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A Systems Evaluation on the Effectiveness of In-Use Vehicle Emission Control Programs in Asia

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Background

Ford China Rare Earth Oxide (REO) Catalyst R&D Program Overview

- **REO Catalyst Formulation R&D**
- **REO Catalyst Materials Production R&D**
- **Ceramic Catalyst Substrate R&D**
- **Catalyst Systems Performance Evaluation and Testing Program**
- **System Evaluation on the Effectiveness of a Catalyst In-Use Fleet Vehicle Retrofit Program in Kunming, China**

System Evaluation on Catalyst Retrofit Program In Kunming



- **Agreement signed Dec. 1998 with Kunming Institute of Precious Metals**
- **Two year Project**
- **Retrofit Methodology Development at Ford**
- **Kunming, China Fleet Testing Program: 200 Vehicles**
- **Vehicle Testing at University of California, Riverside**



Retrofit Methodology Development At Ford

- **Two VW Santanas from Shanghai**
- **Tune-up (spark plugs, wires, rotor, distributor, carburetor cleaning)**
- **Temperature Profile Measurement**
- **Base-line Emissions**
- **Emissions Evaluation of REO Catalyst**
 - **Idle conditions**
 - **Chinese drive cycles**



Retrofit Methodology Development At Ford

Purpose: to determine the effectiveness of the REO catalyst to meet emission regulations for in-use vehicles in China.

- **Test Vehicle:**

- **1995 carbureted Chinese vehicle, 4 cylinder**
- **Manual transmission with manual choke**
- **1.8L engine, with 50,000 km actual vehicle aging**

- **Test Cycles:**

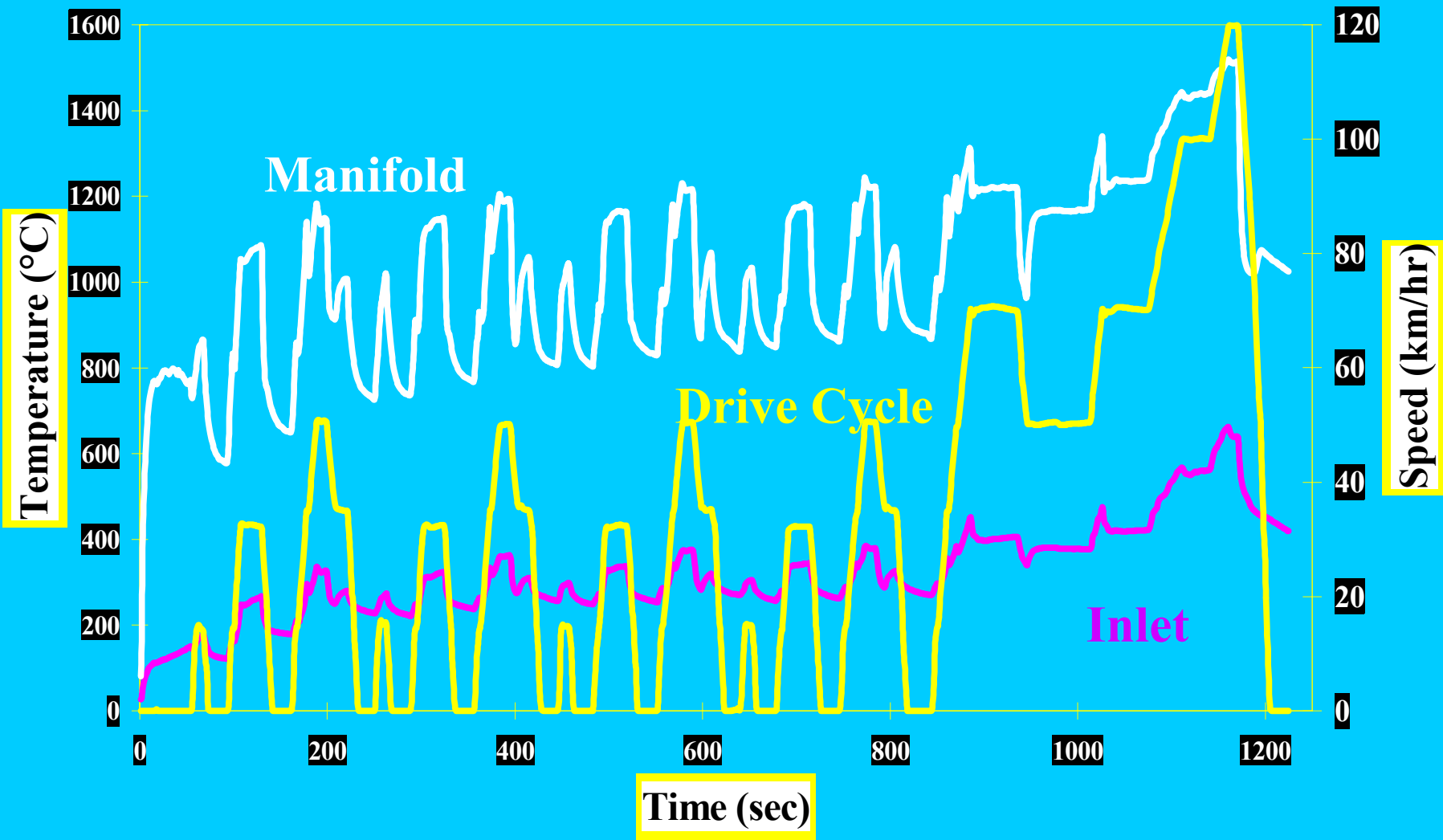
- **ECE 15.04 + EUDC Drive Cycles**
- **Chinese Dual Idle Emission Test method**

