

# AQIP Hybrid Off-Road Pilot Project

Public Work Group Meeting  
April 23, 2013

**Presented By:**

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# Hybrid Off-Road Equipment Pilot Project

- \$2M in FY 2010-11 AQIP Funding Plan
  - \$1M for equipment deployment
  - \$1M to evaluate in-use emissions
- Commercialized hybrid equipment only
  - Caterpillar Hybrid D7E Dozer
  - Komatsu Hybrid HB215LC-1 Excavator
- CE-CERT selected as project Grantee in May 2011

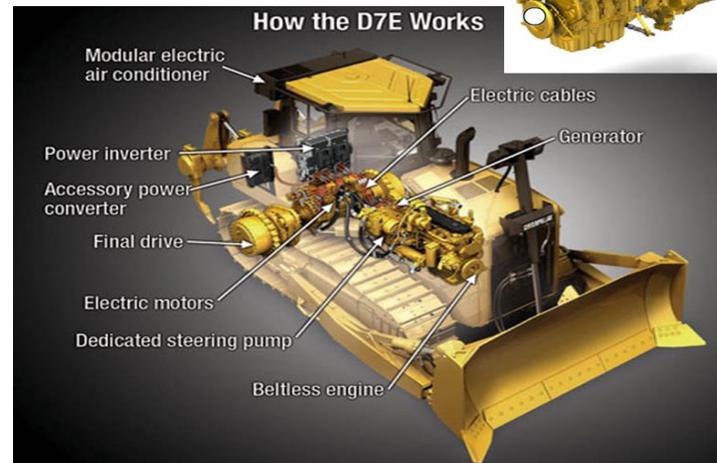
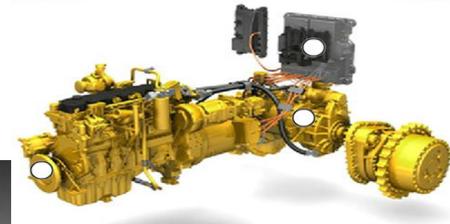
# Outline

- › Hybrid deployment
- › Activity measurements
- › Duty cycle development
- › Emissions testing
- › Preliminary emissions result

# Deployment

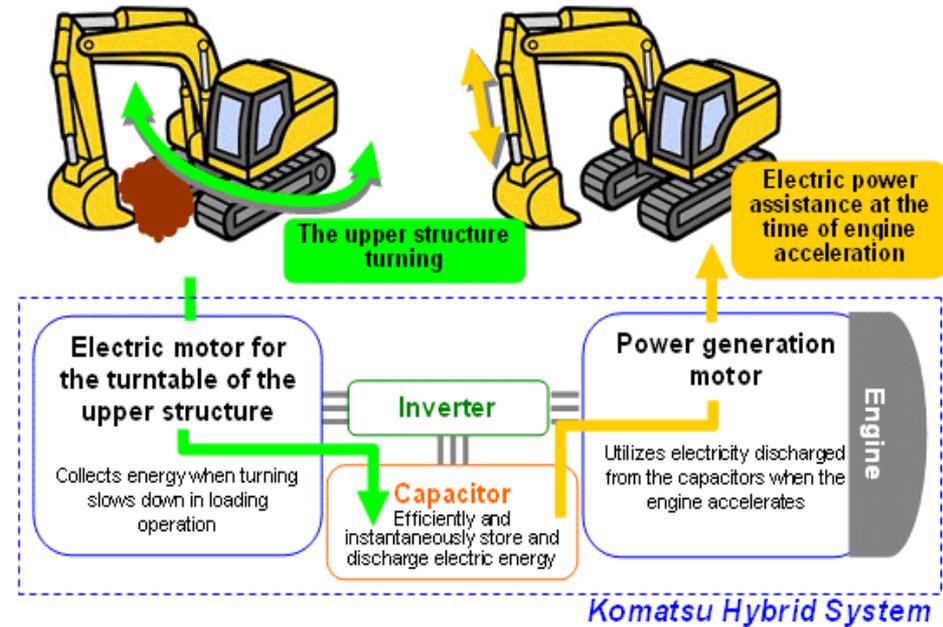


# Caterpillar D7E Bulldozer



Bulldozer	Hybrid (2011 D7E)	Conventional 1 (2012 D6T)	Conventional 2 (2012 D8T)	Conventional 3 (2003 D8R)
<b>Gross Power</b>	252hp@1700rpm	229hp@1800rpm	348hp@1800rpm	348hp@1800
<b>Engine</b>	C9.3 ACERT 9.3 Liters Tier 4i	C9.3 ACERT 9.3 Liters Tier 4i	C15 ACERT 15.2 Liters Tier 4i	C3406E 14.6 Liters Tier 2
<b>Energy Storage</b>	None (electric drive)	None	None	None

# Komatsu HB215 Excavator



Excavator	Hybrid (2011 HB215)	Conventional 1 (2007 PC200)	Conventional 2 (2006 PC220)
Gross Power	148hp@2000rpm	155hp@2000rpm	180hp@2000rpm
Engine	SAA_4D10_7E-1 4.5 Liters Tier 3	SAA_6D10_7E-1 6.7 Liters Tier 3	SAA_6D10_7E-1 6.7 Liters Tier 3
Energy Storage	Capacitor + Electric Motor	None	None

# 16 Hybrid Units Deployed

Vehicle Type	Vouchers Issued	Total Voucher Funds	Typical Voucher Amount	Typical Equipment Purchase Price
Caterpillar Hybrid D7E Bulldozer	10	\$730,538	\$75,000 <sup>1</sup>	\$607,514
Komatsu Hybrid HB215LC-1 Excavator	6	\$171,000	\$28,500	\$288,389
<b>Totals</b>	16	\$901,578	-	-

- 16 units net worth ~ \$7 million
- Hybrids now being purchased with-out vouchers

