

# Characterization of the Off-Road Equipment Population

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## Chair's Air Pollution Seminar Series California Air Resources Board

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# Presentation Summary

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- Overview – Off-road Equipment
- Study Objectives and Outputs
- Data Collection
- Data Analysis
- Observations and Conclusions
- Recommendations for Future Study

# Overview – Off-road Equipment

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- Portable or self-propelled equipment not registered for on-road use
- Internal combustion
  - 2 or 4-stroke gas
  - Diesel
  - Gaseous fuel (LPG, CNG)
- Electric (limited analysis)

# Off-road Equipment Impacts

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- Ubiquitous
  - Industrial, commercial and residential uses
  - Statewide
- Seasonal variability – agricultural, recreational
- Limited or no registration
- **Conclusion**
  - Expect significant, widespread emissions
  - *Very difficult to survey, complicated surrogates*

# Study Objectives

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- **Goal** - Characterize off-road equipment population & activity for CA engines < 175 hp
- Survey Outputs and Uses
  - OFFROAD & emission inventory updates
  - Evaluation of off-road engine preemption status (agricultural and construction)
- Instrumentation Outputs and Uses
  - Profiling equipment for possible PM/other retrofits

# Previous Studies

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- First of its kind attempt to collect bottom-up comprehensive, consistent off-road data
  - ARB - Previous limited surveys for lawn and garden, TRUs, other specialty equipment
  - EPA's NONROAD model – utilizes national-level proprietary data from PSR, w/ extensive surrogates

# Study Team Members

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- Eastern Research Group (ERG)
  - Off-road equipment characterization, instrumentation methods, statistical analysis & reporting
- NuStats
  - Equipment use survey design, phone surveys
- SDV/ACCI
  - Field data collection – logger instrumentation and retrieval

# Data Attributes - Surveys

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- **Equipment Characteristics**
  - Equipment category / fuel type
  - Make/model/model year
  - Engine size – hp and displacement



# Data Attributes - Surveys

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- **Operator Characteristics**
  - Commercial/Residential
  - Commercial activity category (4-digit SIC)
  - Application category
    - Agricultural (by crop type, w/ acreage)
    - Building/Construction
    - Residential
    - Other commercial

# Data Attributes - Surveys

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- **Activity Attributes – *specific to each piece of equipment***
  - Hours of use
  - Temporal profiles
  - Primary area of activity (county)
  - Alternate use categories

# Survey Data Collection Plan

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- Operator groups stratified considering key emission sources and available data sets
  - Agricultural (by crop type)
  - Construction (by SIC grouping)
  - Other Commercial (by SIC grouping)
  - Residential (“recreational” / “other” areas)

# Data Collection - Surveys

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- Phase I surveys – Spring 2006
- Phase II surveys – Winter/Spring 2007
- Computer Assisted Telephone Interview (CATI)
- ~20 questions
- Screen for eligibility - own/operate off-road equipment < 175 hp in California in 2006
- Interview length varies by fleet size and number of equipment types
  - Average interview time ~15 min

# Data Collection - Surveys

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- Quality Assurance

- Inconsistent nomenclature – assure equipment category assignment
- Confirm activity outliers (e.g., >1,000 hr/yr for ag equipment)
- Confirm inconsistent use category assignments
- Check for equipment type/make/model/model year consistency – VERY time-intensive

# Data Collection - Surveys

## Survey Participation Rates

Survey Parameter	Agriculture		Const/Mining		Other Com.		Residential		Total	
	Count	%	Count	%	Count	%	Count	%	Count	%
Phone Numbers Called	4,146	100%	5,785	100%	4,215	100%	9,404	100%	23,550	100%
Eligible to Participate	385	9%	310	5%	377	9%	396	4%	1,468	6%
Ineligible to Participate	385	9%	1,001	17%	1,278	30%	1,257	13%	3,921	17%
Unable to Obtain Info	3,376	81%	4,474	77%	2,560	61%	7,751	82%	18,161	77%
<b>Completed Surveys</b>	<b>298</b>	<b>7%</b>	<b>246</b>	<b>4%</b>	<b>293</b>	<b>7%</b>	<b>327</b>	<b>3%</b>	<b>1,164</b>	<b>5%</b>

