

TERC/HARC Strategic Technology Assessment

New Technology Research & Development
Workshop

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The Woodlands, Texas

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TERC/HARC Strategic Technology Assessment

Project Sponsor

Texas Environmental Research Consortium (TERC)

Houston Advanced Research Council (HARC) –
New Technology Research and Development Program (NTRD)
Project No. N-01

Project Partners

Eastern Research Group
Rick Baker, Senior Scientist

Emisstar LLC
Michael Block, Principal



Presentation TOC

- Project Summary
- Study Methodology –
 - *EGT Dependent NO_x Reduction Efficiency*
- Engine Database Development
- Technology Assessment
- GUI Development

Project Summary

- Nonroad diesel engines > 50 hp in Houston-Galveston-Brazoria (HGB) area
- Target retrofit candidates for potential NOx reductions (locally operated)
 - Construction equipment
 - Commercial Marine Vessels (harbor vessels)

Project Summary cont'd

- Requires in-use engine profile
 - Engine make/model/year level of detail
 - Across range of SIC* / operations
- *Not feasible through traditional bottom-up surveys*
 - Sales data combined with scrap rates

*Standard Industrial Codes

Project Summary cont'd

- Estimate baseline NO_x/PM/VOC emissions – EDA*
 - Populations by equipment type & Tier level
 - Activity by SIC
 - Texas-specific post-processing adjustments (e.g., TxLED, temperature/humidity)
 - Establish per-unit emission factors

*Equipment Data Associates

- developed from Uniform Commercial Code (UCC-1) filings.
- filed at the state-level: equipment purchase financed, leased, rented to own, or refinanced.
- cash basis, or using an extended line of credit, no UCC-1 filing
- 50-80% nonroad coverage

Project Summary cont'd

- Identify & quantify promising NOx retrofit technologies
 - SCR, LNT, LNC, combinations
 - Compile available field data – equip EGTs
 - Exhaust gas temperature (EGT) impacts
 - EGT profiles by equipment type/application

Project Summary cont'd

- Apply reduction potentials to in-use engine profiles
 - Potential market penetration – MECA Members
 - NOx reductions – Govn't Regulators, others
- GUIs for reporting / scenario evaluation

Project Summary cont'd

- Potential End Uses
 - Assess emission reduction potential for different control options/target equipment
 - Estimate SIP credits (e.g., Carl Moyer, TERP)
 - Vendor market evaluations
 - Fleet-specific evaluations (e.g., state DOTs)

Study Methodology

1. Construct engine & emissions database
2. Identify NO_x control options
3. Obtain and evaluate equipment EGT curves (in-use data)
4. Determine NO_x redux perf = f [EGT] for ECTs
5. Calculate NO_x reduction potentials by equipment/engine type – equip w/EGT data, specific ECTs
6. Bin according to L, M, H load profiles
7. Develop GUI

GUI – Emissions Calculator

frmRegulators : Form

Emissions Calculator

* - denotes a required filter

Field Name **Filter Criteria**

Sector: Construction

County: (No Filter)

Equipment Type: EXCAVATOR

Standard Industrial Classification: (No Filter)

* **Engine Control Technology**: SCR Open Loop Control (no DOC)

* **Load**: M

Year: to

HP Range: to

Pollutants

NOx (ppb)

PM2.5 (ppb)

VOC (ppb)

Group Results By: SIC

Calculate Export Results

Reset Defaults Edit Regulatory Calculator

SIC	NOx Emissions	Adjusted NOx	PM	Population	AvgHP	AvgNOxRedu
REPAIR SERVICES NEC	1,412.6	508.5	115.233,042	222.3	64.0	
RESIDENTIAL CONSTRUCTION NEC	16.4	5.9	0.7 4,717	247.0	64.0	
RETAIL NURSERIES & GARDEN STORES	5.8	2.1	0.9 2,422	94.0	63.8	
RICE	7.9	2.8	0.7 2,763	168.0	64.6	
SANITARY SERVICES NEC	19.6	7.0	1.6 1,844	176.0	64.3	
SCRAP AND WASTE MATERIALS	867.1	312.2	89.9 121,972	231.7	64.0	
SPECIAL TRADE CONTRACTORS NEC	83.6	30.1	7.6 20,011	128.0	64.0	
SUBDIVIDERS & DEVELOPERS NEC	347.1	125.0	28.5 57,260	222.0	64.0	
TOWING SERVICES	347.1	125.0	28.5 57,260	222.0	64.0	
TRUCK SERVICE	437.2	157.4	30.3 77,617	242.7	64.0	
TRUCKING (LOCAL AND LONG DISTANCE)	24.2	8.7	2.0 3,994	228.0	64.0	
UNDERGROUND STORAGE TANK REM INST	88.5	31.9	6.0 20,543	227.2	64.0	

Records: 14 of 37

frmRegulators : Form

Emissions Calculator

* - denotes a required filter

Field Name **Filter Criteria**

Sector: Construction

County: (No Filter)

Equipment Type: EXCAVATOR

Standard Industrial Classification: (No Filter)

* **Engine Control Technology**: SCR Closed Loop Control (no DOC)

* **Load**: M

Year: to

HP Range: to

Pollutants

NOx (ppb)

PM2.5 (ppb)

VOC (ppb)

Group Results By: SIC

Calculate Export Results

Reset Defaults Edit Regulatory Calculator

SIC	NOx Emissions	Adjusted NOx	PM	Population	AvgHP	AvgNOxRedu
REPAIR SERVICES NEC	1,412.6	296.6	115.233,042	222.3	79.0	
RESIDENTIAL CONSTRUCTION NEC	16.4	3.4	0.7 4,717	247.0	79.3	
RETAIL NURSERIES & GARDEN STORES	5.8	1.2	0.9 2,422	94.0	79.3	
RICE	7.9	1.7	0.7 2,763	168.0	78.5	
SANITARY SERVICES NEC	19.6	4.1	1.6 1,844	176.0	79.1	
SCRAP AND WASTE MATERIALS	867.1	182.1	69.9 121,972	231.7	79.0	
SPECIAL TRADE CONTRACTORS NEC	83.6	17.6	7.6 20,011	128.0	78.9	
SUBDIVIDERS & DEVELOPERS NEC	347.1	72.9	28.5 57,260	222.0	79.0	
TOWING SERVICES	347.1	72.9	28.5 57,260	222.0	79.0	
TRUCK SERVICE	437.2	91.8	30.3 77,617	242.7	79.0	
TRUCKING (LOCAL AND LONG DISTANCE)	24.2	5.1	2.0 3,994	228.0	78.9	
UNDERGROUND STORAGE TANK REM INST	88.5	18.6	6.0 20,543	227.2	79.0	

