Summary of Emissions Controls Available for NO_x and PM from Large Stationary Sources in the Western United States

Preliminary Findings

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REI's Tasks

- Review and summarize the WRAP Stationary Source Inventory, as well as more recent and relevant data bases to determine the number/type of stationary sources >100 tpy and what air pollution control devices are currently installed on those sources.
- Survey and document the available range of technologies per the criteria above.
- Conduct an evaluation of the technologies and summarize the results. This includes all the pertinent parameters discussed above.
- Prepare a final document (final report) that addresses all the important criteria and issues listed, and is presented in a format that is most helpful for WRAP personnel to use efficiently.

Topics to be Covered

- Survey of source categories for NO_x and PM; prioritization of effort.
- Comparison of WRAP data with other databases for electric utility generators only.
- Preliminary list of control technologies
- Technology evaluation form

Survey of sources for NO_x and PM

- 13-states:
  - AZ, CA, CO, ID, NM, NV, OR, UT, WY
  - WA, MT, ND, SD
- Databases:
  - WRAP Version 3 (1996 Data for electric utilities)
  - EPA CEMS (2001 Data for electric utilities)
  - EPA E-GRID2002 (2000 Data for electric utilities)
  - EIA 767 (2000 Data for electric utilities)

WRAP NO_x Summary

	Number of Units >100 tpy	NO_x Emissions (tpy)	Average Annual Emissions (tons/yr-source)
Extermal Combustion Boilers	332	657,393	1,980
Internal Combustion Engines	510	111,647	219
Mineral Processing	94	62,176	661
Petroleum Industry	65	18,165	279
Oil and Gas Production	23	12,099	526
Pulp and Paper	38	9,895	260
Primary/Secondary Metal Production	24	7,207	300
Chemical Manufacturing	16	5,876	367
Fixed Wing Aircraft L & TO Exhaust	4	2,297	574
Food and Agriculture	3	730	243
Solid Waste Disposal	2	236	118
Total NO_x Emissions (Sources>100 tpy)	1,111	887,722	799
Total NO_x Emissions (All WRAP sources)	103,237	1,059,213	

Source: 1996 WRAP Inventory, v.3

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NO_x Emissions – External Combustion Boilers

	Number of Units >100 tpy	NOx Emissions (tpy)	Average Annual Emissions (tons/yr-source)	NO_x Controls Used (1996 WRAP Inventory)
Dry Bottom	111	498,999	4495	Low NO_x burners or firing system, low excess air
Wet Bottom	9	25,203	2800	none
Cyclone	5	73,468	14694	Low excess air firing
Coal-fired AFBC	3	2,413	804	Low excess air firing, fluidized bed dry scrubber
Stoker	18	5,876	326	None
Coal-fired Cogen	3	1,544	515	None
Oil Boiler	7	2,267	324	Low excess air firing
Wood Boiler	48	9,776	204	Ammonia injection
Waste Combustion	7	3,424	489	None
NG Boiler	107	31,847	298	Low excess air firing, SNCR
Process Gas Boiler	12	2,049	171	None
Misc, Process Gas	2	527	263	None
Exeternal Combustion Boilers	**332**	**657,393**	**1,980**	

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NO_x Emissions – Internal Combustion Engines, Mineral Processing

	Number of Units >100 tpy	NO_x Emissions (tpy)	Average Annual Emissions (tons/yr-source)	NO_x Controls Used (1996 WRAP Inventory)
Reciprocating	398	81,292	204	Process changes, SCR
Turbine	87	25,437	292	Steam or water injection
NG 4-cycle Rich Burn	12	2,348	196	None
Large Bore Diesel	9	1,929	214	None
NG 2-cycle Lean Burn	4	641	160	None
Internal Combustion Engines	**510**	**111,647**	**219**	
Cement Kilns	31	32,880	1061	None
Glass Manufacture	18	6,564	365	None
Minerals: Crushing, Drying, Handlin	11	2,703	246	None
Cement Grinding, Crushing, Cooling	9	8,129	903	None
Lime Calcining	9	2,317	257	None
Cement In-Process Fuel Use	10	8,831	883	None
Ceramic Clay/Tile Manufacture	3	356	119	None
Fiberglass Manufacturing	2	288	144	None
Asphalt Concrete	1	109	109	None
Mineral Processing	**94**	**62,176**	**661**	