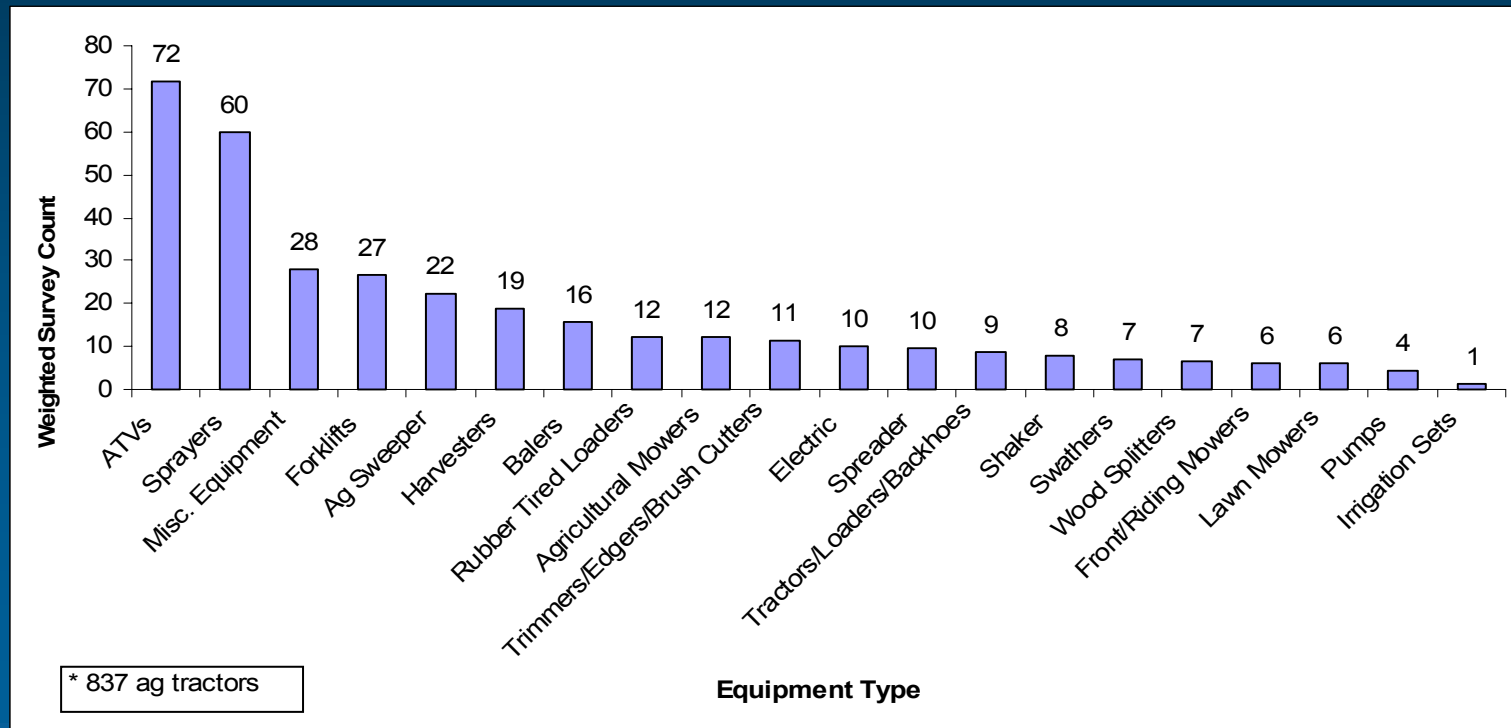
# Survey Data Analysis

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- Response Weightings
  - Adjust completed survey proportions to account for response bias
  - Utilize proportion of records in sample frame for each strata/sub-strata
  - Apply response weights to equipment population counts before further analysis

# Survey Data Analysis

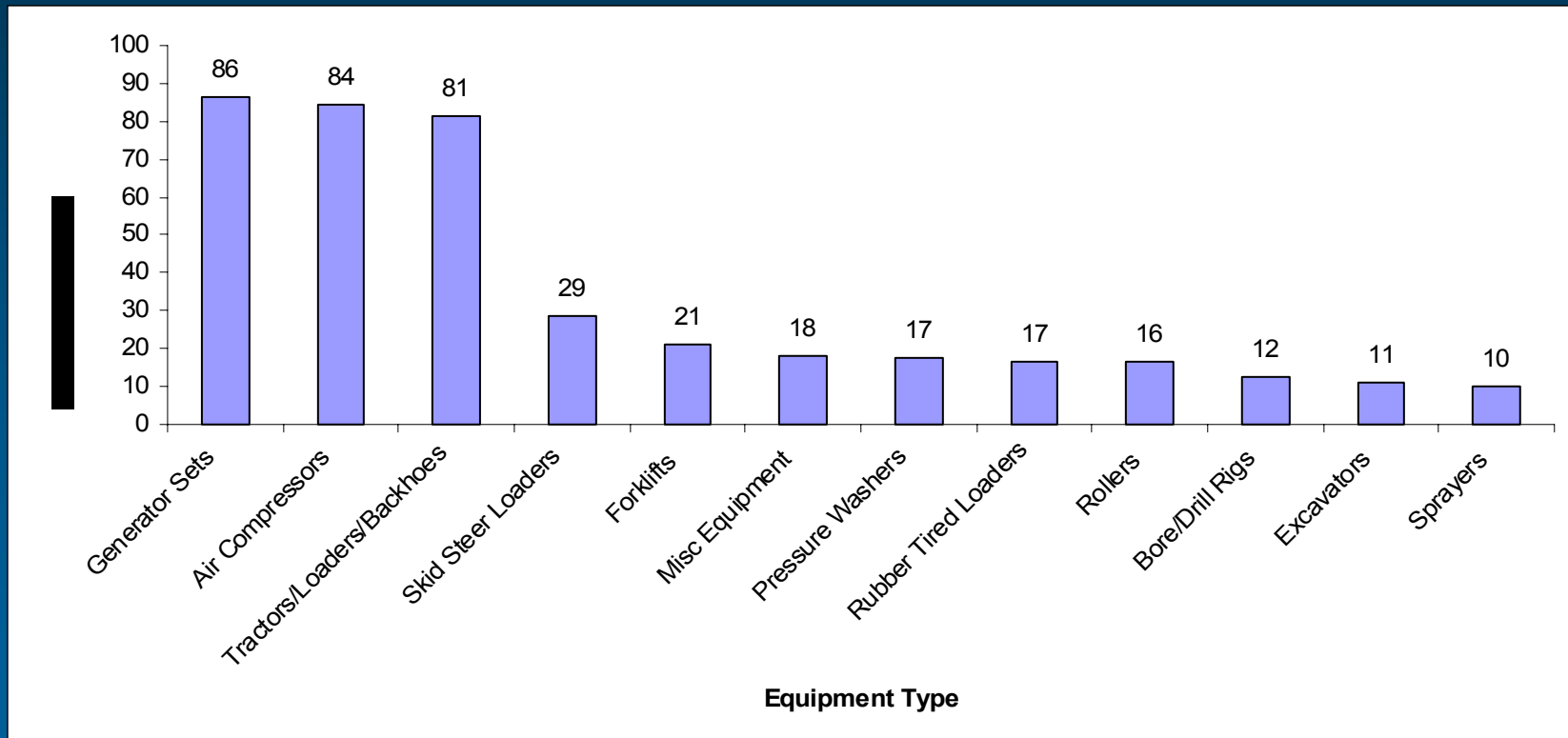
## Equipment Type Distribution – Agricultural Sector