Records: 14 of 37

GUI – Equipment Data Lookup

frmVendors : Form
⏪ ⏩ ⏴ ⏵

Equipment Data Lookup

* - denotes a required filter

Field Name	Filter Criteria
* Engine Control Technology	SCR Open Loop Control (no DOC) ▾
Sector	Construction ▾
Equipment Type	EXCAVATOR ▾
Equipment Make	(No Filter) ▾
Equipment Model	(No Filter) ▾
Engine Make	(No Filter) ▾
Engine Model	(No Filter) ▾
Standard Industrial Classification	(No Filter) ▾
* Load	M ▾
Year	<input type="text"/> to <input type="text"/>
HP Range	<input type="text"/> to <input type="text"/>

Calculate

Export Results

Reset Defaults

Exit Vendor Data Lookup

Pollutants

NOx (ppd)

PM2.5 (ppd)

VOC (ppd)

	ECT Desc	Sector	EDA_BASE_EC	EQTMAN	EQTMODEL	EDA_BASE_Er	EDA_BASE_Er	Year
▶	SCR Open Loop	Construction	EXCAVATOR	CAT	330-B	Caterpillar	3306 TA	
	SCR Open Loop	Construction	EXCAVATOR	CAT	330-B	Caterpillar	3306 TA	
	SCR Open Loop	Construction	EXCAVATOR	CAT	330-B	Caterpillar	3306 TA	
	SCR Open Loop	Construction	EXCAVATOR	CAT	330-B	Caterpillar	3306 TA	
	SCR Open Loop	Construction	EXCAVATOR	CAT	330-B	Caterpillar	3306 TA	
	SCR Open Loop	Construction	EXCAVATOR	CAT	330-B	Caterpillar	3306 TA	

Record: ⏪ ⏩ ▶ ⏴ ⏵ of 4064

Totals:

Population	NOX Emissions	Adjusted NOx	PM Emissions
▶ 10,106.255	39,226.2	14,905.9	2,826.2

Record: ⏪ ⏩ ▶ ⏴ ⏵ of 1

Constraints and Caveats

- ***Exhaust Gas Temperature (EGT)***
- Space Velocity
- Transient Operation
- NO/NO₂ Ratio
- Reductant Injection and Mixing
- Control Technology/Engine Turbocharger Outlet Orientation

Opportunities for Improvement

- Integration of National PEMS study data
- Refined scrap functions/projections
- Regional fleet variability
- Additional years of sales data
- More equipment EGT datasets – gap fill
- EGT – Engine Operating Relationship
- Further ECT assessment & research –
detail and expansion

Future Applications

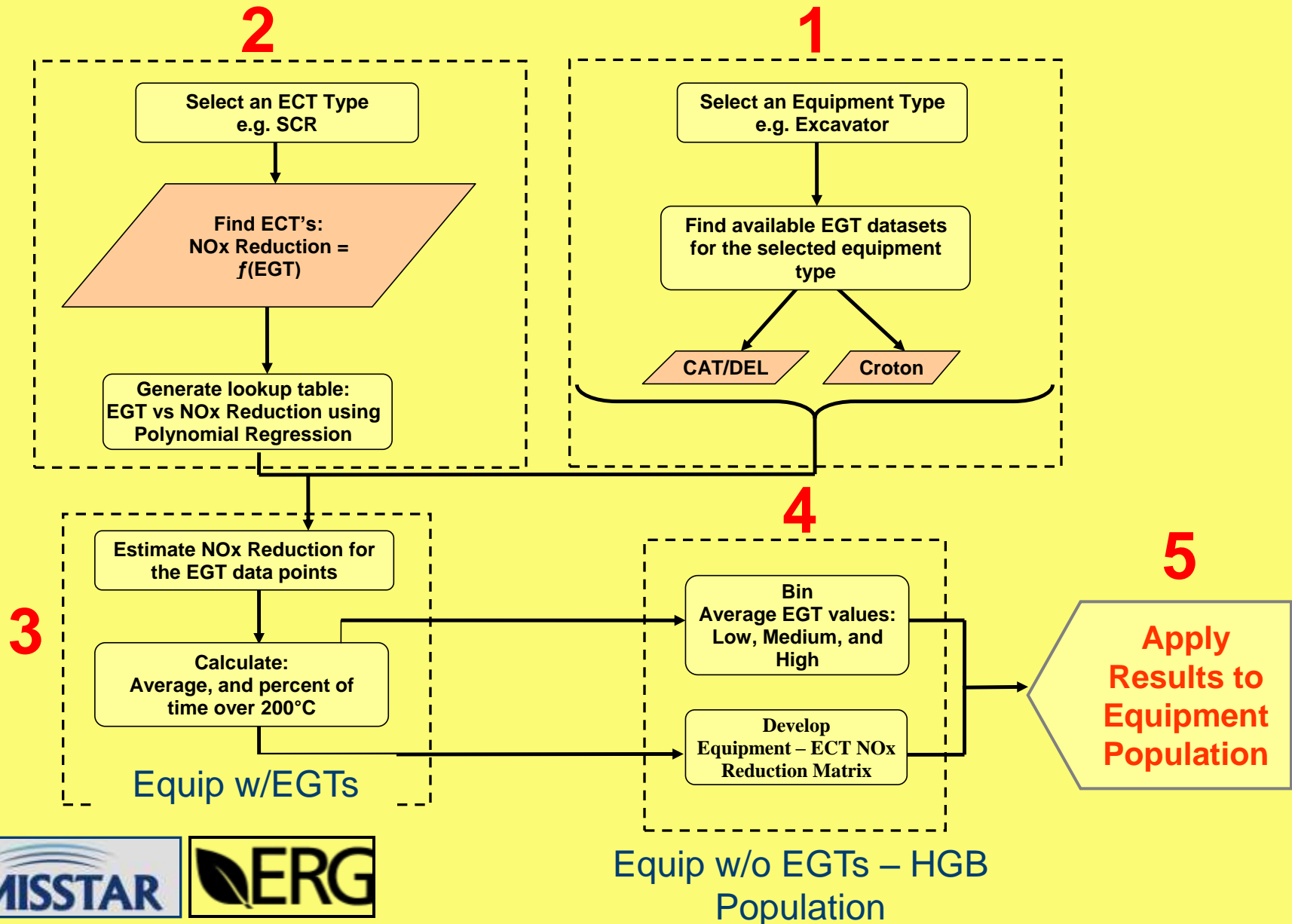
- Fleet-specific evaluations (e.g., large public fleets such as state DOTs)
- Other local, state and/or regional areas
- Nationwide coverage?
- New nonroad applications
 - Commercial/industrial equipment
 - Locomotives
 - Marine – many data gaps