NO_x Emissions – Petroleum Industry and other sources

	Number of Units >100 tpy	NO_x Emissions (tpy)	Average Annual Emissions (tons/yr-source)	NO_x Controls Used (1996 WRAP Inventory)
Refinery Process Heaters	38	9,311	245	None
FCCs	9	2,951	328	None
Refinery Fugitive Emissions	5	2,490	498	None
Misc. Refinery	4	578	145	None
Coking/Calcining	4	1,203	301	Staged combustion
Refinery Blowdown	3	617	206	None
Process Gas Incinerator	2	1,016	508	None
Petroleum Industry	**65**	**18,165**	**279**	
Oil and Gas Production	**23**	**12,099**	**526**	None
Pulp and Paper	**38**	**9,895**	**260**	None
Primary/Secondary Metal Product	**24**	**7,207**	**300**	None
Chemical Manufacturing	**16**	**5,876**	**367**	Catalytic reduction, catalytic afterburner, gas absorber
Fixed Wing Aircraft L & TO Exhau	**4**	**2,297**	**574**	None
Food and Agriculture	**3**	**730**	**243**	None
Solid Waste Disposal	**2**	**236**	**118**	Ammonia injection

Applicable NO_x Technologies – External Combustion Boilers

- Combustion monitoring/modifications
- Burner Modifications
- Low NOx burners (LNB)
- Overfire air (OFA)
- Flue Gas Recirculatino (FGR - gas/oil only)
- Selective Noncatalytic Reduction (SNCR)
  - NH_3, Urea
- Rich Reagent Injection (RRI)
- Selective Catalytic Reduction (SCR)
  - Conventional, High vs. low dust vs. tail end, IDSCR, AHSCR
- Hybrids
  - Reburn + SNCR
  - SNCR + SCR
- New developments
  - Oxygen enhanced combustion (e.g Praxair)
  - Hydrocarbon enhanced SNCR (e.g.Mitsui)

Applicable NO_x Technologies – Internal Combustion Engines

- Reciprocating
  - LEC
  - SCR
  - Nonselective catalytic reduction (NSCR)
  - Prestratified Charge
  - High Energy Ignition
  - SCONOX
  - NOxTech
  - High Pressure Fuel Injection
- Turbine
  - DLN
  - Water/Steam
  - SCR
  - Catalytic combustion
  - SCONOX

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Applicable NO_x Technologies – Other Sources

- Cement Kilns
  - SNCR
  - Tire-derived fuel (TDF) injection
  - Sewage sludge injection
  - CemStarSM
- Refinery Process Heaters
  - Combustion modifications
  - SCR

Conclusions – NO_x

- Major categories
  - External Combustion Boilers => coal-fired boilers
  - Internal Combustion Engines => reciprocating engines using natural gas
  - Mineral Processing => cement kilns
  - Chemical processing => refinery process heaters
- Few sources had NO_x controls in 1996, principally low NO_x burners, combustion modification

WRAP PM Summary

	Number of Units >100 tpy	PM10 (tpy)	Average Annual PM10 (tons/yr-source)
External Combustion Boilers	116	52,656	454
Mining and Mineral Products	79	23,803	301
Metal Production	46	15,297	333
Chemical Manufacturing	28	8,007	286
Pulp and Paper	17	4,717	277
Petroleum Industry	15	2,968	198
US Army Nat'l Training Ctr	1	2,456	2,456
Internal Combustion Engines	5	1,510	302
Food and Agriculture	5	1,150	230
Solid Waste Disposal	4	1,083	271
Cooling Tower Emissions	4	932	233
Total PM10 Emissions (Sources>100 tpy)	320	114,579	358
Total PM10 Emissions (All WRAP sources)	103,237	188,462	

Source: 1996 WRAP Inventory, v.3

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PM Emissions – External Combustion Boilers

	Number of Units >100 tpy	PM10 (tpy)	Average Annual PM10 (tons/yr-source)	PM Controls Used (1996 WRAP Inventory)
Dry/Wet Bottom Boilers	69	41,862	607	ESP, wet scrubber, fabric filter
Wood Boilers	24	5,718	238	wet scrubber, cyclone
Stokers	10	1,552	155	none
NG Boilers	5	1,379	276	none
Cyclone Boilers	4	1,132	283	ESP, wet scrubber, fabric filter
Petroleum Refinery Gas	2	255	128	none
AFBC	1	381	381	multi-cyclone
Oil Boilers	1	378	378	ESP, wet scrubber, fabric filter
External Combustion Boilers	**116**	**52,656**	**454**	