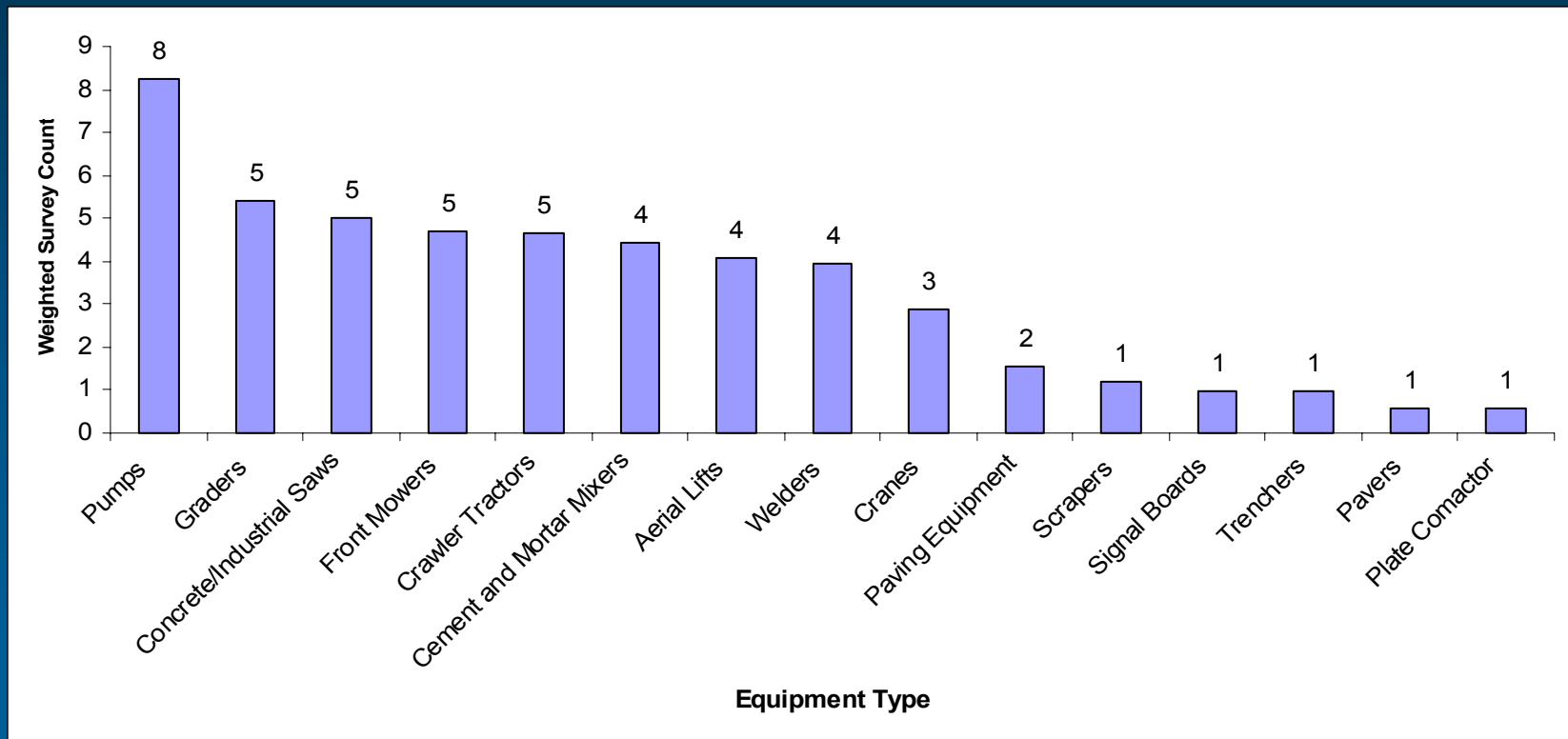
# Survey Data Analysis

## Equipment Type Distribution – Construction Sector



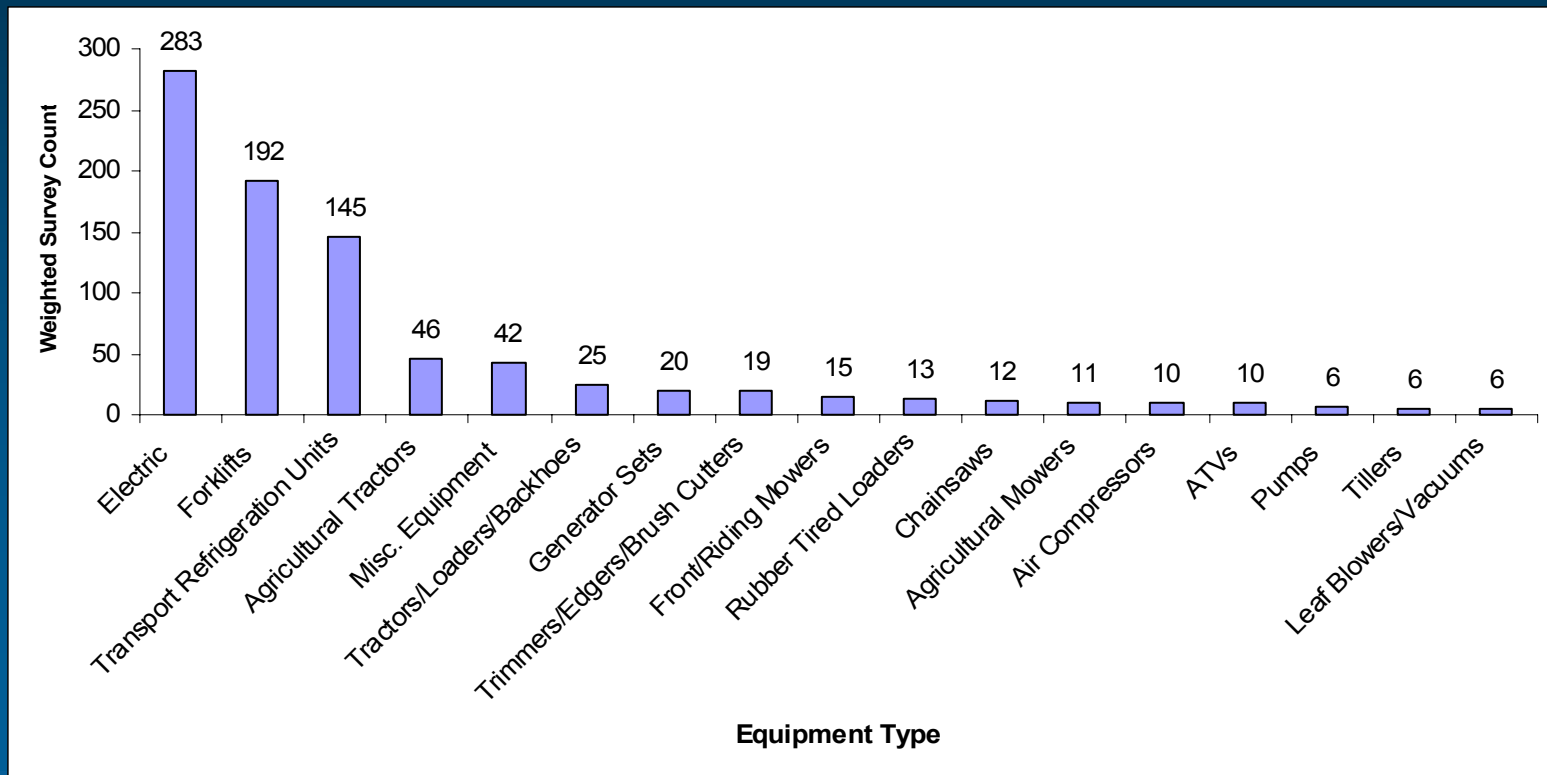
# Survey Data Analysis

## Equipment Type Distribution – Construction Sector Cont'd



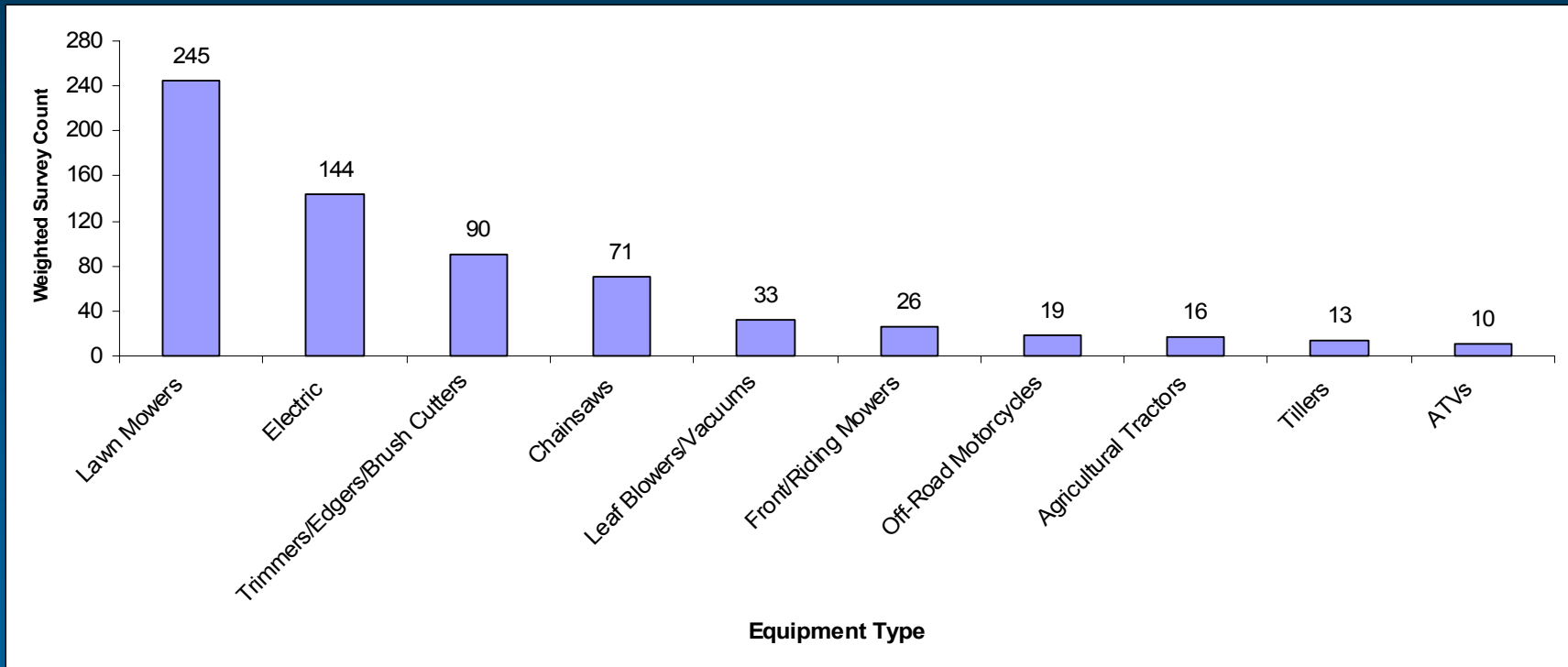