Dual Idle Emission Test Method



- Start the vehicle and increase the engine speed to 3640 rpm
- Hold at 3640 rpm for 60 seconds, then reduce to 2600 rpm
- Keep at 2600 rpm for 15 seconds, then begin measuring the HC and CO
- Measure the HC and CO maximum and minimum during the next 30 seconds
- The **High Idle Emission Value** is the average of the maximum and minimum values of each test.
- Reduce the engine speed to idle (no pressure on the accelerator)
- Idle for 15 seconds, then begin measuring the HC and CO emissions
- Measure the HC and CO maximum and minimum during the next 30 seconds
- The **Low Idle Emission Value** is the average of the maximum and minimum values of each test.

Temperature Profiles



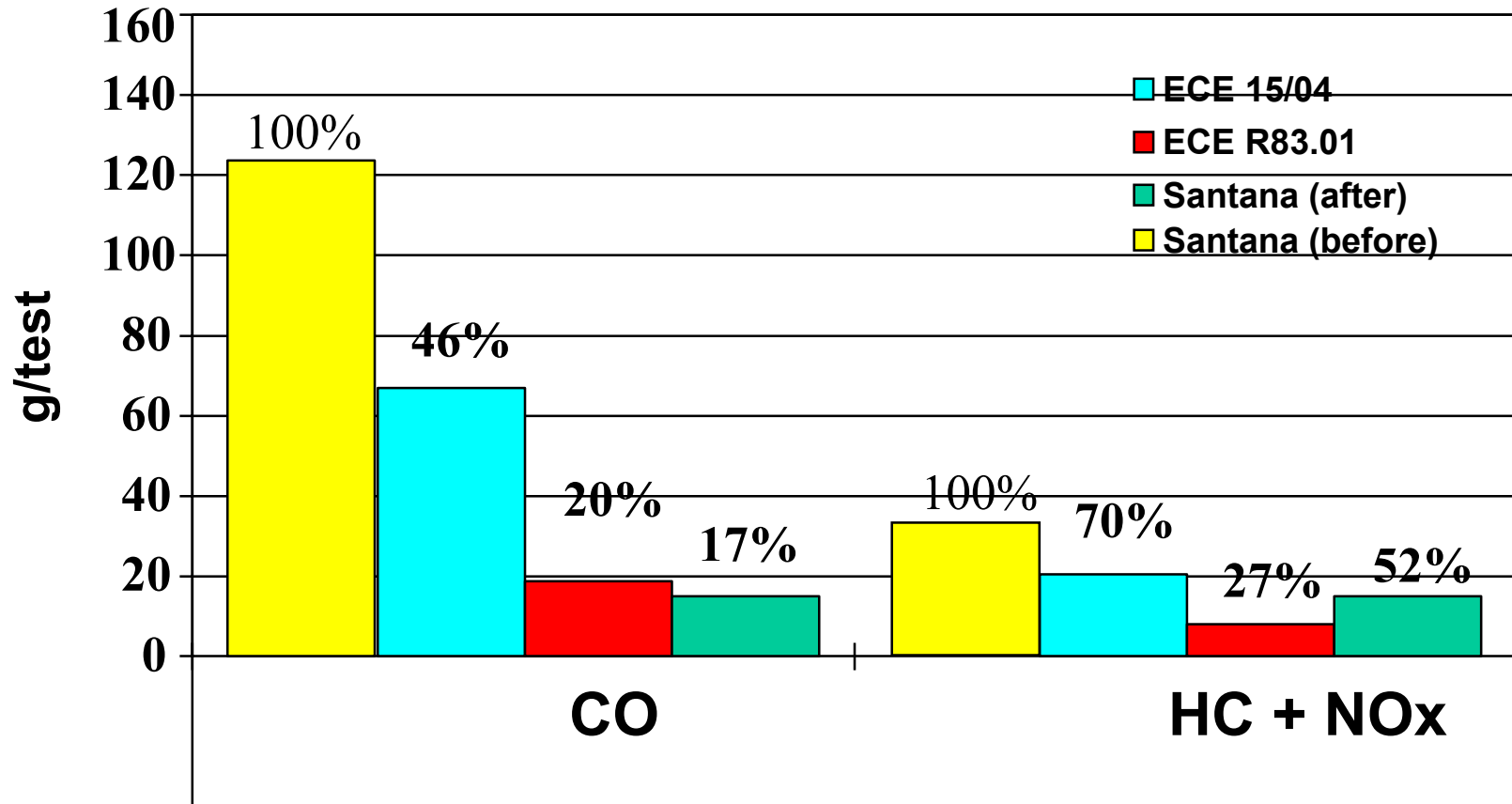


Retrofit System Design

- **Carry out I/M before retrofit of vehicles**
- **Use temperature profile to determine proper location for catalyst installation.**
- **Develop a mechanical secondary air device to improve emission reduction.**
- **Evaluate the effectiveness of the whole system**



Conversion Efficiency for Retrofit





Kunming Retrofit Project: Objectives