Technology Assessment

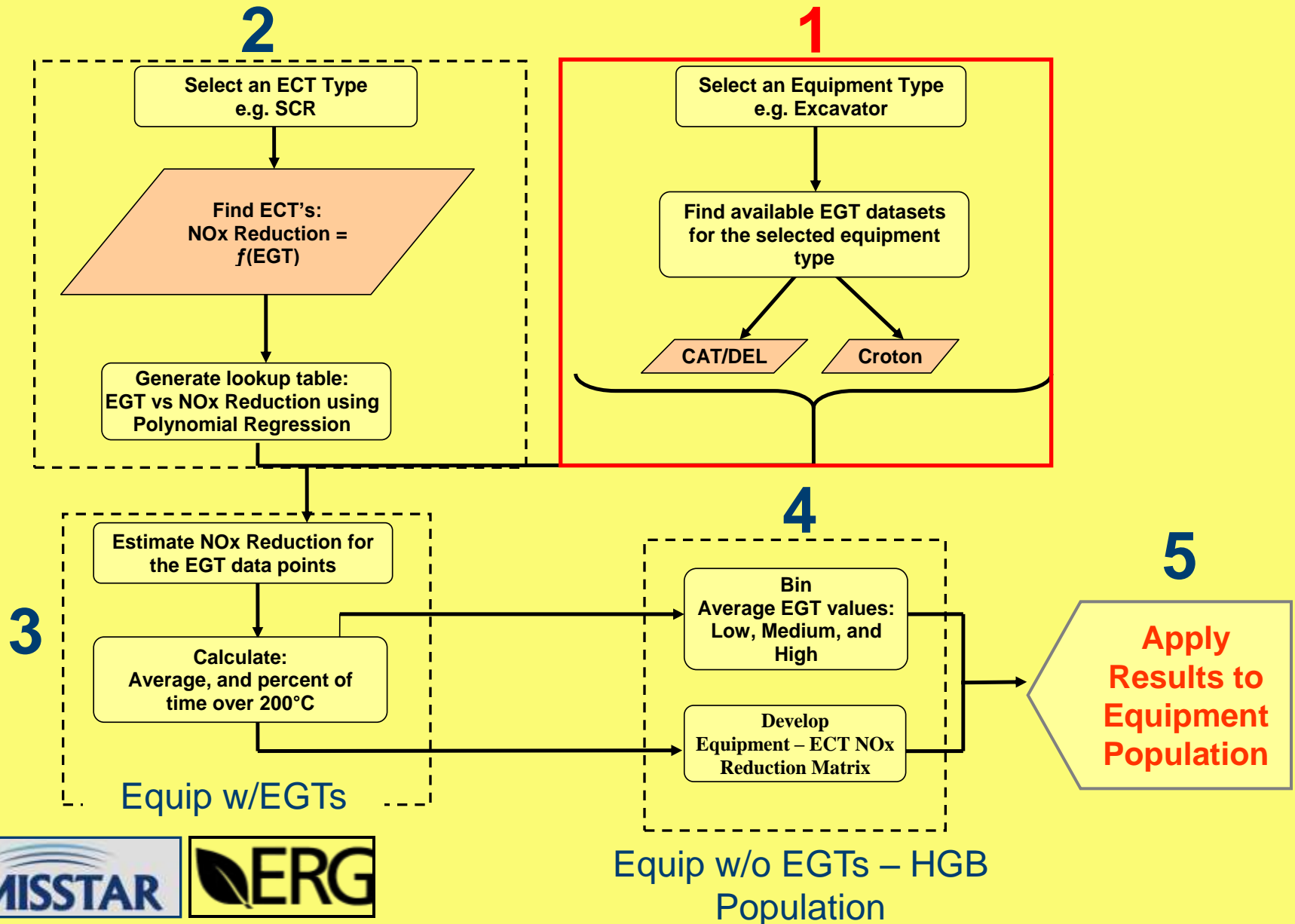
Details:

Equipment EGT
&
ECT NO_x Reduction
Matrix Development

Five Step Analytical Approach



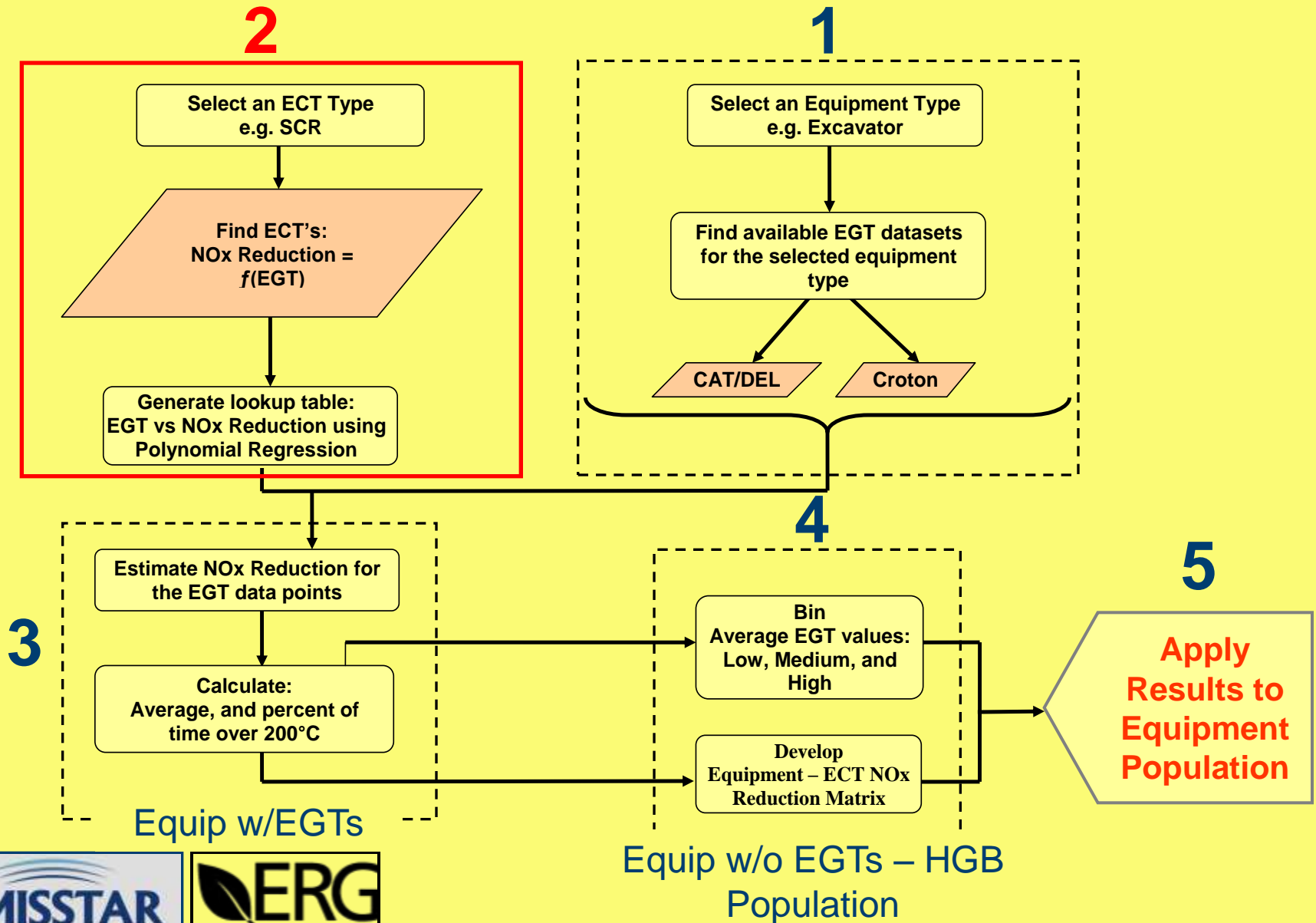
Analytical Approach – Step 1



Step 1 Equipment EGT Datasets

Source	Organization	Objective(s) of In-Use Activity	Operations Description	Test Year	Location	Equipment Type	MY ¹	HP ²	EGT ³	MAP ⁴	Q _{eng} ⁵	Q _{ext} ⁶	RPM	Torque
CAT/DEL	Emisstar	Evaluate the Local Law 77 compliance status of previously retrofitted equipment or to make “Best Available Technology” determinations for new non-retrofitted equipment	Excavation for UV water treatment plant	2006-2007	Valhalla, NY	Backhoe	1992	111	•	•	•		•	
						Dozer	1989-1999	95-189	•	•	•		•	
						Excavator	1993-2004	131-515	•	•	•		•	
						Motor Grader	1980	99	•	•	•		•	
						Quarry Truck	1988-2006	414	•	•	•		•	
						Wheel Loader	1988-1999	160-362	•	•	•		•	
Croton (Emisstar EGT data)	Emisstar	Evaluate the Local Law 77 compliance status of previously retrofitted equipment or to make “Best Available Technology” determinations for new non-retrofitted equipment	Excavation for under-ground filter-based water treatment plant	2006	Bronx, NY	Excavator	2004-2005	150-684	•					
						Hydraulic Drill	2006	225	•					
						Manlift	2000	64	•					
						Wheel Loader	2005	700	•					
Croton (EC Testing data)	Emisstar	Demonstrate and evaluate the performance of “best available” emission control technologies for reduction of PM and NOx emissions using in-use field testing approaches	Excavation for under-ground filter-based water treatment plant	2006	Bronx, NY	Compressor	2005	170	•		•			•
						Dozer	2004	332	•		•		•	
						Excavator	2004	474	•	•	•		•	
						Quarry Truck	2005	700	•		•			
						Wheel Loader	2004	259	•	•	•		•	
						Tiger Drill	2005	173	•		•		•	
DSNY	DSNY	Internal data collection for potential future retrofit	Unknown	Unknown	Queens, NY	Wheel Loader	1998	190						•
SPOT	EPA	Develop simple portable on-board emission testing system	Unknown	2002	Columbus, IN	Dozer	1985-1995	200-285	•				•	•
						Excavator	1989	165	•				•	•
						Wheel Loader	1983	285	•				•	•
						Quarry Truck	2001	375	•				•	•
WVU Scraper	WVU	Internal university project	Unknown	Unknown	Morgantown, WV	Scraper	NA	NA	•				•	•
Waste Management	Waste Management	Determine “Best Available Technology” determinations for new non-retrofitted equipment	Refuse treatment operations	2007	Bronx, NY	Compactor	2001-2007	340-442	•					
7 World Trade Center	Emisstar	EGT for prospective control technology matching	Construction of 35+ story commercial building	2002-2004	Manhattan, NY,	Crane	1970	500	•					
						Crane	1997	600	•					

Analytical Approach – Step 2



Step 2

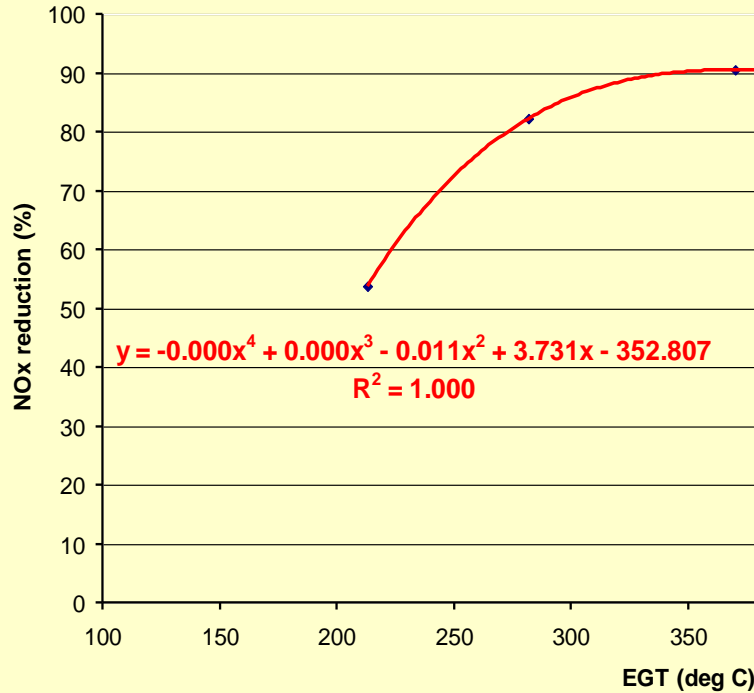
NO_x Reduction Lookup Tables, Technologies Considered