# Survey Data Analysis

## Equipment Type Distribution – Other Commercial Sector



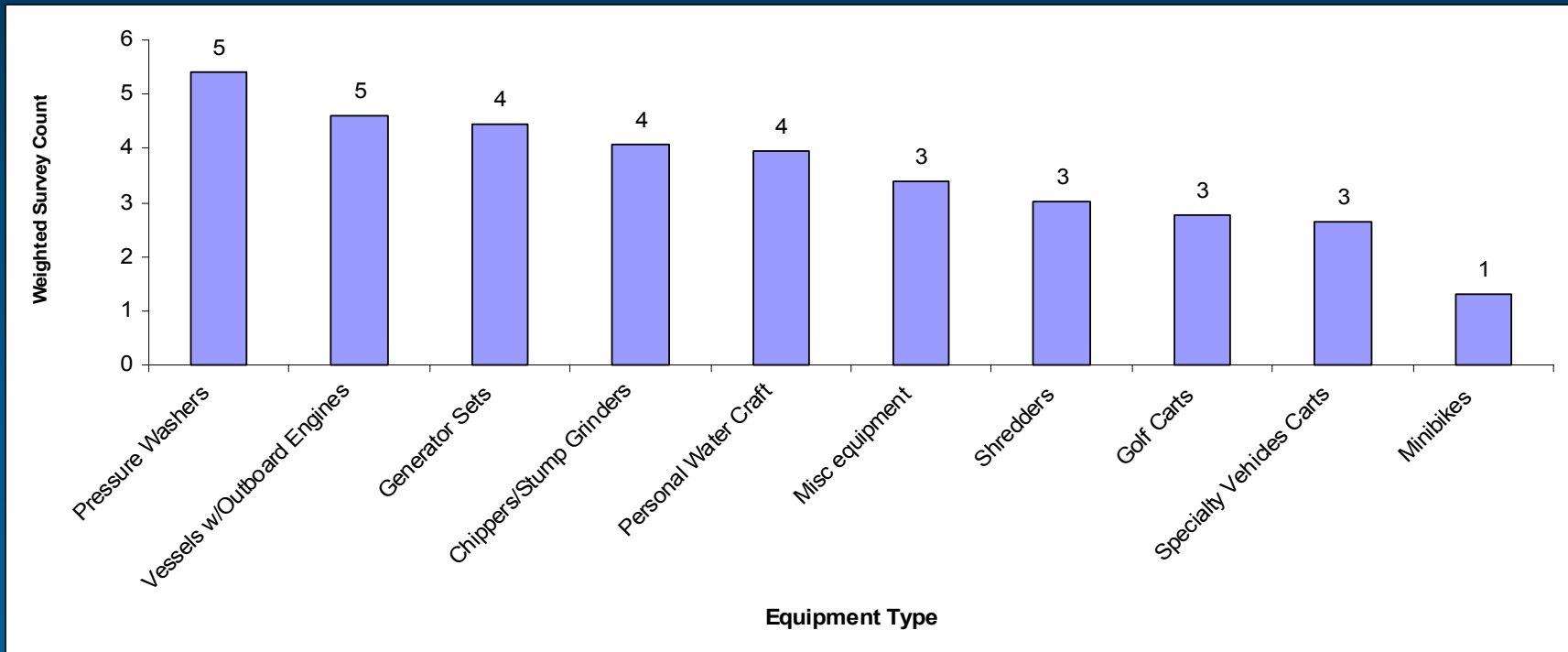
# Survey Data Analysis

## Equipment Type Distribution – Residential Sector



# Survey Data Analysis

## Equipment Type Distribution – Residential Sector Cont'd



# Survey Data Analysis

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## Fuel Type Distribution by Equip. Count, All Sectors

Sector	Compressed Gas	Diesel	Gasoline
Agricultural	2%	78%	19%
Construction	3%	50%	46%
Other Commercial	26%*	21%	54%
Residential	< 1%	1%	99%