- **Implement the retrofit methodology developed at Ford on a demo fleet**
- **Evaluate the emission reduction potential of an effective I/M program**
- **Demonstrate the emissions reduction benefits for the retrofit of in-use vehicles with a 3-way Rare-Earth Oxide (REO) catalyst and secondary air pump**
- **Determine baseline CO, HC, and NO_x idle emissions for typical in-use Chinese vehicles**



Kunming Retrofit Project: Testing

- **Two service centers chosen in Kunming City**
- **Fleet Vehicles (200) studied included mini vans, economy cars, sub-compact cars and imports**
- **Standard emissions test performed:**
 - **Before inspection and maintenance**
 - **After maintenance**
 - **After catalyst retrofit**
 - **HC and CO emissions measured**



Kunming Retrofit Project: Results

	Vehicle Class	Emissions			Reductions, %	
		Initial	After Repair	After Catalyst	I/M	Catalyst*
CO, %	Mini-Van	8.3	5.4	0.4	34.6	93.3
	Economy	7.3	4.1	0.6	43.8	85.2
	Sub-Compact	6.7	4.7	0.7	29.9	85.1
	Import	7.3	2.0	0.3	72.6	87.5
HC, ppm	Mini-Van	1316	771	125	41.4	83.8
	Economy	718	492	74	31.5	85.1
	Sub-Compact	1044	685	95	34.3	86.1
	Import	1170	606	87	48.2	85.6