<sup>1</sup> Last D7E voucher was issued for ~\$55k

# **In-Use Activity Study Duty Cycle Development**

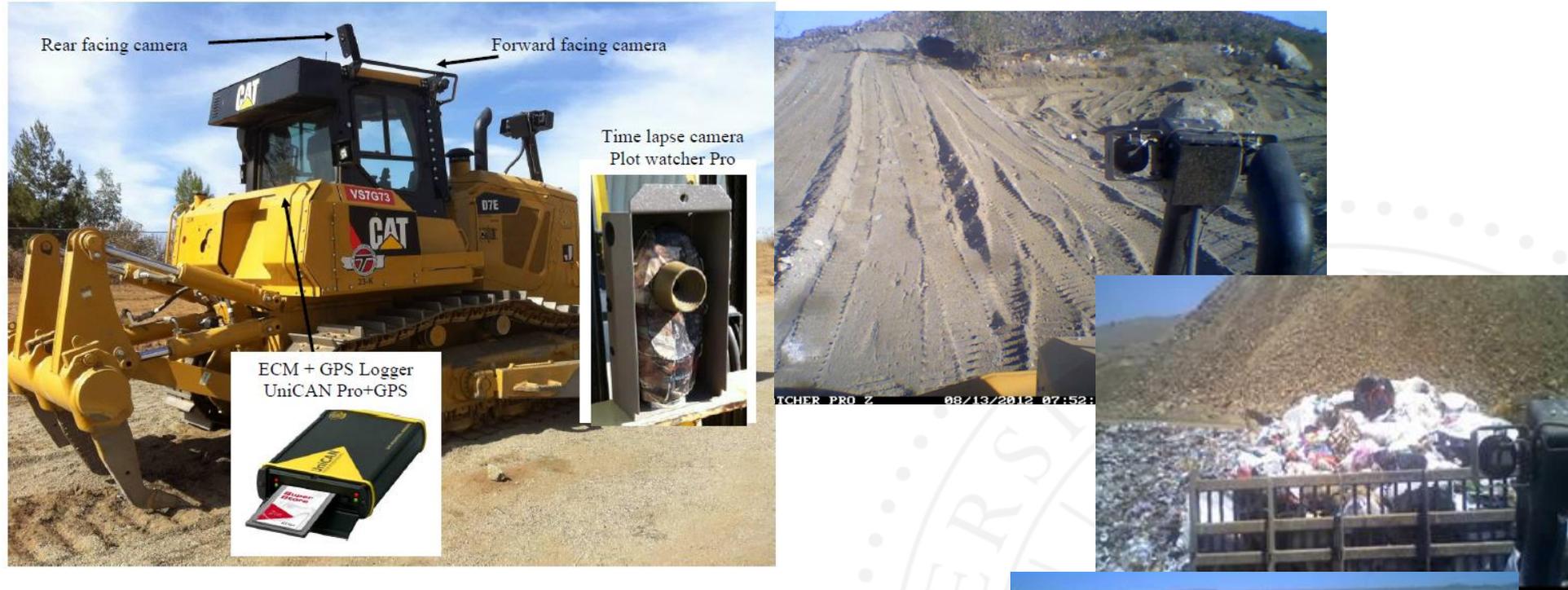


# Six Project Participants Selected

<b>Bulldozer Participant</b>	<b>Public/Private Fleet</b>	<b>Work Type (as observed)</b>	<b>Location</b>
Waste Management (WM)	Private	Landfill	Corona, CA
County of Riverside (RC)	Public	Rock Quarry	Homeland, CA & Temecula, CA
Orange County Water District (OC)	Public	River/Lake Maintenance	Anaheim, CA
<b>Excavator Participant</b>	<b>Public/Private Fleet</b>	<b>Work Type (as observed)</b>	<b>Location</b>
Diamond D General Engineering (DD)	Private	General Construction	Fort Hunter Liggett, CA
Road Machinery (RM)	Private (Rental)	General Construction	Lancaster, CA, & Sacramento, CA
Claremont Equipment (CE)	Private (Rental)	Demolition	Escondido, CA

- Public and private fleet participation was excellent
- OEM involvement was requested, but not provided

# Bulldozer In-Use Activity Setup



- › **Physical Work** - Time lapse video
- › **Engine work** – ECM data logger <sup>1</sup>
- › **Equipment Location** - GPS



<sup>1</sup> UCR provided ECM logger (not from OEM)

# Excavator In-Use Activity Setup

UniCAN + GPS Data Logger



ECM + GPS Logger  
UniCAN Pro+GPS



Rear Facing Camera



Forward Facing Camera



Time lapse camera  
Plot watcher Pro



- **Physical Work** - Time lapse video
- **Engine work** – ECM data logger <sup>1</sup>
- **Equipment Location** - GPS

<sup>1</sup> UCR provided ECM logger (not from OEM)

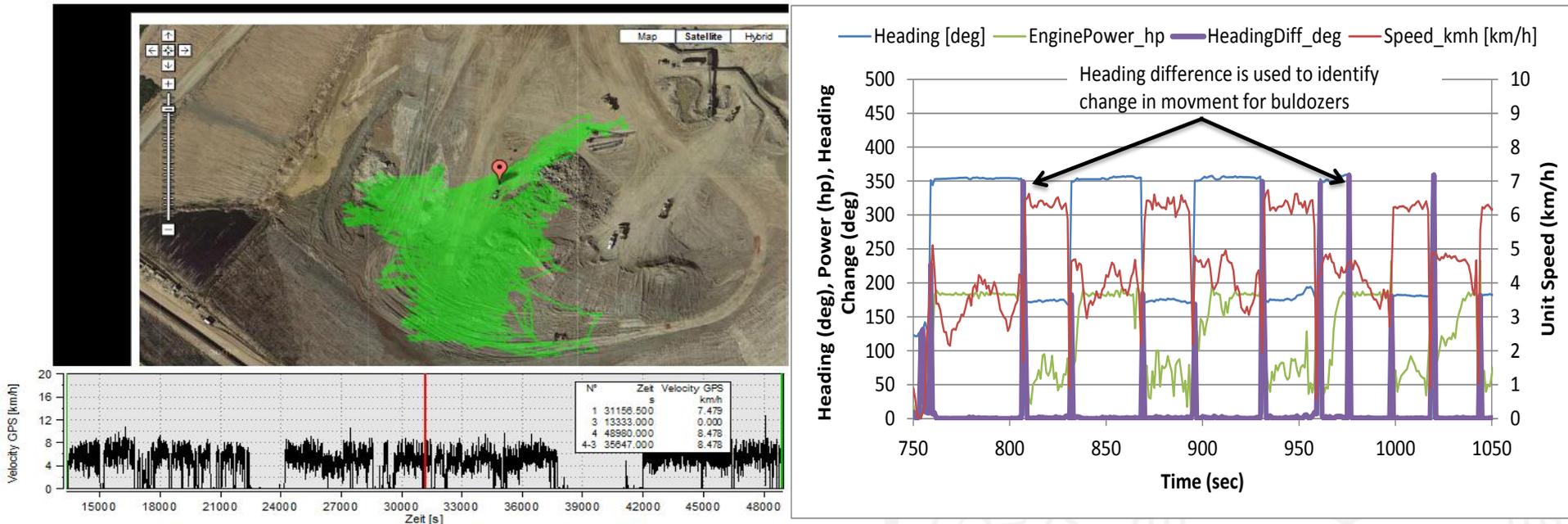
# Activity Summary

Bulldozer Participant	Unit Tested	Location	ECM Hours	Video Hours
WM	2011 D7E T4i	Corona, CA	55.5	1289
WM	2003 D8R T2	Corona, CA	23.8	168
OC	2011 D7E T4i	Anaheim, CA	54.1	432
RC	2011 D7E T4i	Homeland, CA & Temecula, CA	38.3	684
<b>Bulldozer Total</b>			<b>171.7</b>	<b>2573</b>

Excavator Participant	Unit Tested	Location	ECM Hours	Video Hours
DD	2011 HB215 T3	Ft. Hunter Liggett, CA	43.9	280
DD	2007 PC200 T3	Ft. Hunter Liggett, CA	35.3	276
CE	2011 HB215 T3	Escondido, CA	70.8	840
RM	2011 HB215 T3	Lancaster, CA & Sacramento, CA	14.6	708
<b>Excavator Total</b>			<b>164.6</b>	<b>2104</b>