\* Dual to compressed gas industrial forklifts

# Survey Data Analysis

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## Seasonal Activity Distribution by Sector (annual hrs)

Sector	Winter	Spring	Summer	Fall
Agricultural	15%	28%	32%	25%
Construction & Mining	23%	25%	28%	24%
Other Commercial	23%	26%	27%	24%
Residential	11%	29%	40%	21%

- Noticeable variance in Ag and Residential Sectors

# Survey Data Analysis

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- Evaluations by Equipment Type
  - By sector and fuel type
  - Including response weightings
  - Distributions include
    - ▣ Hours/yr
    - ▣ HP
    - ▣ Model year
  - Need high counts for reliable distributions



# Survey Data Analysis

## Avg Hrs/Yr – Selected Equipment Types (Ag Sector)

Equipment Type	Fuel Type	Weighted Count	Average Hrs/Yr
Ag Sweepers	Diesel	21	464
Agricultural Tractors	Diesel	774	391
Agricultural Tractors	Gasoline	50	160
All Terrain Vehicles	Gasoline	61	506
Balers	Diesel	15	363
Combines	Diesel	15	402
Industrial forklifts	Compressed Gas	15	700
Rubber Tired Loaders	Diesel	10	1,161
Sprayers	Diesel	15	353
Sprayers	Gasoline	45	190
Spreaders	Compressed Gas	10	240
Trimmers/Edgers/Brush Cutters	Gasoline	11	386

- Relatively low annual hours across types

# Survey Data Analysis

## Avg Hrs/Yr – Selected Equipment Types (C/M Sector)

Equipment Type	Fuel Type	Weighted Count	Average Hours/Year
Air Compressors	Diesel	25	658
Air Compressors	Gasoline	40	160
Bore/Drill Rigs	Diesel	10	1,600
Industrial forklifts	Compressed Gas	10	1,276
Generator Sets	Gasoline	78	345
Pressure Washers	Gasoline	13	384
Rubber Tired Loaders	Diesel	13	154
Skid Steer Loaders	Diesel	19	439
Tractors/Loaders/Backhoes	Diesel	68	1,131

- Low equipment counts => high uncertainty

# Survey Data Analysis

## Avg Hrs/Yr – Selected Equipment Types (Other Comm. Sector)

Equipment Type	Fuel Type	Weighted Count	Average Hr/Yr
Agricultural Mowers	Gasoline	10	633
Agricultural Tractors	Diesel	33	477
<b>Industrial forklifts</b>	<b>Compressed Gas</b>	<b>127</b>	<b>1,056</b>
Industrial forklifts	Diesel	11	491
Industrial forklifts	Gasoline	24	171
Front/Riding Mowers	Gasoline	11	200
Generator Sets	Gasoline	13	189
Rubber Tired Loaders	Diesel	11	476
Tractors/Loaders/Backhoes	Diesel	16	1,130
Trimmers/Edgers/Brush Cutters	Gasoline	19	194

# Survey Data Analysis

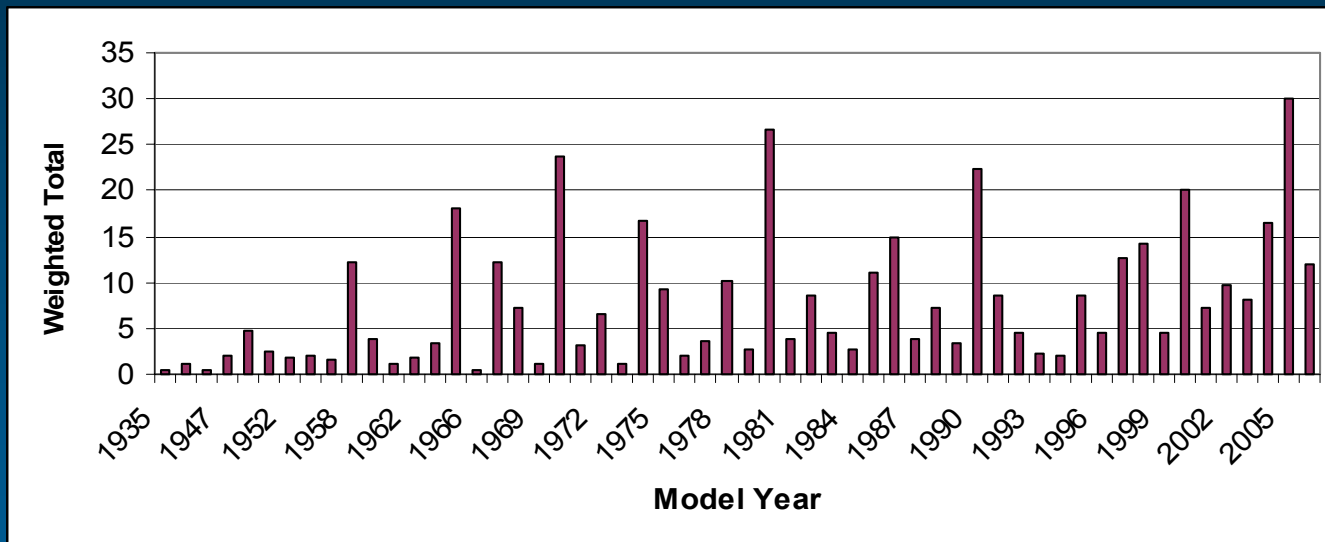
## Avg Hrs/Yr – Selected Equipment Types (Residential Sector)