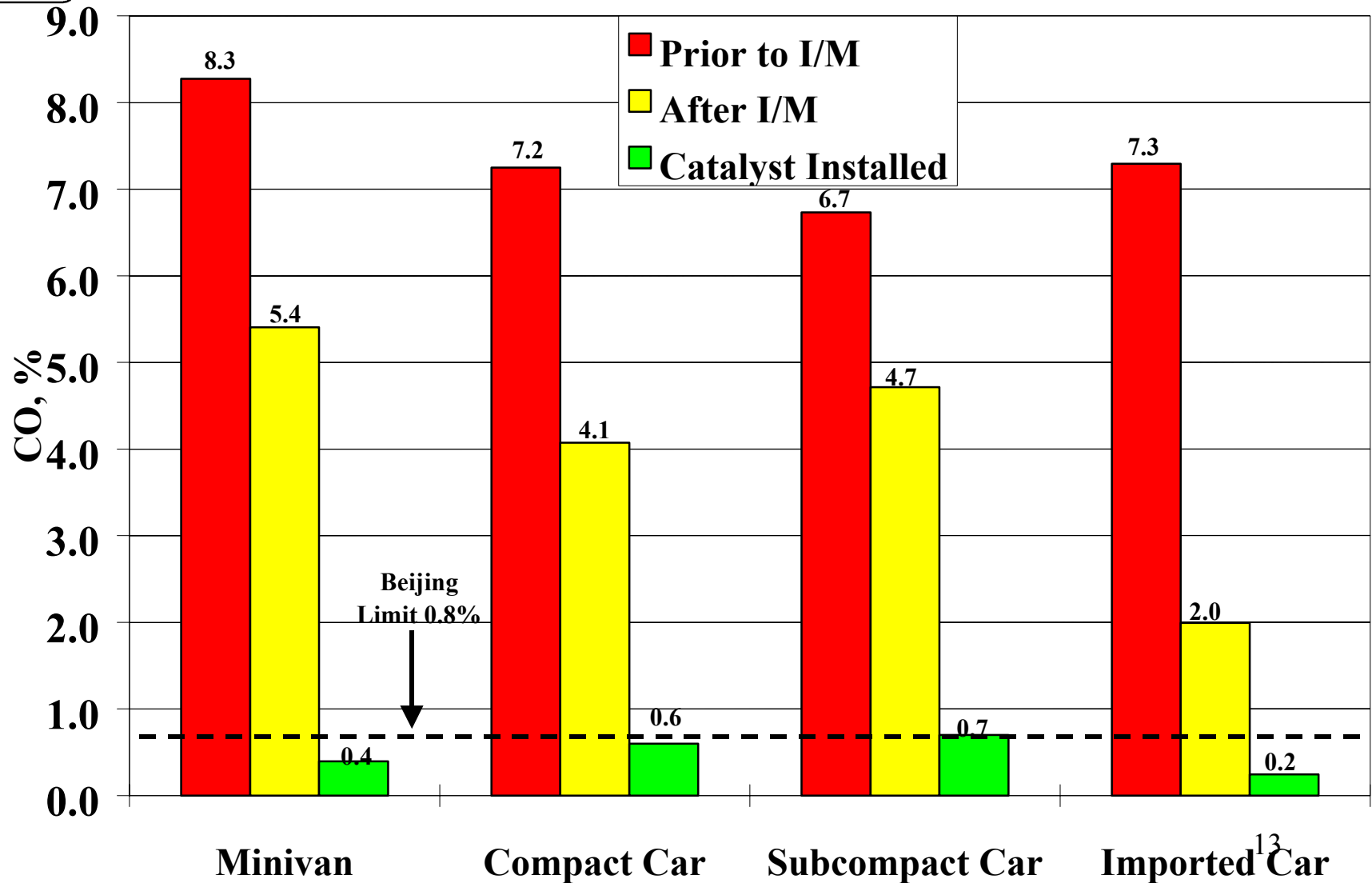
I/M decreases emissions by ~ 42%

Catalyst retrofit drastically reduces emissions (~ 86 %)

