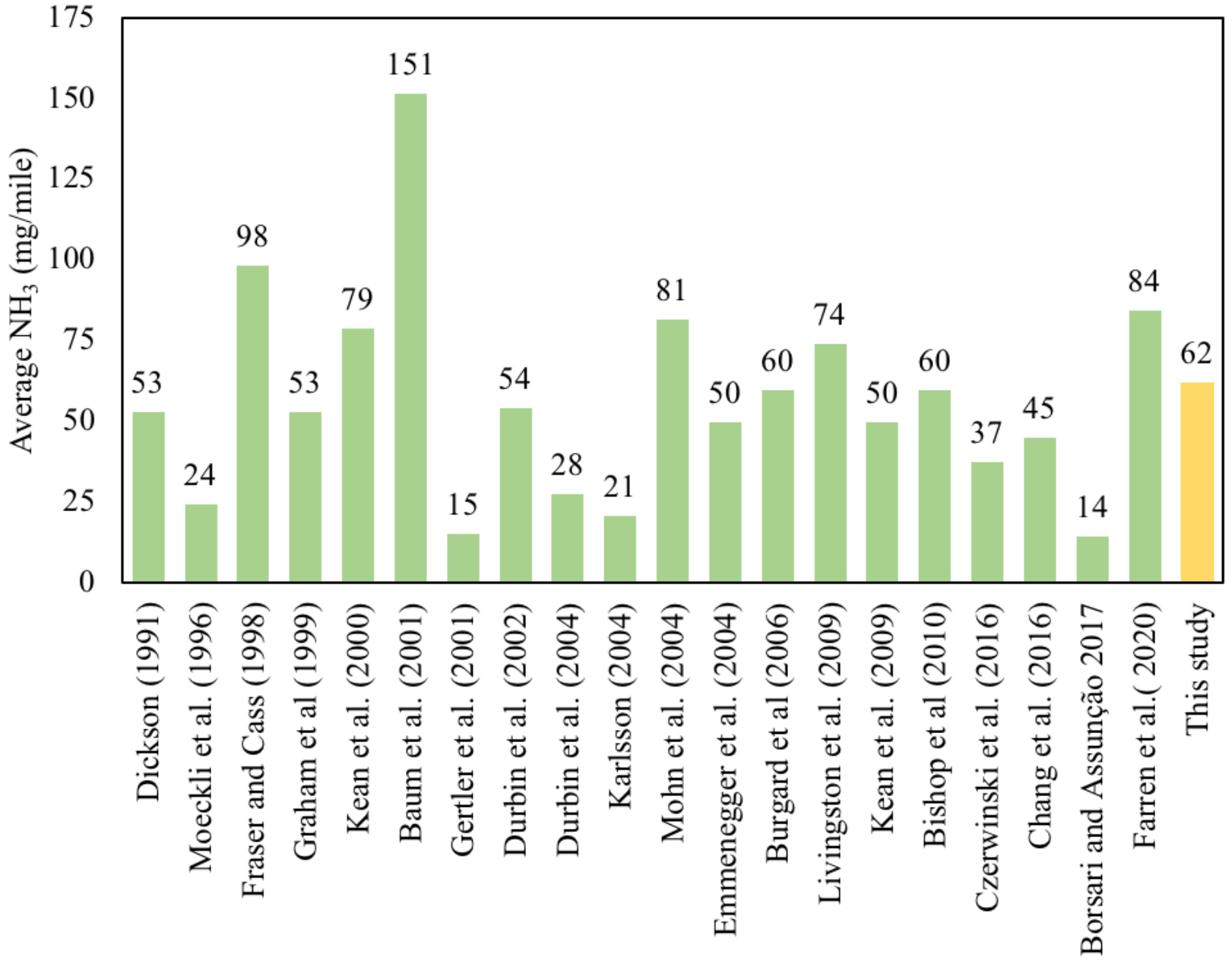
Histogram of NH_3 averaged emission rates