Equipment Type	Fuel Type	Weighted Count	Average Hours/Year
Agricultural Tractors	Gasoline	13	40
Chainsaws	Gasoline	60	11
Front/Riding Mowers	Gasoline	22	98
Lawn Mowers	Gasoline	212	50
Leaf Blowers/Vacuums	Gasoline	30	61
Off-Road Motorcycles	Gasoline	18	70
Tillers	Gasoline	11	84
Trimmers/Edgers/Brush Cutters	Gasoline	70	41

- Very low activity levels, all types

# Survey Data Analysis

## Model Year Distribution – Diesel Agricultural Tractors



- Remarkably flat across several decades
- 1981 “anomaly” – one respondent w/ 20+ ‘81 models

# Survey Data Analysis

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- Surrogate Expansion
  - Scale factors for statewide population estimates
  - Apply ratio of state totals to survey incidence rates
  - Factors are sector-specific
    - ▣ Ag: acreage / head of cattle (CAFO/Dairy) – USDA  
2002 Ag Census
    - ▣ C/M , Other Commercial: # establishments – USA Data
    - ▣ Residential: # households – Census Bureau

# Survey Data Analysis

## Surrogate Expansion Example – Ag Sector

<b>Surrogate Counts</b>	<b>Citrus (acres)</b>	<b>CAFO/Dairy (# head)</b>	<b>Nut (acres)</b>	<b>Row (acres)</b>	<b>Tree Fruit (acres)</b>	<b>Vineyard/Other (acres)</b>
Survey	3,113	24,526	26,880	38,570	10,053	44,185
State	927,899	4,552,237	1,108,984	8,255,732	658,967	994,682
<b>Survey Coverage</b>	<b>0.34%</b>	<b>0.54%</b>	<b>2.42%</b>	<b>0.47%</b>	<b>1.53%</b>	<b>4.44%</b>

# Survey Data Analysis

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- Statewide Equipment Population
  - Expansion factors applied to survey ownership rates
    - ▣ Ag sector - # pcs / 1,000 acres or 1,000 head
    - ▣ C/M and Other Commercial sectors - # pcs / 1,000 establishments
    - ▣ Residential - # pcs / 1,000 households



# Survey Data Analysis

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- Statewide Equipment Population Cont'd
  - Sum totals across all sectors
    - 95 equipment/fuel type combinations
  - Comparisons w/ NONROAD & OFFROAD defaults
  - Findings *highly* inconsistent across sources
  - County allocation using same/similar surrogates

# Survey Data Analysis

## Example Statewide Equipment Population Estimates Selected Ag Equipment (All Sectors)

Equipment Type	Fuel Type	Study Estimate	NONROAD	OFFROAD
Agricultural Mowers	Gasoline	5,663	230	1,996
Agricultural Tractors	Diesel	101,675	29,618	155,198
Agricultural Tractors	Gasoline	<b>98,105</b>	73	531
Balers	Diesel	2,252	153	1,410
Balers	Gasoline	23	503	2,577
Combines	Diesel	1,825	3,784	2,626
Hydro Power Units	Gasoline	102	2,919	961
Irrigation Sets	Diesel	428	595	-
Other Agricultural Equipment	Diesel	2,520	442	3,205
Other Agricultural Equipment	Gasoline	606	597	762
Swathers	Diesel	1,122	1,673	7,681
Swathers	Gasoline	41	314	3,088

# Survey Data Analysis

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- Statewide Population – Observations
  - Missing specialty equipment (GSE, rough terrain forklifts, commercial turf equipment, L/G tractors, etc.)
  - Ag equip estimates roughly consistent w/ other sources (e.g., Ag Census)
  - Gasoline ag tractor estimates surprisingly high – appear to be “antique/recreational” rather than working tractors
  - Suspect C/M equipment systematically under-responding for many equipment categories

# Survey Data Analysis

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- Statewide Population – Observations Cont'd
  - Other common industrial and recreational equipment consistently lower than model values (air compressors, gensets, pumps, welders, recreational marine)
  - TRU estimates most likely skewed high
  - Residential L/G estimates typically between OFFROAD and NONROAD values

# Survey Data Analysis

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- Statewide Activity – Observations
  - Much greater consistency with other sources
  - No pattern for ag equipment vs. model values
  - Construction activity systematically < model values
  - Industrial activity roughly similar to model values
    - ▣ Independent validation for LPG forklifts – 975 vs. 1,124 hr/yr
  - Residential L/G activity systematically > model values
  - Recreational activity systematically < model values

# Survey Data Analysis

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- Statewide Engine HP – Observations
  - Overall consistency with model defaults including
    - ▣ Diesel ag tractors, gensets, LP forklifts
  - Construction equipment hp systematically lower than model values

# Survey Data Analysis

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- Uncertainty Analysis and Confidence Intervals
  - Data set very thin for certain equipment/fuel type combinations
  - Error bounds evaluated for population, average hr/yr, average hp
  - For this analysis error bounds are reported at the 95% level of confidence ( $p = 0.05$ )

# Survey Data Analysis

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- Confidence Intervals – Equipment Population
  - From avg ownership rates / 1,000 units, by strata
  - Upper and lower bound counts calculated and summed across strata to estimate statewide confidence intervals
  - Only 8 types w/ 95% CI  $\leq$  50%
  - 30 types w/ upper CI  $>$  100%