PM Emissions – Metal and Minerals

	Number of Units	PM10 (tpy)	Average Annual PM10 (tons/yr-source)	PM Controls Used (1996 WRAP Inventory)
Coal Mining	37	13,010	352	fabric filter, chemical or water spray
Sand, Gravel and Quarrying	11	2,965	270	chemical or water spray
Unclassified Mining	8	986	123	none
Cement Kilns	6	1,067	178	cyclone, ESP
Misc. Fugitive Emissions	5	2,578	516	water spray
Phosphate Drying/Calcining	5	1,864	373	wet scrubber
Refractory/Brick Manufacture	3	672	224	none
Potash Grinding/Drying	2	270	135	none
Misc. Materials Handling	2	391	196	none
Mineral Products	**79**	**23,803**	**301**	
Unclassified Smelting Emissions	11	7,318	665	none
Aluminum Production	11	2,556	232	fabric filter, wet scrubber, alkalized alumina
Mining: Ore Crushing/Handling	10	1,788	179	none
Copper Smelting	6	1,659	277	none
Steelmaking, Misc. Emissions	5	1,394	279	none
Gold Mining	3	582	194	water spray
Metal Production	**46**	**15,297**	**333**	none

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PM Emissions – Petroleum, Chemical, Pulp & Paper, Other

	Number of Units	PM10 (tpy)	Average Annual PM10 (tons/yr-source)	PM Controls Used (1996 WRAP Inventory)
Chemical Manufacturing	**28**	**8,007**	**286**	wet scrubber, sulfuric acid plant
Misc. Pulp and Paper	5	943	189	none
Recovery Furnace/Direct Contact Evaporator	5	2,704	541	none
Lime Kiln	3	493	164	none
Wood Drying	2	220	110	none
Recovery System: MgO	2	357	179	wet scrubber, cyclone
Pulp and Paper	**17**	**4,717**	**277**	
Catalytic Crackers	9	1,744	194	cyclone
Refinery Combustion Sources	3	872	291	none
Cooling Towers	2	237	118	none
Refinery Fugitive Emissions	1	115	115	none
Petroleum Industry	**15**	**2,968**	**198**	
US Army Nat'l Training Ctr	**1**	**2,456**	**2,456**	none
Internal Combustion Engines	**5**	**1,510**	**302**	none
Food and Agriculture	**5**	**1,150**	**230**	cyclone
Solid Waste Disposal	**4**	**1,083**	**271**	none
Cooling Tower Emissions	**4**	**932**	**233**	none

Applicable PM Technologies

- PM Control Technologies applicable to combustion and petrochemical sources
  - ESPs
    - Dry
    - Wet
  - Fabric Filters
  - Compact Hybrid Particulate Collector (COHPAC)
  - Cyclones
  - Scrubbers
    - Venturi Scrubbers
  - EDV
- PM Control Technologies applicable to solids handling operations
  - Surface Modification
    - Water
    - Surfactants
    - Area shape
  - Traffic Operations

Conclusions: PM

- Major categories
  - External Combustion Boilers => coal-and wood-fired boilers
  - Mining => emissions from coal handling and transport
  - Metal production => “unclassified” smelting emissions
  - Chemical processing => “unclassified” emissions from coal mining
  - Pulp & Paper => recovery boilers
  - Petroleum => cat crackers
  - US Army National Training Center
- Unclassified or unspecified emissions make up 22% of PM emissions

Comparison for Electric Utilities

- Databases:
  - WRAP Version 3 (1996 Data for electric utilities)
  - EPA CEMS (2001 Data for electric utilities)
  - EPA E-GRID2002 (2000 Data for electric utilities)
  - EIA 767 (2000 Data for electric utilities)

NO_x Comparison – Electric Utility Boilers

E-Grid 2001	Number of Units	NO_x Emmisions (TPY)	Average Emmisions (Tons/Source)	Total MMBtu/yr	NOx Control Technology
Dry/Wet Bottom	98	514,055	5,245	2,638,946,393	Low Excess Air, Low NOx Burner, OFA, other Biased Firing, Flue Gas Recirculation, Low
NG Boiler	71	35,609	502	484,049,349	Excess Air, Low Nox Burner, OFA, SNCR, SCR
Cyclone	7	72,036	10,291	183,683,363	None
Oil Boilers	3	2,514	838	24,449,792	Low NOx Burner
Coal-fired AFBC	2	1,796	898	13,012,511	Fluidized Bed Combustion
No Description	23	21,115	918	257,804,771	Flue Gas Recirculation, Low NOx Burner
Total	**204**	**647,124**	**3,172**	**3,601,946,179**	