- › Large and diverse data set collected

# Event/Trip Development

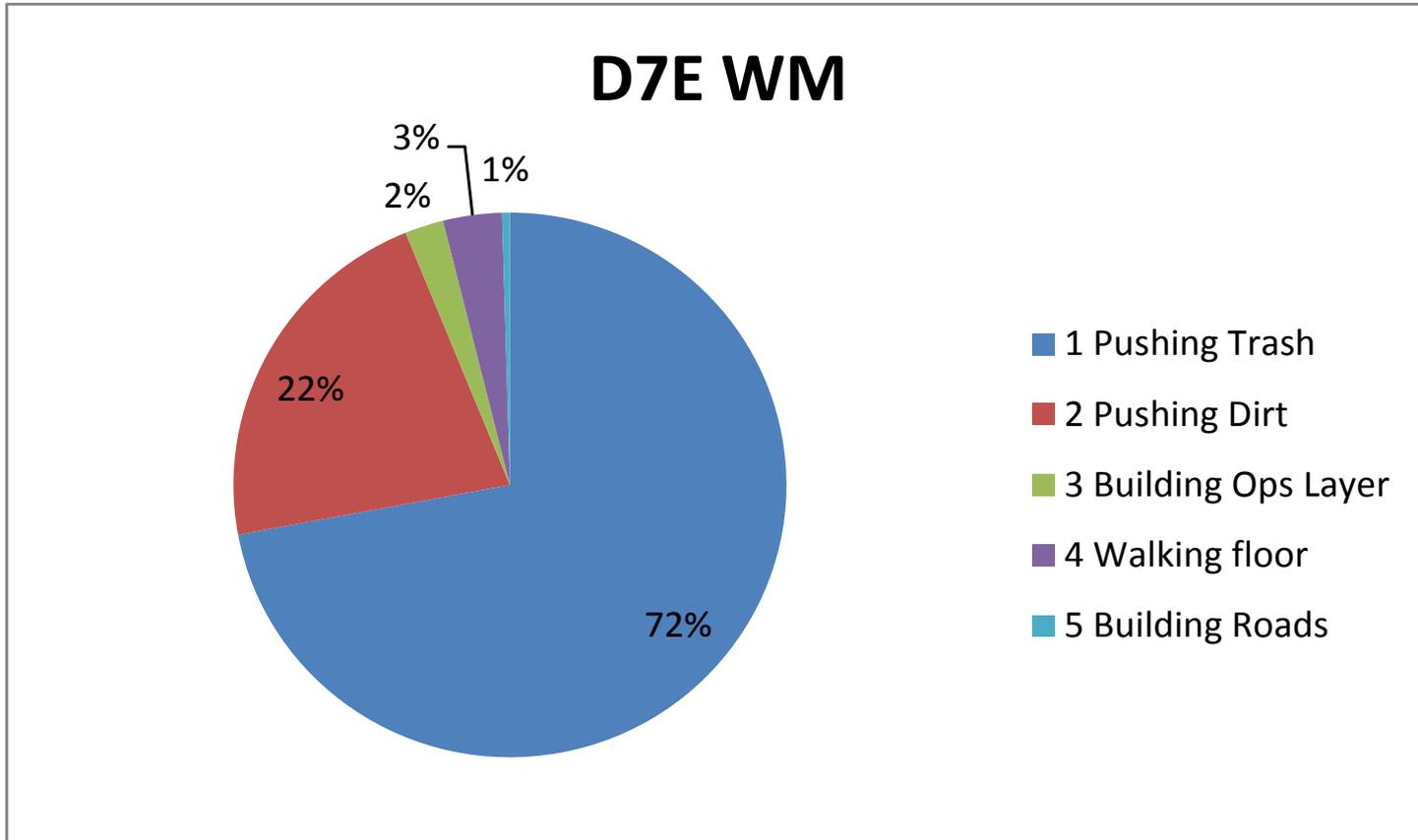


- Forward/backward motion = change in GPS heading
- Each flip in GPS heading is an event
- Excavator event depend on video only

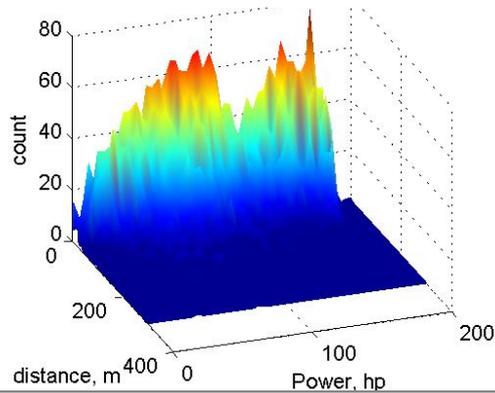
# Observed Activity: Bulldozer

Participant	Equipment	Activity		ECM Hours <sup>1</sup>	ECM %	Video Hours <sup>2</sup>	Video %
WM	D7E T4i	Trash <sup>1</sup>	1	16.9	31.7%	231	72.0%
WM	D7E T4i	Dirt <sup>1</sup>	2	24.3	45.4%	69.9	21.8%
WM	D7E T4i	Ops Layer <sup>2</sup>	3	0.8	1.5%	7.3	2.3%
WM	D7E T4i	Floor <sup>3</sup>	4	10.6	19.9%	11.0	3.4%
WM	D7E T4i	Roads <sup>2</sup>	5	0.8	1.5%	1.5	0.5%
WM	D8R T3	Trash <sup>1</sup>	1	21.3	100.0%	186	100.0%
OC	D7E T4i	Wet River <sup>1</sup>	8	2.2	4.1%	3.8	5.1%
OC	D7E T4i	Water basin <sup>1</sup>	9	42.5	77.7%	59.1	79.8%
OC	D7E T4i	Dry pond <sup>1</sup>	10	2.5	4.6%	3.0	4.0%
OC	D7E T4i	Sides <sup>2</sup>	11	7.4	13.6%	8.2	11.0%
RC	D7E T4i	Prep <sup>3</sup>	6	15.8	41.4%	42.7	51.8%
RC	D7E T4i	Rocks <sup>1</sup>	7	22.4	58.6%	39.7	48.2%