1	LNT	LNT Theoretical	Pt/BaO/Rh
2		LNT Dual Leg	Pt/BaO/Rh
3		LNT Single Leg	Pt/BaO/Rh
4	LNC	LNC	Ag/AL ₂ O ₃
5		LNC	Ag/AL ₂ O ₃ w/Ethanol
6		LNC Copper Zeolite	Cu/ZSM-5
7		LNC Platinum/Alumina	Pt/AL ₂ O ₃
8	SCR	SCR Closed Loop Control	No DOC
9		SCR Open Loop Control	No DOC
10		SCR Vanadia	No DOC
11		SCR Vanadia	With DOC
12		SCR "Multi-Function"	non-vanadia Titania (TiO ₂)
13		SCR Closed Loop Control	V ₂ O ₅ /WO ₃ /TiO ₂
14		Nett Technologies SCR	Fe/ZSM; no DOC; closed loop
15	Combinations	LNT+SCR	NH ₃ → for SCR redux
16		H ₂ Assist LNT	Xonon Fuel Processor
17		HC Assist LNC	Reformer Assist

Step 2

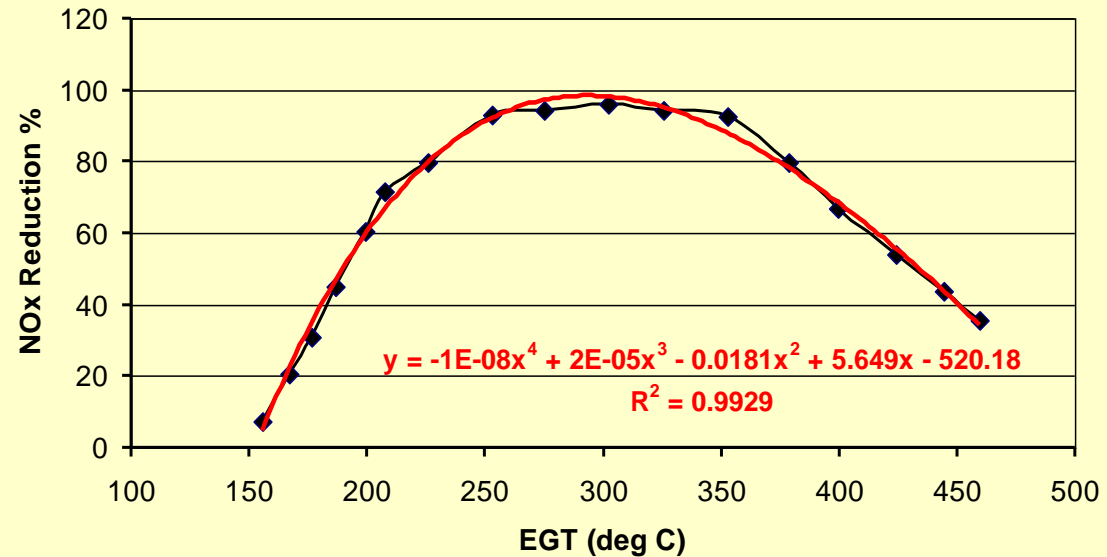
Develop Lookup Tables / Match EGT Data With ECT NOx Reductions

NETT Technologies Inc. Urea SCR System

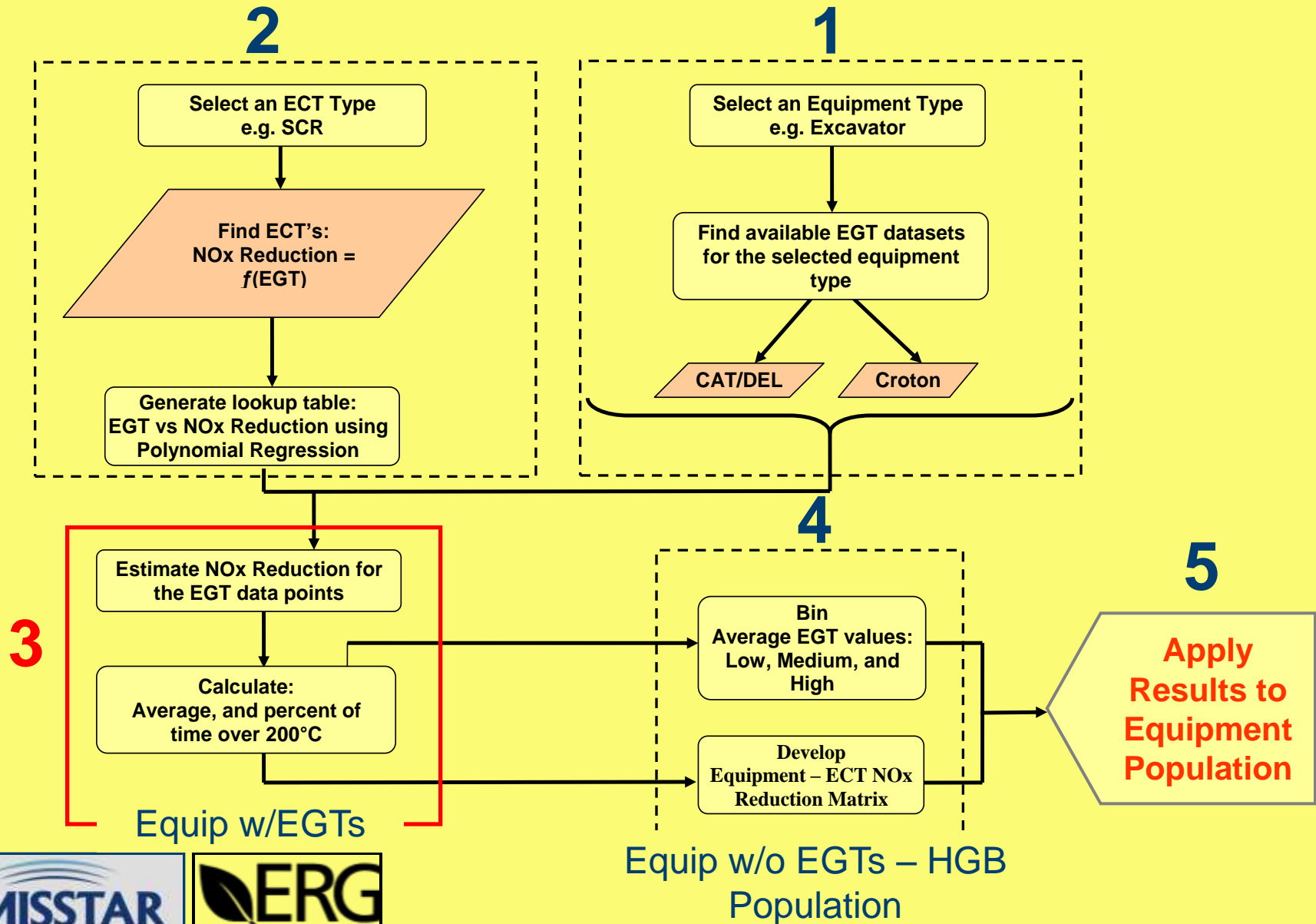


Two Sample
ECT Performance Curves

LNT Dual Leg, Pt/BaO/Rh



Analytical Approach – Step 3



Step 3

Equipment Specific NO_x Reduction Estimation

- Estimate NO_x Reduction for the EGT Datapoints
- Calculate Average, and Percent of Time over 200 °C