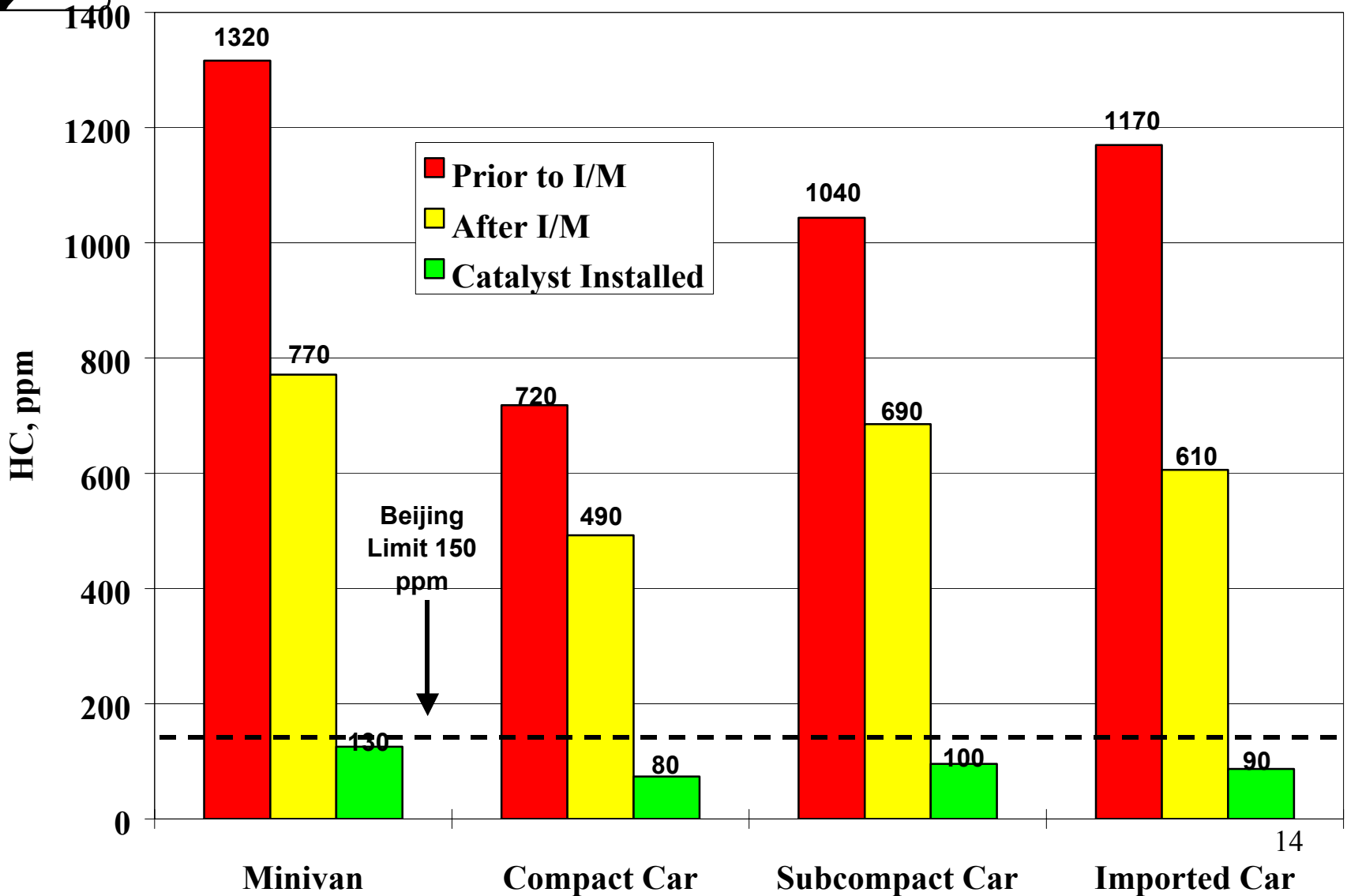
Beijing's in-use standard: 150 ppm HC, 0.8% CO