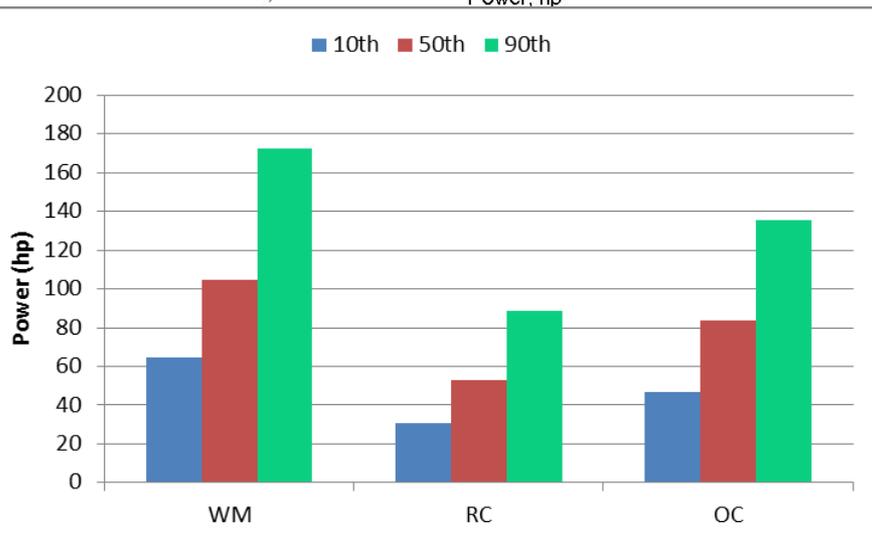
# Observed Activity: Bulldozer



# Activity Summary Analysis



Facility	Facility	Distance			Use Fraction
		10 <sup>th</sup>	50 <sup>th</sup>	90 <sup>th</sup>	
WM	1	8.8	32.2	61.7	72.0%
WM	2	8.7	20.9	45.7	21.8%
WM	3	7.2	14.7	21.0	2.3%
WM	4	5.9	12.1	32.9	3.4%
WM	5	7.3	19.4	40.1	0.5%
RC	6	11.5	37.8	106.0	51.8%
RC	7	11.0	26.0	55.4	48.2%
OC	8	8.3	29.0	138.8	5.1%
OC	9	13.1	29.1	124.4	79.8%
OC	10	12.9	27.0	48.8	4.0%
OC	11	17.5	30.9	37.6	11.0%



➤ Most significant factor is distance and load

# Activity Summary

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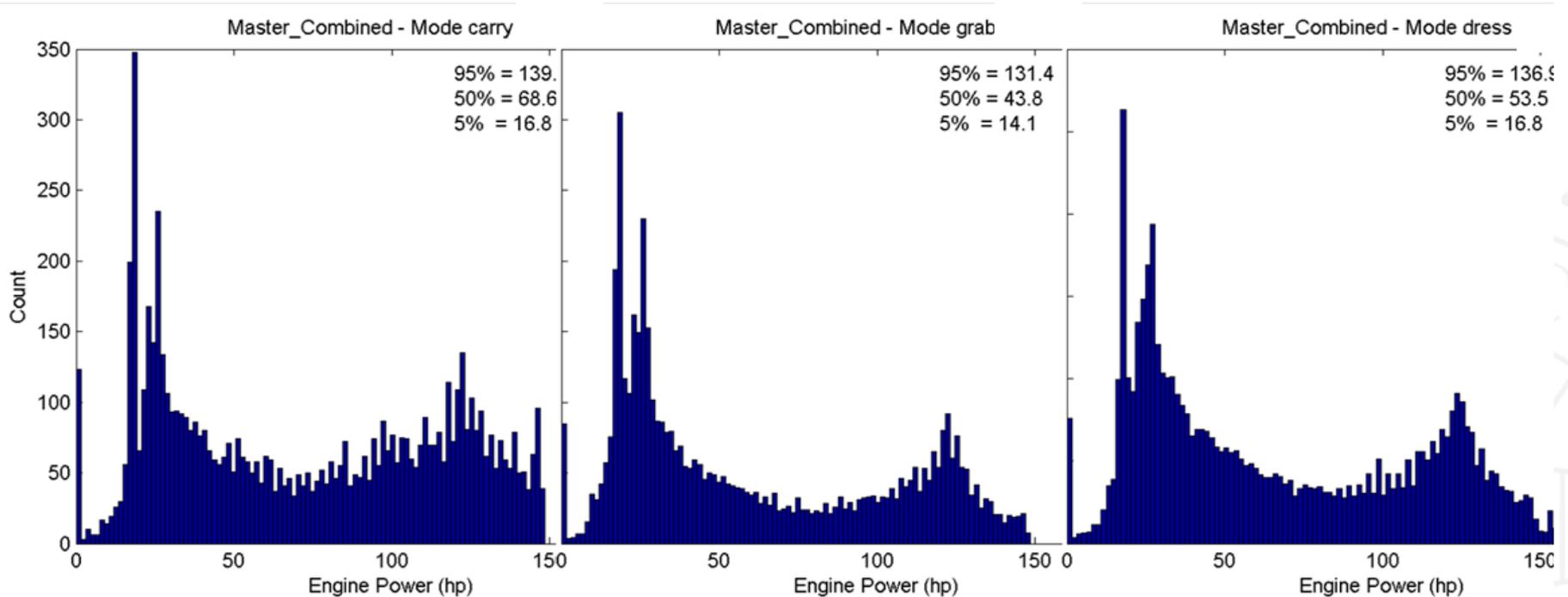
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		<b>Excavator Total</b>	<b>164.6</b>	<b>2104</b>

- › Large and diverse data set collected

# Observed Activity: Excavator

Mode Name	Duty Cycle No.	Work Mode Description
Maneuver	1	Short moves. Change attachments. Reposition at same work location.
Move	1	Move on tracks longer than 30 (or so) seconds. Change work locations.
Stop	2	Stop doing what was being done and be still for 30 (or so) seconds or more
Carry	3	Carry items, debris, etc. to pile, hopper
Crane	3	Move objects. Hold them in the air. Hold or push them down. Usually without attachment but sometimes with.
Compact	3,5	Use compacting wheel attachment to compact dirt.
Grab	3	Grab items, debris and put them somewhere nearby. 90 to 180 ° swings.
Dress	3	Scrape, break-up packed surface with teeth, move loose dirt, smooth the surface. Light demolition (wall, fence), move loose material, clear debris. Up to 45 ° swings.
Trench	4	Trench or dig with bucket facing backward (toward operator) with big bucket and 45 ° swings.
Scoop	4, 5, 6, 7	Trench or dig with bucket facing forward (away from operator) with big bucket. All swings.
Dig	7	Dig with 180° swings.
Backfill	5	Move loose dirt back into a hole or trench with big bucket and 45 ° swings.
Ditch	6	Dig over the side track with bucket facing backward (toward operator) with big bucket and 90 ° swings.
Unknown	n/a	Unknown activity due to obscured camera view (rain, bucket low, etc.)