Step 3

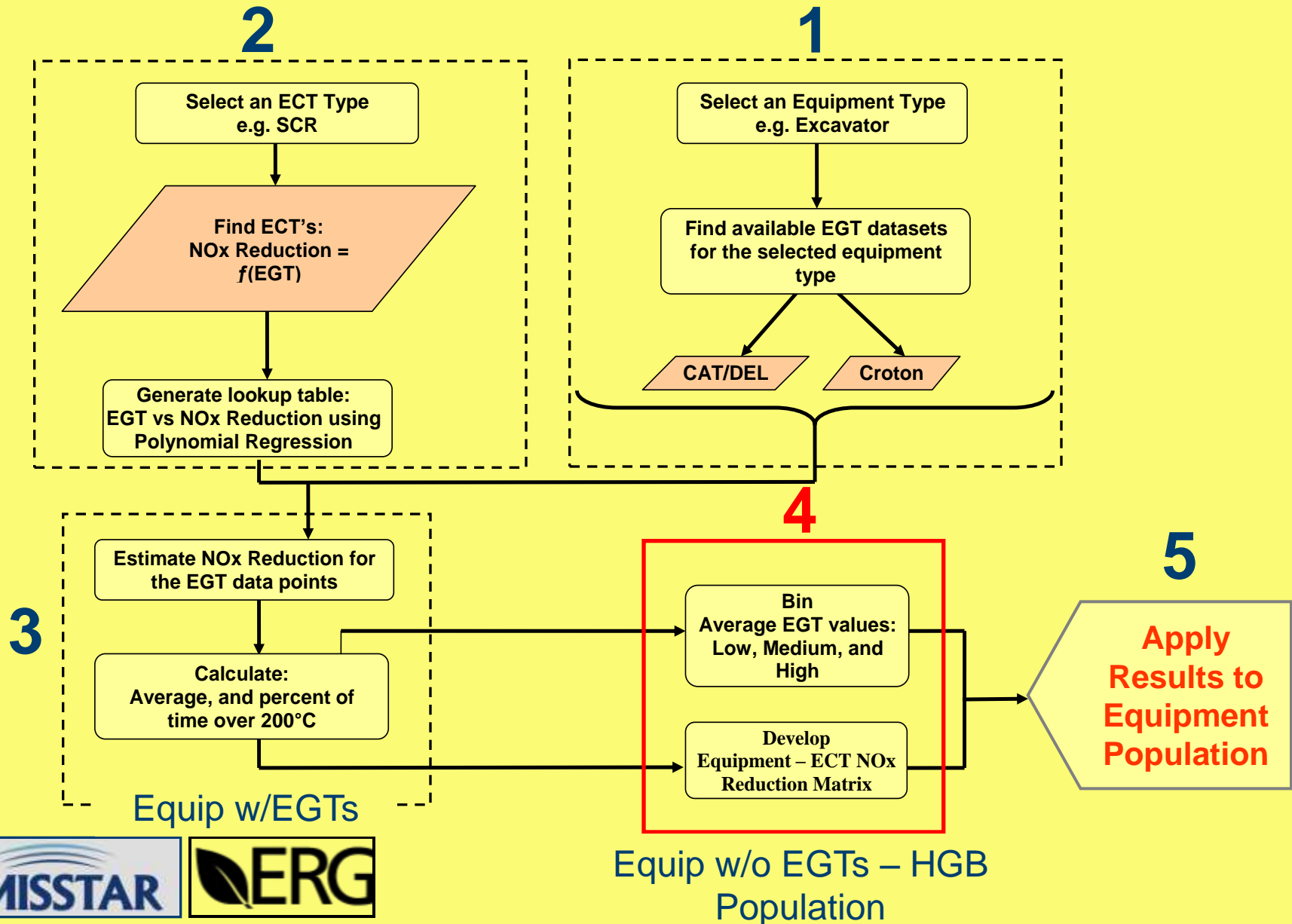
Equipment Specific NO_x Reduction Estimations

Example Outputs

No.	Duty Cycle Bin	Data Source	Equipment EGT Interval (sec)	Chassis				Engine			
				Type	Manufacturer	Model	Model Year	Manufacturer	Model	Model Year	Power (HP)
1	L	CAT/DEL	7	Backhoe	CAT	446 B	1992	CAT	3306	1992	111
43	H	Waste Management	5	Compactor	CAT	826G	2001	CAT	3406	2001	340
44	H	Waste Management	5	Compactor	BOMAG	BC772RB	2007	Deutz	TCD2015V06	2006	442
45	H	Croton WTP	1	Compressor	Ingersoll Rand	IR600	2005	John Deere	61RF8TE	2005	170
46	L	7 World Trade Center	60	Crane	Manitowac	1900	1970	Detroit Diesel	GM12VA59782	1970	500
47	M	7 World Trade Center	60	Crane	Manitowac	1900T	1997	Cummins	QSK19-0	1997	600
48	L	CAT/DEL	7	Dozer	CAT	D6H	1989	CAT	3306	1989	165
49	M	EPA SPOT	1	Dozer	CAT	D8N	1990	CAT	3406	1990	285

No.	Duty Cycle Bin	Data Source	Average EGT (°C)	Percent of Time over 200°C (%)	2004-01-0156	2005-01-1084
					LNT Dual	LNT Single
					Average NO _x Reduction Est. Over EGT Range (%)	Average NO _x Reduction Est. Over EGT Range (%)
1	L	CAT/DEL	145.18	4.9	51.5	39.9
43	H	Waste Management	318.55	70.9	58.1	61.4
44	H	Waste Management	365.45	78.7	53.8	59.4
45	H	Croton WTP	440.08	100.0	46.5	73.5
46	L	7 World Trade Center	156.15	8.0	34.6	18.7
47	M	7 World Trade Center	224.29	84.1	76.8	35.8
48	L	CAT/DEL	222.84	47.7	75.0	65.3
49	M	EPA SPOT	243.26	76.8	85.3	55.0