Boxplot of NH_3 emission rates for the entire fleet

RESULTS

- **Comparison of NH_3 emission rates from previous studies and current study**



RESULTS

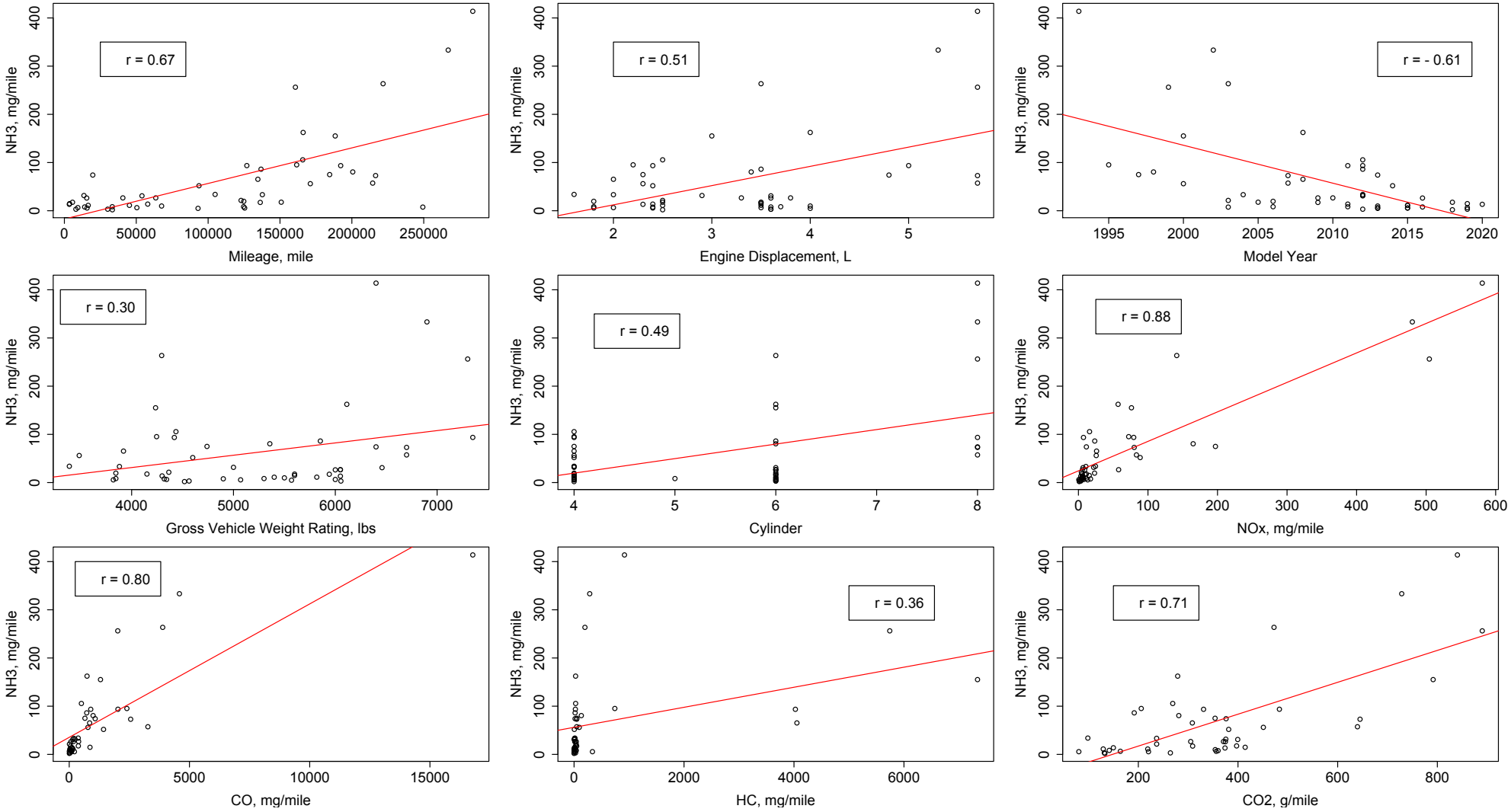
- Removing the four Tier 0, NLEV and Tier I vehicles (23.4 % of the vehicle test fleet) that recorded the extreme emission rates from the entire test fleet would reduce the mean NH_3 emission rate by 36.5% from 62.0 mg/mile to 39.3 mg/mile.

- According to the Office of Highway Policy Information (OHPI) in the U.S. Department of Transportation Federal Highway Administration (FHWA), motor vehicles in the State of Utah are usually driven approximately 13,884 miles per year (OHPI 2018). This would yield a total NH3 emission of 1,572 metric tons per year (4.3 tons of NH3 every day) from the entire gasoline-powered fleet.

- The 2014 national emission inventory, which estimated that the Wasatch Front gasoline motor vehicles fleet emits 2.3 tons of NH3 every day.

RESULTS

- **Correlation between NH_3 emission rates and the vehicle characteristics and post-catalyst exhaust gases**



CONCLUSIONS

- A total of 145 on-road RDE tests were carried out to estimate the NH_3 emission rate of the on-road gasoline vehicle fleet along the Wasatch Front in the U.S. State of Utah. The outcomes showed that the tested vehicles had an average ammonia emission rate of 62.0 mg/miles.

- Older motor vehicles (Tier 0, Tier 1 and NLEV) with high odometer readings recorded higher emission rates of NH_3 than newer motor vehicles (Tier II and Tier 3) with low odometer readings.

- Gasoline motor vehicles in the Wasatch Front emit higher rates of exhaust ammonia than what inventory studies estimate.