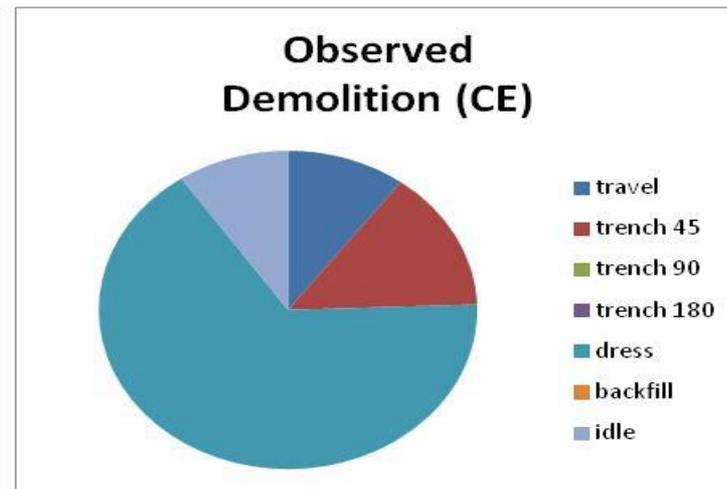
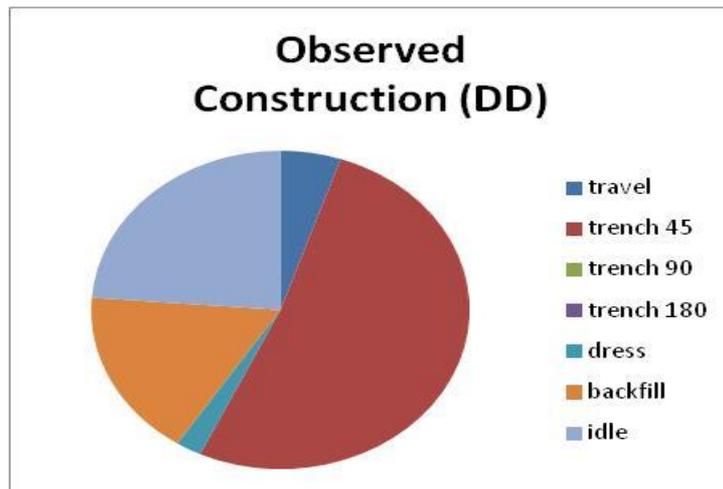
# Reduce Similar Excavator Modes



- Engine power similar trend between modes
- Group common modes to reduce activities

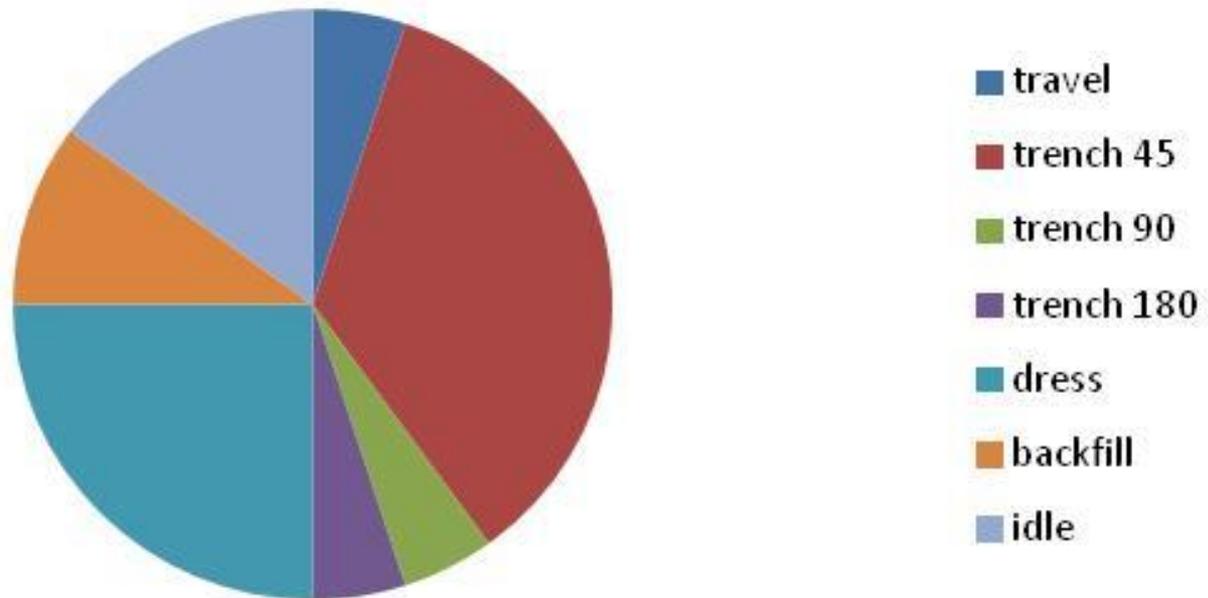
# Observed Activity: Excavator

Mode No	Mode Name	Observed Construction (DD)		Observed Demolition (CE)		Assumed % Construction	Job Type Wtd Avg	Proposed Cycle
		Engine Hours	% of Total	Engine Hours	% of Total			Engine Time Weighting
1	travel	4	5.2%	3.2	10.2%	66%	6.9%	5%
2	trench 45	40.1	51.8%	4.5	14.3%	66%	39.1%	35%
3	trench 90	0	0.0%	0	0.0%	66%	0.0%	5%
4	trench 180	0	0.0%	0	0.0%	66%	0.0%	5%
5	dress	1.7	2.2%	20.8	66.0%	66%	23.9%	25%
6	backfill	13.2	17.1%	0	0.0%	66%	11.3%	10%
7	idle	18.4	23.8%	3	9.5%	66%	18.9%	15%
		77.4	100%	31.5	100%		100%	100%