# Survey Data Analysis

## Equipment Population CI $\leq$ 50%

Equipment Type	Fuel Type	Upper Bound	Lower Bound
Lawn Mowers	Gasoline	13%	13%
Trimmers/Edgers/Brush Cutters	Gasoline	25%	24%
Chainsaws	Gasoline	29%	29%
Leaf Blowers/Vacuums	Gasoline	34%	34%
Agricultural Tractors	Diesel	36%	34%
Front/Riding Mowers	Gasoline	39%	39%
Industrial forklifts	Compressed Gas	42%	42%
Industrial forklifts	Gasoline	50%	49%

# Survey Data Analysis

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- Confidence Intervals – Equipment Activity
  - Tighter CI than for population
  - 16 types w/ 95% CI  $\leq$  50% - see next slide
  - 27 of 66 types w/ upper CI  $>$  100%

# Survey Data Analysis

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- Confidence Intervals – Equipment HP
  - Tightest CIs – reflects manufacturer uniformity
  - 41 types w/ 95% CI  $\leq$  50%
    - ▣ Ag tractors, lawn mowers  $<$  5%
    - ▣ Chainsaws, backhoes, LP forklifts  $\leq$  10%
  - Only 11 of 66 types w/ upper CI  $>$  100%

# Survey Data Analysis

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- Preemption Analysis
  - 1990 Federal CAAA preempt California from regulating equipment < 175 hp primarily used for construction or agricultural crop production
  - Current list includes 70 equipment categories, and excludes 11 categories
  - Goal – use survey data analysis to assist with updating preemption list (multiple data sources)
  - Evaluation on equipment count & annual hour basis

# Survey Data Analysis

## Preemption Analysis – Construction Equipment

Equipment Type	Population Basis			Activity Basis			95% Activity CI - High	95% Activity CI - Low
	Ag.	Const.	Other	Ag.	Const.	Other		
Air Compressors	0%	61%	39%	0%	89%	11%	51%	47%
Bore/Drill Rigs	0%	46%	54%	0%	99%	1%	24%	21%
Cement and Mortar Mixers	0%	23%	77%	0%	97%	3%	92%	53%
Combines	100%	0%	0%	100%	0%	0%	40%	37%
Concrete/Industrial Saws	0%	100%	0%	0%	100%	0%	1093%	100%
Cranes	23%	77%	0%	1%	99%	0%	107%	100%
Crawler Tractors	15%	84%	1%	10%	81%	9%	109%	64%
Excavators	2%	98%	0%	5%	95%	0%	53%	53%
Generator Sets	7%	28%	65%	1%	75%	24%	41%	40%
Graders	22%	40%	37%	28%	71%	1%	139%	100%
Pavers	0%	100%	0%	0%	100%	0%	-	-
Paving Equipment	0%	100%	0%	0%	100%	0%	-	-
Rollers	0%	100%	0%	0%	100%	0%	97%	97%
Scrapers	0%	50%	50%	0%	99%	1%	134%	100%
Signal Boards	0%	100%	0%	0%	100%	0%	-	-
Skid Steer Loaders	4%	61%	34%	19%	46%	35%	53%	53%
Tampers/Rammers	0%	100%	0%	0%	100%	0%	-	-
Tractors/Loaders/Backhoes	13%	40%	47%	1%	43%	56%	26%	26%

# Survey Data Analysis

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- Preemption Analysis - Observations
  - General consistency w/ current list
  - Some bi-modal operation patterns apparent
  - Inconsistencies w/ current list
    - ▣ Aerial lift, chipper/stump grinder, shredder, and welder results indicate majority of equipment and hours in non-preempted categories
    - ▣ Low response rates and high uncertainty for each
    - ▣ Many specialty equipment types on current not even observed during survey

# Instrumentation Task Summary

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- 75 instrumentations, 1 wk/unit
- Construction sector only, including backhoes, loaders, excavators, and compactors
- Second x Second readings
- Descriptive statistics compiled for each unit
  - Hours/day of on-time
  - Estimated idle fraction
  - Exhaust gas temperature distribution
- Data provided to ARB for further evaluation

# Observations and Conclusions

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- Bottom-up survey data may provide substantial improvements over default OFFROAD data for prevalent equipment types
- Random survey approach not adequate for characterizing uncommon/specialty equipment



# Observations and Conclusions

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- Confidence intervals should be considered
  - Activity and hp more accurate than population
  - Robust results for diesel ag tractors, LP forklifts, assorted L/G equipment, among others

# Observations and Conclusions

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- Model year distributions for selected equipment, including ag tractors and LP forklifts
- Fuel type distributions for ag tractors / ATVs
- Promising seasonal profiles & county allocation
- Results can *inform* the update of the preemption list, but are not definitive

# Observations and Conclusions

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- Systematic under-reporting suspected for
  - Construction sector
  - Recreational equipment
  - Generator sets / welders
- Data unreliable / missing for
  - Airport GSE
  - TRU
  - Rough terrain forklifts, surfacing equipment, others

# Recommendations for Future Study

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- Conduct a targeted assessment of construction equipment populations and activity profiles
- Conduct similar assessment for recreational vehicles
- Utilize data from other specialty equipment studies
  - TRUs
  - Commercial L/G
  - Ag pumps
  - Publicly operated fleets (TIAX study)
  - GSE (?)

# Acknowledgements

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# Acknowledgements

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