CEMs 2001	Number of Units	NO_x Emmisions (TPY)	Average Emmisions (Tons/Source)	Total MMBtu/yr	NOx Control Technology
Dry Bottom	84	436,534	5,197	2,294,527,775	LNB, LNBO, LNC2, LNC3, LNCB, O, OFA,
NG Boiler	68	35,936	528	577,221,234	LNB, LNBO, OFA, SCR, SNCR
Cyclone	4	49,559	12,390	129,710,565	None
Oil Boilers	2	15,555	502	13,904,854	None
Coal-fired AFBC	2	2,118	1,059	14,918,011	O
No Description	31	15,555	502	282,781,142	CM, DLNB, (DLNB, H2O), LNB, LNBO, O
Total	**191**	**555,257**	**2,841**	**3,313,063,581**	

WRAP 1996	Number of Units	NO_x Emissions (TPY)	Average Emissions (Tons/source)	NOx Control Technology
Dry/Wet Bottom	101	509,259	5,042	Low NO_x burners or firing system, low excess air
NG Boiler	48	18,576	387	Low excess air firing, SNCR
Cyclone	6	73,468	12,245	Low excess air firing
Resid.Oil Boiler	2	1,442	721	Low excess air firing
Coal AFBC	2	1,954	977	Low excess air firing, fluidized bed dry scrubber
Spreader Stoker	6	1,779	296	None
Wood Boiler	2	598	299	None
Total	**167**	**607,075**	**3,635**	

- WRAP NO_x emissions similar to EPA
- More NO_x control technologies in use 1996-> 2000/2001

PM Comparison – Electric Utility Boilers

(MMBtu/yr data from E-GRID)	Number of Units	PM Emissions (TPY)	Average Emissions (Tons/Source)	Total MMBtu/yr	PM Control Technology
Dry/Wet Bottom	64	79,345	1,268	2,124,711,298	B, ESP, WS, C
Cyclone	5	1,947	389	166,785,196	B, ESP
Coal-fired AFBC	2	243	122	16,233,072	B
NG Boiler	1	229	229	45,856,525	B
Misc	1	164	164	32,866,456	None
Total	**73**	**81,929**	**1,122**	**2,386,452,547**	

(MMBtu/yr data from CEMs)	Number of Units	PM Emissions (TPY)	Average Emissions (Tons/Source)	Total MMBtu/yr	PM Control Technology
Dry/Wet Bottom	61	77,984	1,278	1,986,187,165	B, ESP, WS, C
Cyclone	4	1,694	423	129,710,565	B, ESP
Coal-fired AFBC	2	255	127	16,975,180	B
NG Boiler	1	256	256	51,115,319	B
Total	**68**	**80,188**	**1,179**	**2,183,988,229**	

WRAP 1996 Inventory	Number of Units	PM Emissions (TPY)	Average Emissions (Tons/Source)	PM Control Technology
Dry/Wet Bottom Boilers	69	41,862	607	B, ESP, WS, C
Cyclone Boilers	4	1,132	283	B, ESP, WS
AFBC	1	381	381	C
NG Boilers	5	1,379	276	None
Wood Boilers	24	5,718	238	WS, C,
Stokers	10	1,552	155	None
Petroleum Refinery Gas	2	255	128	None
Oil Boilers	1	378	378	B, ESP, WS
Total	**116**	**52,656**	**454**	

- WRAP PM emissions ~50% lower than EPA
- Reporting methodology may differ

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Conclusions: Electric Utility Boilers

- NO_x
  - WRAP: 13% of sources with NO_x controls
  - Recent EPA databases: 55-60% of sources with NO_x controls
- PM
  - Emissions numbers differ between WRAP and EPA databases (WRAP about half of EPA)
- Need to update electric utility boiler source category

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Conclusions: Improvements to WRAP Database

- For combustion sources: firing rate (MMBtu/hr) needed
- PM sources: improve classification of technology/process to reduce “unclassified” emissions

SAMPLE ONLY

NO_x Control Technology **Process: Reburn**	
Application to WRAP Sources: **Category**	**tons/yr NO_x**
External Combustion Boilers	657,393

Process Description:

Reburning, while generically included in the "Combustion Modification" category of NO_X control technologies, differs from the others (BCM, LNB and OFA)) by "destroying" NO rather than by minimizing its formation. Fuel is introduced above the main burner zone in the furnace, creating a fuel-rich (reducing) atmosphere in which NO_X formed in the main burner zone is destroyed by reacting with hydrocarbon and nitrogen compounds. The hardware needed for reburning includes reburn fuel burners or nozzles and overfire or burnout air ports (see discussion on fuel-lean reburn for deviations from this). The level of complexity of a particular system depends mostly on the choice of the reburn fuel itself (gas, coal, oil, orimulsion), as well as on the status and capability of the existing boiler (e.g., the burner/boiler control system).