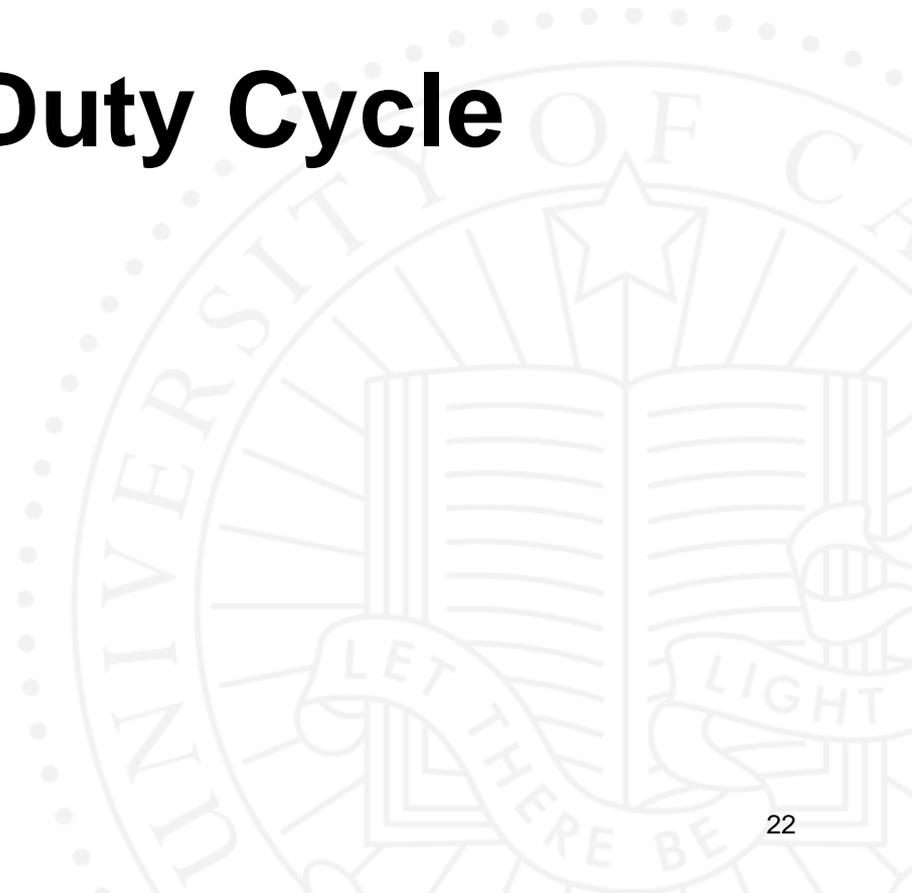


# Expected Activity: Excavator

**Excavator Cycle Weighting for Report  
(2/3 Construction, 1/3 Demolition)**



# Proposed Duty Cycle



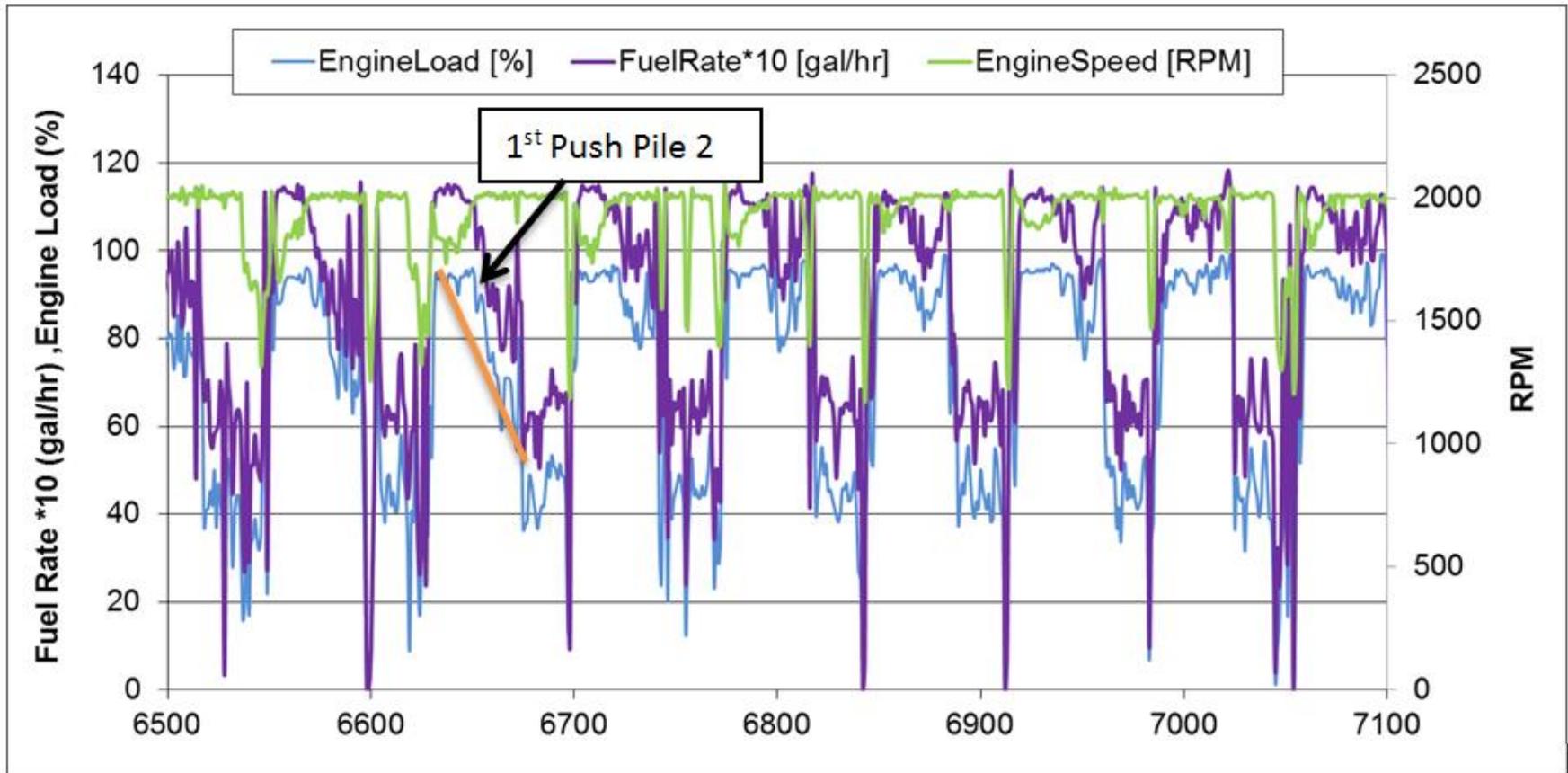
# Proposed Bulldozer Duty Cycle

- ▶ 7 test cycles, two different materials, two different grades
  - ▶ **Heavy** push **10** meters (10<sup>th</sup> percentile dist.)
  - ▶ **Heavy** push **30** meters (50<sup>th</sup> percentile dist.)
  - ▶ **Heavy** push **80** meters (90<sup>th</sup> percentile dist.)
  - ▶ **Light** push **30** meters (50<sup>th</sup> percentile dist.)
  - ▶ **Idle**
  - ▶ **Heavy** push **30** meters up 10% grade
  - ▶ **In-service** with **std. grade** operation

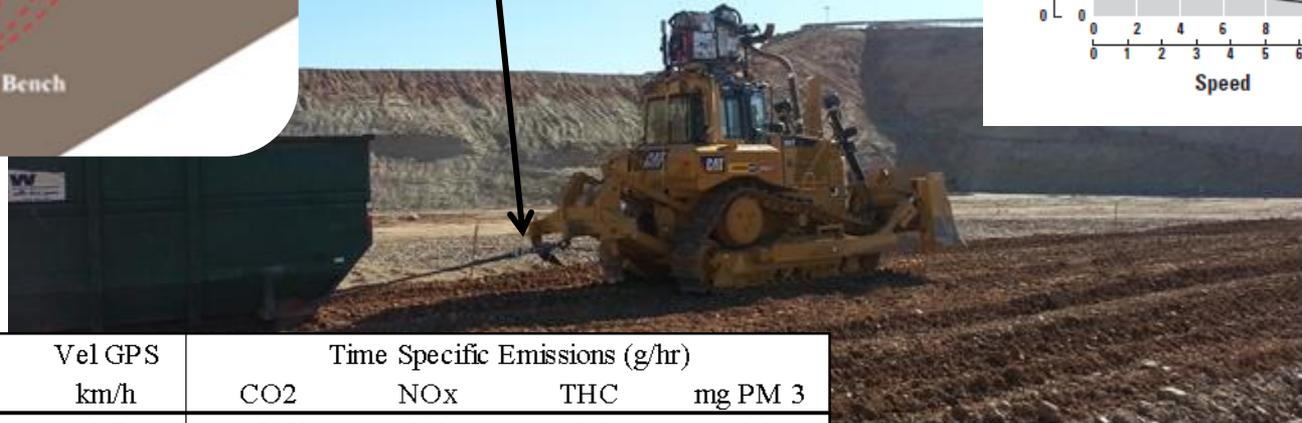
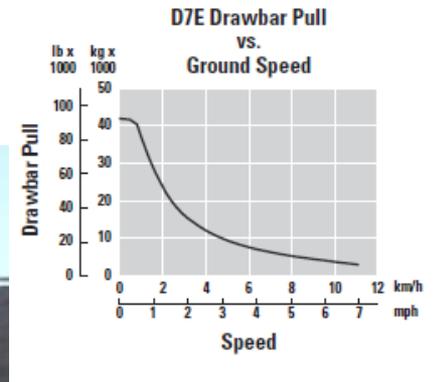
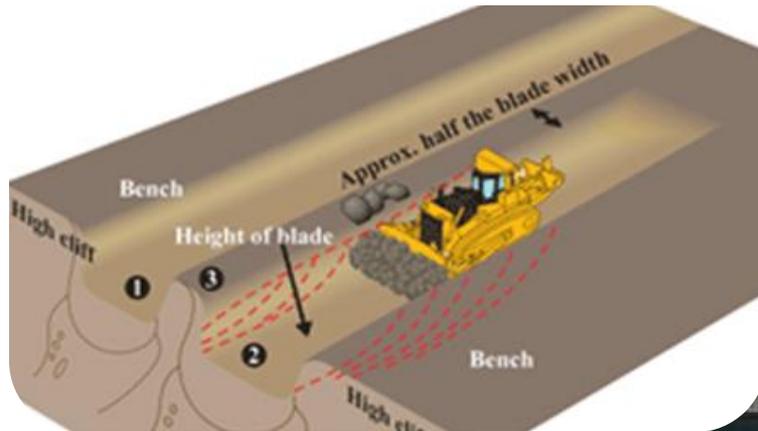
# Bulldozers Cannot Push Piles 30 Meters Without Losing Material