China's in-use standard: 900 ppm HC, 4.5% CO

Results: CO Reduction



Results: HC Reduction



REO Catalyst Testing At UC, Riverside



- 1 Vehicle: 1976 Ford Pinto
 - 4 cylinder, overhead cam, 8 valve, 2.3 liter
 - Carbureted fuel system
 - EGR and air injection
- FTP driving cycle on a chassis dynamometer
 - Exhaust was fully speciated
- 2 Catalysts; Kunming three-way and Ford oxidation
- 3 Fuels; California reformulated gasoline, oxygenated Chinese fuel, and non-oxygenated Chinese fuel

Parameter	Fuel		
	RFG	Oxy	Non-oxy
Aromatics, vol %	27.2	12.6	12.5
Olefins, vol %	6.5	35.4	34.5
Saturates, vol %	66.3	51.6	53.0
MTBE, vol %	10.92	14.85	0.0
Sulfur, ppm	32.5	290	246
Lead, mL/gal	0.0	0.0	0.018
Octane Number	91.7	88.7	84.3

High Reduction Efficiencies Are Also Observed During Chassis Dynamometer Testing



Pollutant	Fuel	Catalyst				
		None Emissions, g/mile	Kunming Emissions, g/mile	% Reduction	OEM Emissions, g/mile	% Reduction
THC	Non-Oxy	1.353 ± 0.023	0.249 ± 0.018	81.6	0.218 ± 0.003	83.9
	Oxy	1.728	0.208	88.0	0.233	85.3
	RFG	1.723 ± 0.070	0.204 ± 0.019	88.2	0.187 ± 0.035	89.1
NMHC	Non-Oxy	1.269 ± 0.024	0.157 ± 0.018	87.7	0.132 ± 0.001	89.6
	Oxy	1.621	0.118	92.7	0.152	89.3
	RFG	1.615 ± 0.067	0.110 ± 0.013	93.2	0.106 ± 0.020	93.5
CO	Non-Oxy	23.511 ± 0.435	3.393 ± 0.189	85.6	2.758 ± 0.012	88.3
	Oxy	23.703	2.119	91.1	2.168	90.8
	RFG	27.064 ± 1.230	2.531 ± 0.534	90.6	2.372 ± 1.071	91.2
NO _x	Non-Oxy	1.305 ± 0.007	1.317 ± 0.032	-0.9	1.355 ± 0.043	-3.9
	Oxy	1.026	0.953	7.1	1.022	0.8
	RFG	1.027 ± 0.052	0.954 ± 0.041	7.1	0.982 ± 0.061	4.3

- Similar emissions rates are observed for all fuel/catalyst combinations
- High HC and CO reductions and low NO_x reductions

Large Emissions Reductions Are Observed For Nearly All Hydrocarbon Functional Groups