Analytical Approach – Step 4



Step 4

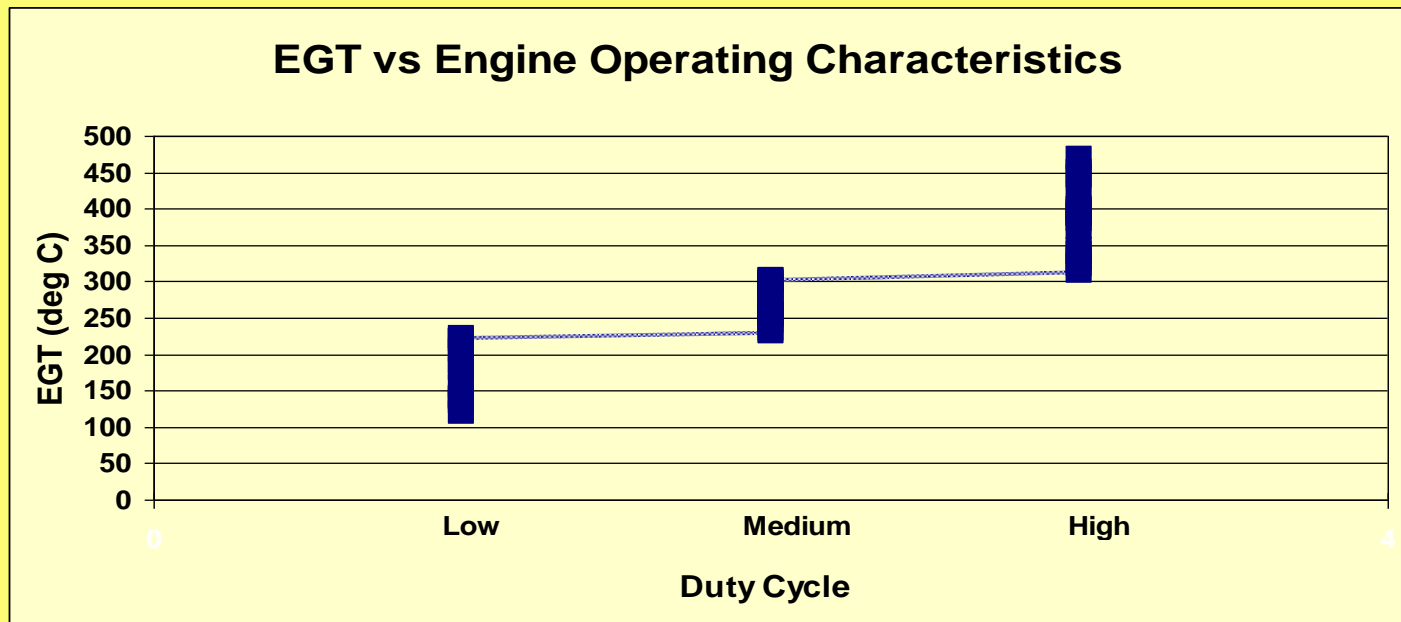
NO_x Reduction Matrix

- **Duty Cycle Development**
 - **Binning Average EGT Values**
 - **Define Low, Medium, and High Duty Cycles**
- **Develop Equipment–ECT NO_x Reduction Matrix**
 - **Equipment w/o EGT Data (“HGB Equipment”)**
 - **Equipment Operation → Corresponding EGT**
 - **Engineering Judgment & Field Operations Suggests Good Correlation**

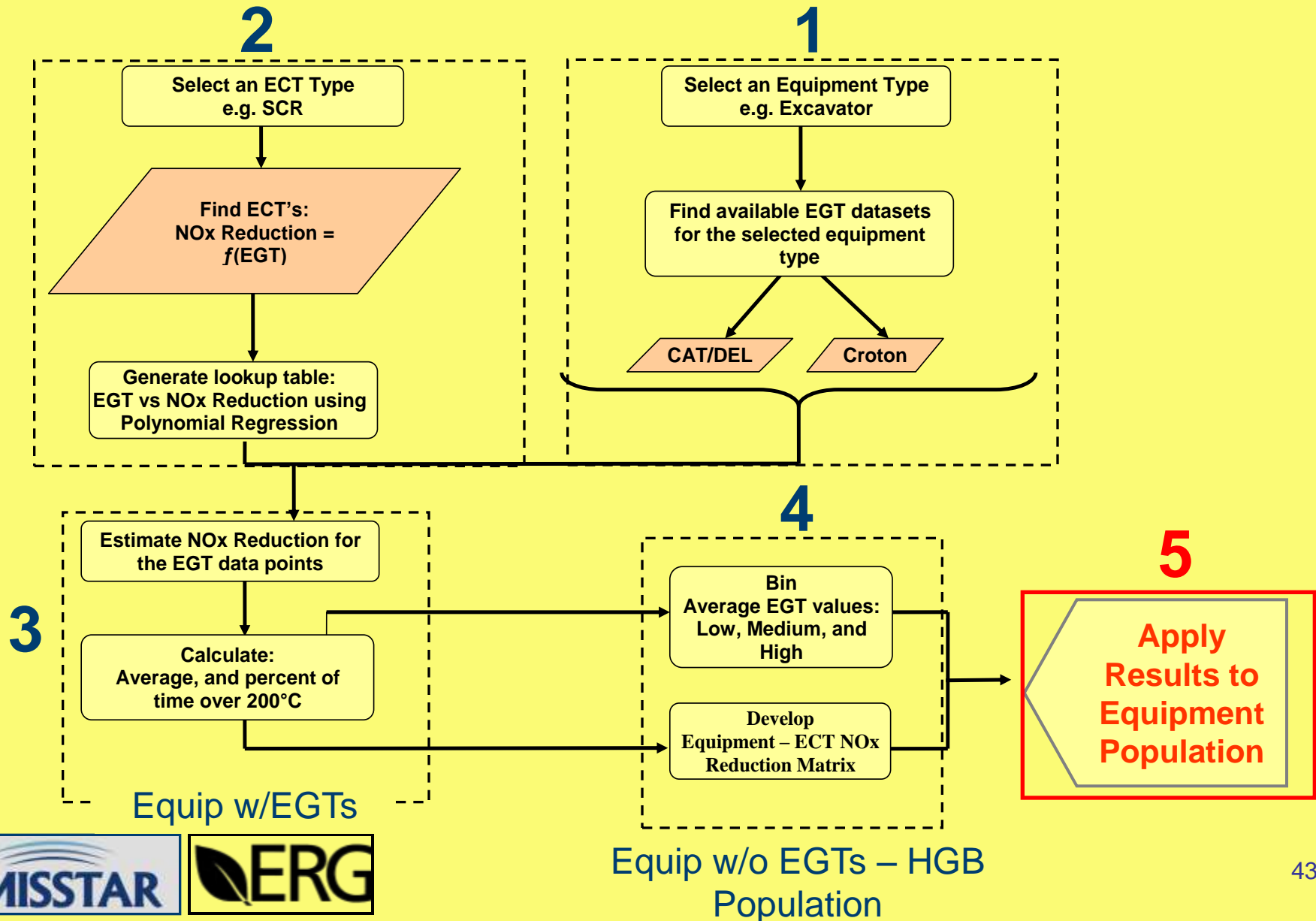
Step 4

Outputs – HGB Equipment

- Development of EGT/Engine Operating Characteristics
 - Binning exercise – “L”, “M”, “H”
 - Assign representative EGT profile from one of 44 machines that best match equipment w/o EGT