# When Material is Lost Load and Fuel Rate Are Reduced



# Bulldozer Performance Methods



Power bhp	Torque ft-lb	Fuel kg/hr	Vel GPS km/h	Time Specific Emissions (g/hr)			
				CO2	NOx	THC	mg PM 3
196.8	516.5	36.5	3.7	115450	202	2.5	43.8
197.3	521.5	35.4	4.0	112089	197	2.5	41.5
198.2	518.6	38.2	3.6	120765	199	2.0	45.1
197.0	516.4	35.9	3.7	113479	211	2.3	41.8
204.8	536.0	37.4	3.8	118201	212	1.8	43.8
195.0	510.2	35.9	3.8	113654	202	2.0	39.3
203.4	533.3	36.9	3.5	116617	206	2.1	44.1
198.9	521.8	36.6	3.7	115751	204.2	2.2	42.8
3.7	9.4	1.0	0.2	3026	6.0	0.3	2.0
1.8%	1.8%	2.6%	4.8%	2.6%	2.9%	12.3%	4.7%

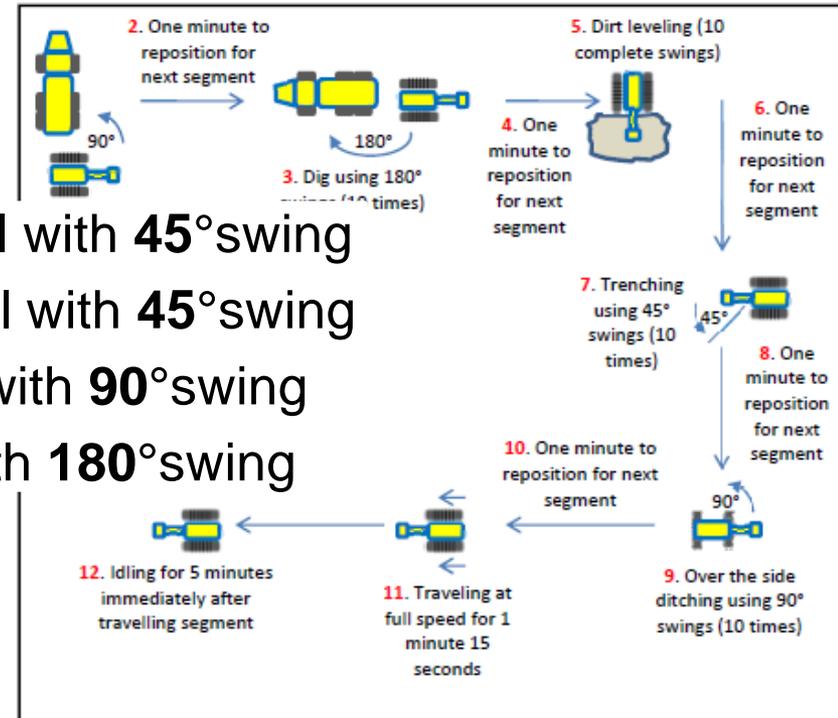
# Utilized Bulldozer Duty Cycle

- 7 test cycles, various loads, two different grades
  - **Heavy & medium** push equiv. **10** meters (10<sup>th</sup> percentile dist.)
  - **Heavy & medium** push equiv. **30** meters (50<sup>th</sup> percentile dist.)
  - **Heavy & medium** push equiv. **80** meters (90<sup>th</sup> percentile dist.)
  - **Idle**
  - **In-service heavy & medium** push operation
  - **In-service** with **50' x 50'** pad **light & full** cut operation
  - **In-service** with **std. grade** operation

# Excavator Duty Cycle

## › 7 test cycle, two different material

- › Move/Travel
- › Idle
- › Dress
- › Trench **heavy & medium** material with **45°** swing
- › Backfill **heavy & medium** material with **45°** swing
- › Ditch **heavy & medium** material with **90°** swing
- › Dig **heavy & medium** material with **180°** swing