Functional Group	Fuel	Catalyst		
		None Emissions, mg/mile	Kunming Emissions, mg/mile	OEM Emissions, mg/mile
Normal Alkanes	Non-Oxy	136.84 ± 0.15	111.75 ± 3.22	103.25 ± 3.89
	Oxy	181.91	116.10	107.05
	RFG	160.99 ± 9.30	104.93 ± 0.60	99.46 ± 9.91
Branched Alkanes	Non-Oxy	169.21 ± 13.86	48.60 ± 7.12	37.25 ± 0.16
	Oxy	216.36	31.99	36.91
	RFG	284.37 ± 10.60	34.72 ± 3.01	31.70 ± 3.63
Cyclo Alkanes	Non-Oxy	30.73 ± 0.76	6.14 ± 0.98	5.27 ± 0.02
	Oxy	35.11	4.70	5.86
	RFG	14.05 ± 2.44	2.24 ± 0.01	1.82 ± 0.31
Alkenes	Non-Oxy	458.91 ± 9.15	37.44 ± 4.68	33.28 ± 0.20
	Oxy	608.94	27.32	37.39
	RFG	447.35 ± 14.81	19.78 ± 3.75	22.52 ± 3.06
Alkynes	Non-Oxy	120.36 ± 0.26	5.13 ± 1.07	3.02 ± 0.76
	Oxy	149.30	3.20	3.31
	RFG	118.70 ± 0.70	1.92 ± 0.50	3.38 ± 1.69
Aromatics	Non-Oxy	189.39 ± 7.78	21.56 ± 2.06	22.79 ± 1.38
	Oxy	198.28	11.94	14.34
	RFG	328.66 ± 4.19	19.58 ± 3.62	21.18 ± 2.93
Ethers	Non-Oxy	1.51 ± 1.51	0.69 ± 0.62	0.20 ± 0.16
	Oxy	36.52	4.74	3.75
	RFG	22.83 ± 4.80	2.34 ± 0.05	1.22 ± 0.23
Aldehydes & Ketones	Non-Oxy	160.26 ± 1.64	8.00 ± 0.45	9.98 ± 0.67
	Oxy	189.23	9.37	15.29
	RFG	159.86 ± 0.05	4.06 ± 0.13	6.04 ± 3.51

Emissions of Air Toxics Are Greatly Reduced By The Kunming Catalyst



Pollutant	Fuel	Catalyst				
		None Emissions, mg/mile	Kunming Emissions, mg/mile	% Reduction	OEM Emissions, mg/mile	% Reduction
Acetaldehyde	Non-Oxy	29.07 ± 0.17	1.50 ± 0.17	94.8	2.73 ± 0.22	90.6
	Oxy	24.99	2.05	91.8	3.21	87.2
	RFG	26.17 ± 1.01	0.74 ± 0.20	97.2	1.31 ± 0.63	95.0
Benzene	Non-Oxy	53.61 ± 8.09	6.23 ± 0.77	88.4	5.93 ± 0.01	88.9
	Oxy	56.89	3.24	94.3	4.25	92.5
	RFG	49.20 ± 0.44	3.32 ± 0.36	93.3	3.52 ± 0.46	92.8
1,3-Butadiene	Non-Oxy	24.68 ± 0.01	0.52 ± 0.03	97.9	0.43 ± 0.09	98.3
	Oxy	21.21	0.42	98.0	0.62	97.1
	RFG	16.23 ± 0.45	0.23 ± 0.08	98.6	0.39 ± 0.04	97.6
Formaldehyde	Non-Oxy	84.28 ± 0.78	4.20 ± 0.25	95.0	4.70 ± 0.14	94.4
	Oxy	101.91	4.63	95.5	7.62	92.5
	RFG	99.12 ± 1.16	1.59 ± 0.65	98.4	2.68 ± 1.63	97.3

- The Kunming catalyst decreased emissions rates of all air toxics by greater than 87%