Analytical Approach – Step 5



Step 5

Outputs – HGB Equipment

Equipment Information					Emission Control Technology (ECT) Type/Description % NOx Reduction																	Data Source For Machines w/No EGT Data
No.	Equipment Type	EGT/Load (L, M, H)	No. of Machines	% T >200 deg C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
					LNT Theoretical	LNT Dual Leg	LNT Single Leg	LNC Ag/AL2O3	LNC Ag/AL2O3 w/Ethanol	LNC CU Zeolite	LNC Pt/AL2O3	SCR Closed Loop Control (no DOC)	SCR Open Loop Control (no DOC)	SCR Vanadia, without DOC	SCR Vanadia, with DOC	SCR TiO2 (no vanadia)	SCR Vanadia (theoretical)	SCR, NETT Tech, Inc. FEZeolite	LNT+SCR	H2 Assisted LNT	HC Assisted LNC	
1	Backhoe	L	1	5	OEOR	52	40	OEOR	58	11	20	50	36	14	52	79	63	76	89	85	57	
		M	0	67	47	75	63	13	74	30	18	74	59	62	78	91	82	84	85	91	76	
2	Compactors	H	2	75	43	56	60	28	82	33	17	65	55	74	90	88	86	84	90	84		
3	Cranes	L	1	8	OEOR	35	19	OEOR	43	OEOR	18	25	19	30	80	40	80	74	38			
		M	1	84	12	77	36	OEOR	52	OEOR	42	46	32	66	95	47	65	80	83	46		
4	Dozers	L	1	48	48	75	65	OEOR	77	35	15	76	60	63	77	91	84	85	86	92	78	
		M	4	71	49	77	63	OEOR	71	27	18	75	60	64	80	92	82	84	86	92	76	
5	Excavators	H	5	90	65	68	72	16	85	44	OEOR	84	69	74	84	92	90	88	77	96	87	
		L	2	42	30	73	57	OEOR	59	17	22	69	54	50	73	90	76	85	91	89	69	
6	Gen Sets	M	7	73	54	78	67	OEOR	73	31	16	79	64	67	82	92	85	85	93	79		
		H	2	84	58	55	65	27	84	38	10	83	68	59	69	90	91	87	79	87		
7	Grader	H	1	100	58	47	73	19	86	41	OEOR	88	72	79	85	91	96	89	62	98		
8	Lifts	L	1	14	OEOR	62	38	OEOR	57	12	25	48	34	39	56	88	66	78	90	86	59	
		L	1	7	10	58	49	OEOR	67	22	19	59	45	36	61	85	76	82	88	89	69	
9	Loaders	L	1	27	18	73	56	OEOR	61	17	21	70	55	51	73	88	76	81	92	90	70	
		M	3	67	47	77	64	18	72	28	17	77	62	66	81	92	83	84	87	92	77	
10	Offroad Trucks	H	2	93	70	71	75	12	86	46	8	86	70	77	85	92	93	87	75	97	87	
		L	2	62	29	75	45	OEOR	54	9	30	57	43	50	69	93	65	72	89	86	59	
11	Pipe Layers	M	4	80	41	82	54	OEOR	58	14	27	67	52	60	78	94	72	79	91	88	66	
		M	0	72	51	78	64	OEOR	70	26	18	77	62	66	81	92	83	84	88	92	77	
12	Reclaimers, Stabilizers, Milling Machines	H	0	75	48	55	65	27	84	38	10	83	68	59	69	90	91	87	79	94	87	
13	Rough Terrain Forklift	L	0	5	OEOR	52	40	OEOR	58	11	20	50	36	14	52	79	63	76	89	85	57	
		M	0	67	47	75	63	13	74	30	18	74	59	62	78	91	82	84	85	91	76	
14	Scrapers	M	1	57	34	68	58	15	74	25	19	72	57	54	74	90	81	83	87	90	75	
15	Steady-State Machines (Compressors, Pumps)	H	0	100	58	47	73	19	86	41	OEOR	88	72	79	85	91	96	89	62	98	91	
16	Surfacing & Paving Equipment	H	0	100	58	47	73	19	86	41	OEOR	88	72	79	85	91	96	89	62	98	91	
17	Trenchers	H	0	100	73	71	76	19	75	36	5	90	74	84	91	93	95	88	78	99	88	
18	Boring and Drilling	M	1	97	52	91	59	OEOR	55	12	27	74	59	69	87	96	73	78	92	90	68	
		H	1	100	87	95	78	OEOR	64	31	OEOR	92	75	88	96	96	93	89	94	97	86	
OEOR *Out (of) ECT Operating Range*				Max	87	95	78	28	86	46	42	92	75	88	96	96	96	89	94	99	91	
				Min	10	35	19	12	43	9	5	25	13	14	30	79	40	65	62	38	46	
				AV	47	67	59	19	70	28	19	72	57	58	74	90	80	83	83	80	75	
					LNT Av = 58					LNC Av = 34					SCR Av = 72					Comb Av = 83		

Step 5

Outputs – HGB Equipment (detail)

No.	Equipment Type	EGT/Load (L, M, H)	No. of Machines	% T >200 deg C	1	2	3	4
					LNT Theoretical	LNT Dual Leg	LNT Single Leg	LNC Ag/AL2O3
1	Backhoe	L	1	5	OEOR	52	40	OEOR
		M	0	67	47	75	63	13
2	Compactors	H	2	75	43	56	60	28
3	Cranes	L	1	8	OEOR	35	19	OEOR
		M	1	84	12	77	36	OEOR
4	Dozers	L	1	48	48	75	65	OEOR
		M	4	71	49	77	63	OEOR
		H	5	90	65	68	72	16
5	Excavators	L	2	42	30	73	57	OEOR
		M	7	73	54	78	67	OEOR
		H	2	84	48	55	65	27

**OEOR: Out of ECT Operating Range

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