Development Status: Commercially available

While reburning does not account for a significant fraction of installed NO_X reduction technologies compared to LNBs, SNCR and SCR worldwide, it is gaining acceptance, and a number of recent activities suggest it has become a viable strategic option for NO_X control. This increase in interest is due to two key factors, among others: (1) increased experience and encouraging results, which increase the level of comfort with the technology; and (2) the "proliferation" of advanced reburn technologies, each with its own features, advantages and disadvantages.

These "advanced" reburning options involve enhancements of the conventional approach, with features ranging from combinations with SNCR to the outright avoidance of overfire/burnout air, as in fuel-lean gas reburn (FLGR).

Cost Information:

Retrofit and O&M costs associated with reburn are site specific and depend on factors such as:

- unit capacity,
- primary fuel type,
- upper furnace geometry,
- space availability,
- type of existing controls,
- availability of reburn fuel at the site,
- reburn fuel required as a percentage of the total boiler heat input, and
- differential prices between primary and reburn fuel.

NO_x Control Technology

Process: Reburn

In general, the capital costs range from $15/kW to $30/kW for gas reburn and $30/kW to $60/kW when using coal as the reburn fuel. Operating costs are mainly driven by fuel cost differential (certainly gas vs coal). For coal/orimulsion reburning, fuel preparation costs become more important (micronization, atomization) as there are no fuel cost differentials.

Retrofit schedules are directly related to the scope of the retrofit requirements. In most cases, 3-6 weeks are adequate for a reburn retrofit.

Technical considerations:

Many applications in the U.S. have been on cyclone-type boilers, while T- and wall-fired boilers lag behind in numbers. This is not surprising as cyclones were not considered suitable candidates for other combustion modification NO_x controls until recently. However, the reburn experience outside the U.S. (primarily in Italy), while mostly on oil/gas boilers, is based on T- and wall-fired boilers (well over 3,000 MW). These projects involve unit sizes ranging from 30 MW to 600 MW, which is important for scale-up concerns over the dynamics of jet penetration/mixing.

Boilers with the following design and operating characteristics are expected to be more suitable candidates for reburning:

- firing low-sulfur coals (e.g., less propensity for waterwall corrosion)
- low baseline unburned carbon (e.g., to minimize ash salability impacts).
- favorable cross-section/height profiles (e.g., tall boilers which provide for adequate mixing/residence time to maximize effectiveness).
- gas availability, very efficient/effective coal pulverizers (e.g., approaching micronization) or access to orimulsion for the reburn fuel

Of major importance is the choice of reburn fuel. The increasing experience with coal and orimulsion dictates that these must be considered in light of cost, availability, deliverability and overall project objectives. However, the use of natural gas provides benefits from lower maintenance costs (e.g., less demand on pulverizers) and lower emissions of other pollutants (particulate, SO_x, CO2)

NO_x Reduction:

Full load NO_x reductions with reburning can be expected to range from 35% to 60% depending on factors such as:

- reburn fuel type and quantity; typically the reburn fuel needs to provide 15-20% of the total heat input if it is gas or 25-30% if coal to obtain 50-60% ΔNO_x
- initial NO_x level

- "tolerance" of negative impacts (e.g., efficiency loss, ash quality)

At low loads, NO_x reduction may fall to the 20-40% range, depending on the burner zone stoichiometry and low load operating characteristics of the boiler (e.g., operating at high excess air to control reheat temperature).

Reburning, like SNCR and SCR, may be thought of as a "dial-in" technology in that NO_x reductions will be a function of the amount of reburn fuel (or the amount of nitrogen compound reagent in the case of SNCR and SCR). This feature may make it particularly attractive for compliance scenarios based on seasonal use, averaging and/or trading.

Secondary Environmental Impacts:

Reburn technology has the potential to effect both positive and negative secondary environmental impacts depending on factors such as the reburn fuel, main combustion and reburn zone stochiometries, boiler physical characteristics, etc.

The following are potential impacts that must be analyzed on an individual unit basis

- CO may increase due to stochiometry in the reburn zone
- LOI may increase due to stochiometries and OFA design
- SO_2/CO_2 benefits when reburn fuel is gas (proportional to gas input)

Compatibility with other air pollution control technologies:

Reburn Technology can be implemented with both Low NO_x combustion approaches (e.g. LNBs) and post combustion technologies (SNCR/SCR). However, the overall NO_x reductions are not strictly additive and careful evaluation is required to ensure cost effective strategies.