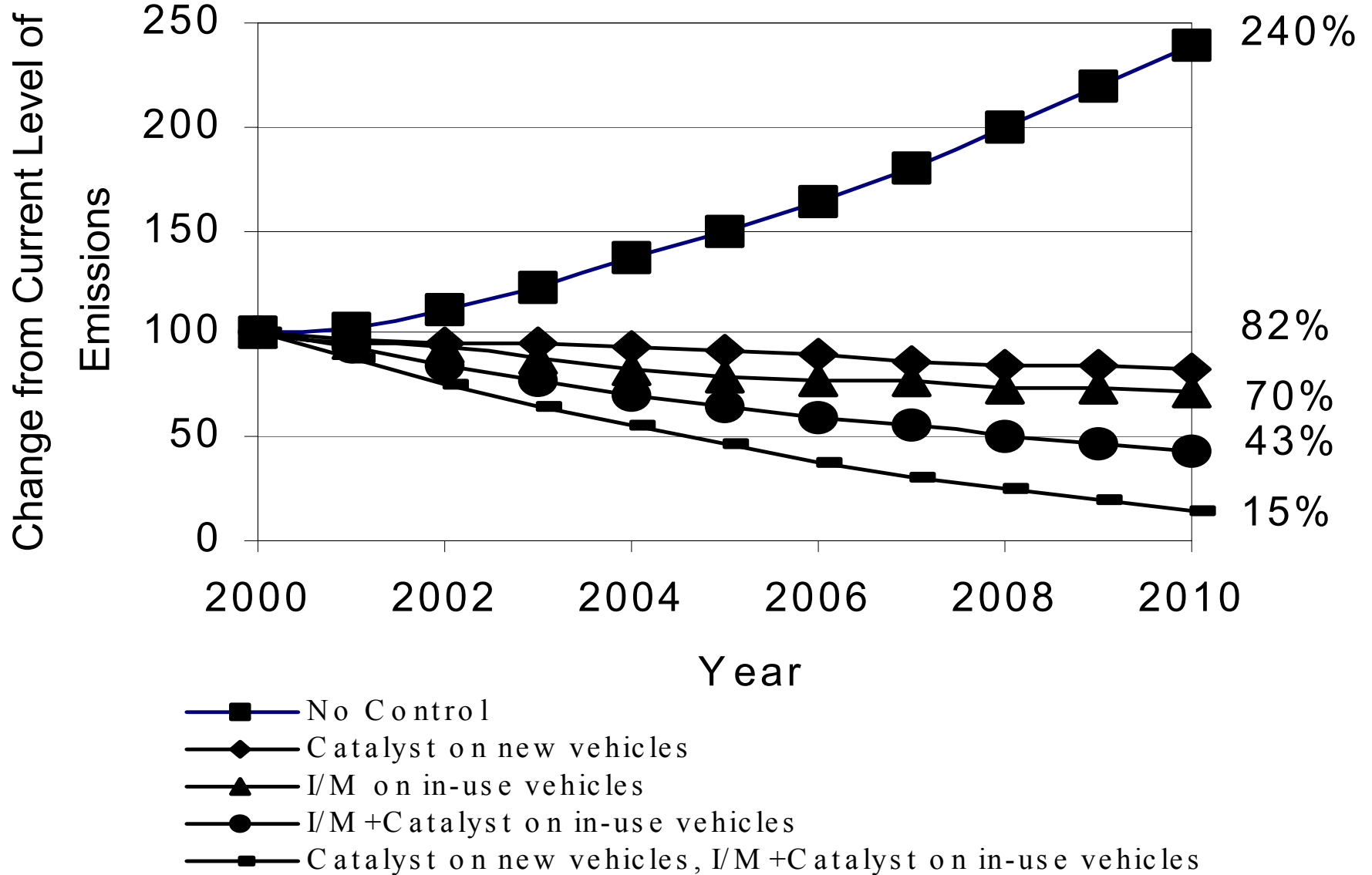
The Retrofit Program can have a Large Effect on Reducing Ambient Pollution Levels in China

- Generalized rollback model (GRM)
- The model predicts a fairly significant reduction of CO

Retrofit Extent, %	Reduction, %
20	8.6
40	17.4
60	26.0
80	34.6
100	43.4

- Use the GRM model to predict the reduction of air toxics
- Include vehicle retirement and revise fleet growth in the model to account for new (catalyst equipped) vehicles

Effect of Various Light-Duty Vehicle Emission Control Strategies in Shanghai





Conclusions

- **I/M is a very important first step in reducing vehicle emissions. I/M can reduce vehicle emissions by an average of 30-50%.**
- **Emissions of HC, CO and air toxics can be reduced by up to 80% with the proper installation of REO catalysts.**
- **A successful retrofit program for in-use vehicles requires a system engineering approach including a rigorous I/M program, the proper catalyst, optimized catalyst location and implementation of fuel quality standards.**
- **The Kunming REO catalyst represents a feasible and effective approach to curbing emissions from current Chinese vehicle fleet.**