Source: komatsu.com

# Emissions Testing



# Controlled Pull Testing D6T



# Controlled Push Testing D7E

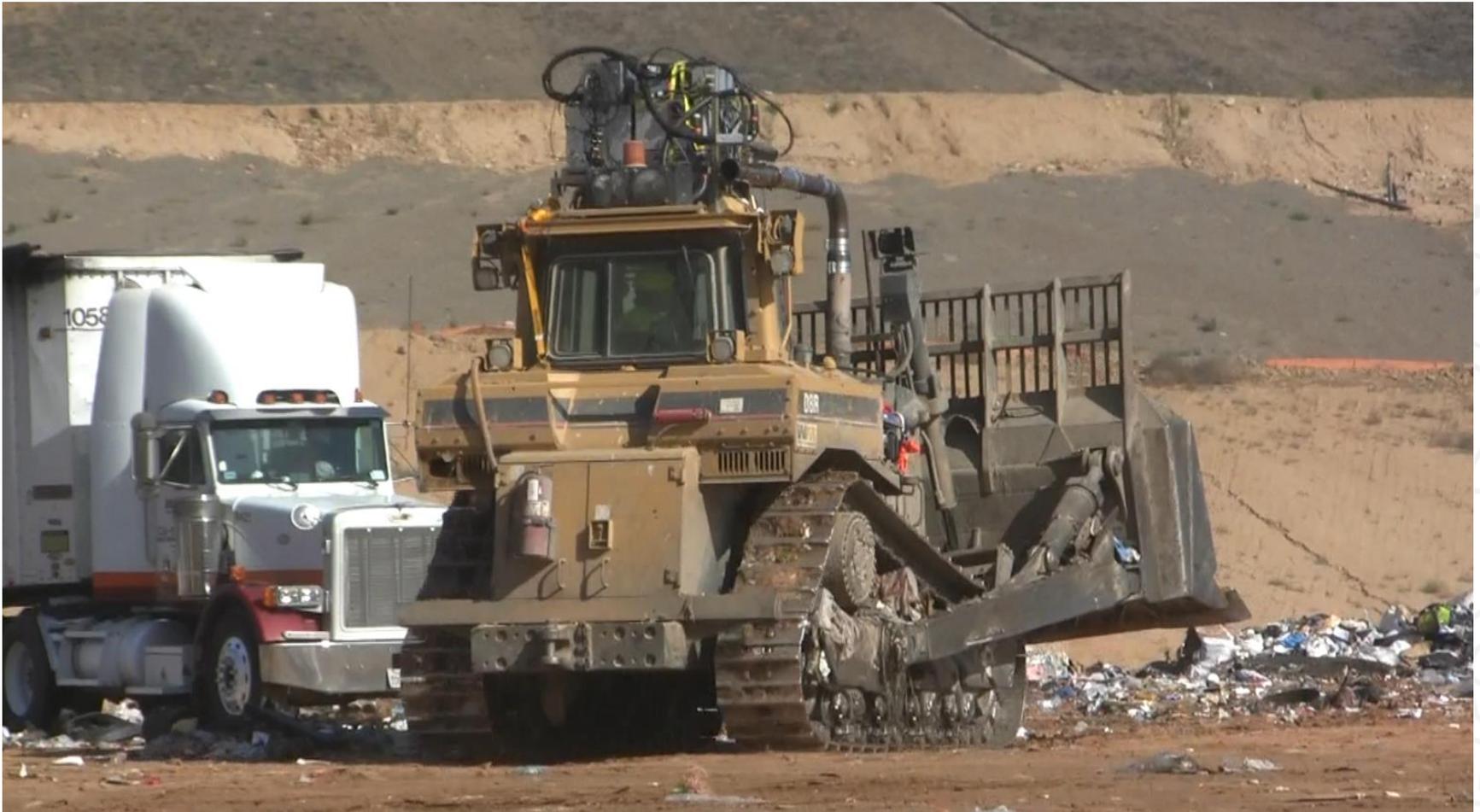


# Controlled Push Testing On A Grade



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# In-Service Testing D8R



# In-Service Testing D7E



# Controlled Trench HB215



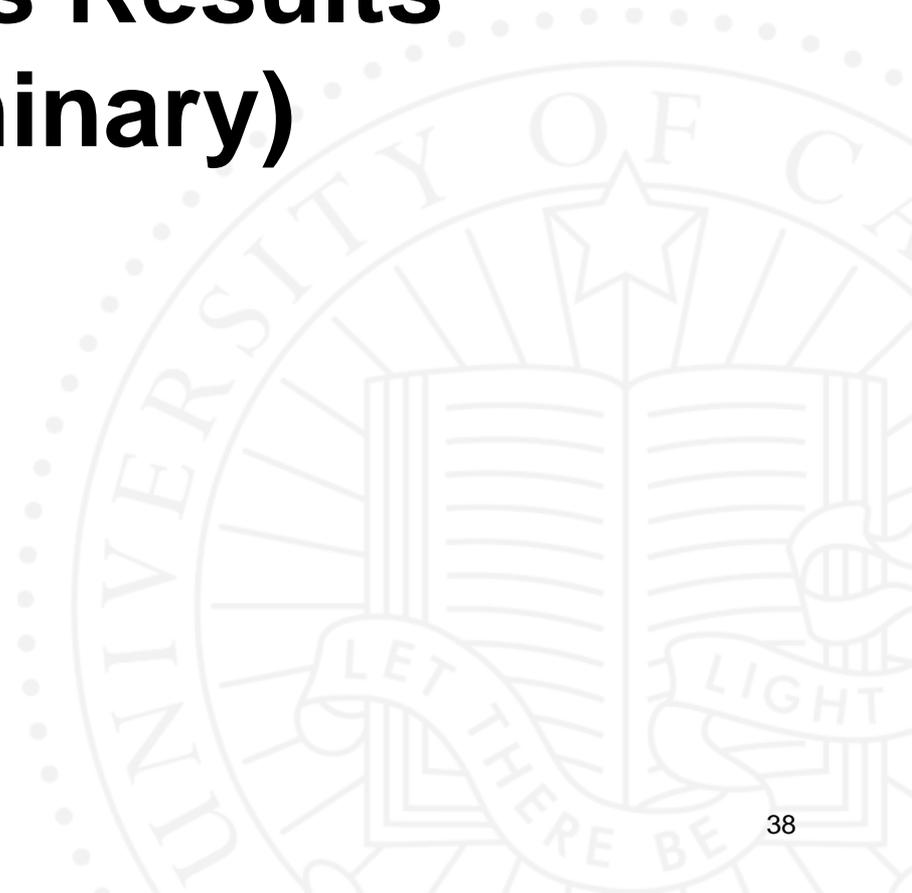
# Controlled Trench PC200



# Controlled Trench PC220



# Emissions Results (preliminary)



# Bulldozer D7E Comparison Results

	D7E-T4i Overall Trend to Conventional				
	CO <sub>2</sub>	NO <sub>x</sub>	PM	THC	CO
D6T T4i	↓	↑	---	---	---
D8T T4i	↓↓	↓	---	---	---
D8R T2	↓↓	↓↓	↓↓↓	↓↓	↓↓↓

- **Fuel benefit largest at light loads and short distances**
- **NOx dis-benefit for D6T** (may be a result of Lug Curve operation)
- **PM, CO, and THC no benefit for D6T and D8T** (due to very low measurements levels from DPF equipped D7E T4i)
- **PM, CO, and THC benefit for the D8R** (most likely due to DPF equipped D7E T4i)

# Excavator PC215 LC Comparison Results

	HB-215LC T3 Overall Trend to Conventional				
	CO <sub>2</sub>	NO <sub>x</sub>	PM	THC	CO
PC-200 T3	↓	↑↓	↑↑	↓	↑↑
PC-220 T3	↓↓	↓	↑	↓	↑

- **Fuel consumption benefit over all conventionals and all modes**
- **NOx benefit and dis-benefit depending on the mode for the PC200**
- **PM and CO dis-benefit for both conventionals** (may be due to higher RPM variation for hybrid compared to conventionals)
- **THC benefit for both conventionals**

# Acknowledgments

## › Fleet Partners

- › Waste Management
- › Orange County Water District
- › County of Riverside Transportation Department
- › Diamond D Engineering
- › Road Machinery
- › Claremont Equipment Rental

## › Project Partners

- › South Coast AQMD
- › Bay Area AQMD
- › Johnson Machinery
- › Road Machinery

## › Funding

- › CARB

## › Technical

- › UCR Staff Don, Eddie, and Joe, Joseph Menke
- › CSM UniCAN



# Questions ?

