NOx RECLAIM
Working Group Meeting

March 18, 2014

Agenda

- Welcome & Introductions
- General BARCT Methodology
- Refinery Sector
  - Gas Turbines
  - Review of FCCUs (January 22, 2014 WGM)
- Non-Refinery Sector
  - Gas Turbines
- Discussion
- Schedule/Next Meeting

Status

Category	Control Equipment Manufacturer Contacted	Preliminary Cost Effectiveness Analysis Completed
FCCU	X	X
Cement Kilns	X	X
Gas Turbines (Refinery and Non-Refinery)	X	X
Coke Calciner	X	In progress
Glass Furnaces	X	In progress
Metal Melting Furnaces	In progress	In progress
SRU/Tail Gas	In progress	In progress
ICEs	X	X
Boilers/Heaters	X	In progress

Overall BARCT Methodology

- Technical Feasibility
- Cost Effectiveness
  - Incremental Cost Effectiveness Based on 2000/2005 BARCT
  - Based on 2011 activity

Refinery Sector
Preliminary Analysis
Gas Turbines

Overview of Emission Control Technologies

- Water or Steam Injection: 50 ppmv - 20 ppmv
- Dry Low NOx (DLN), Dry Low Emissions (DLE), Cheng Low NOx (CLN): 25 ppmv - 9 ppmv
- Selective Catalytic Reduction: 9 ppmv - 2 ppmv
- Other Types of Control
  - CO Oxidation Catalysts for CO Emissions
  - Ammonia Slip Catalysts for NH3 Slip, CO, HC Emissions

Proposed BARCT for Gas Turbines

- 2 ppmv NOx
- SCR with as applicable
  - Dry Low NOx (DLN) / Dry Low Emissions (DLE)
  - Cheng Low NOx (CLN)
- Implementation Schedule
  - 2017 to 2020
  - May Consider Synchronization with Refinery's Turnaround Schedule

Development of Cost Data

Refinery's Information

(Present Worth Value)

- 7 MW Gas Turbine
  - Total Installed Costs (TIC) = $1.83 M
  - Annual Operating Costs (AOC) = $93,000
  - Catalysts Replacement (CR) = $435,500 every 10 years
  - PWV = TIC + (15.62*AC) + (1.14*CR) = $3.80 M
- 83 MW Gas Turbine
  - Total Installed Costs (TIC) = $5.90 M*
  - Annual Operating Costs (AC) = $375,000*
  - Catalysts Replacement (CR) = $950,000 every 10 years*
  - PWV = $15.5 M*

(* adjusted up 20% to match cost effectiveness provided in permit application)

Development of Cost Data

Manufacturers' Information

(Present Worth Value)

- 7 MW and 83 MW Gas Turbines
- SCR and CO Catalysts
- SCR and Ammonia Slip Catalysts
  - Dual Function. Equivalent or Better Control Efficiency for NOx, CO, HC Compared to Conventional SCR and CO Catalysts at Less Costs
  - Extend SCR Life and Achieve Low Ammonia Slip

Development of Cost Data

EPA's Information

(Present Worth Value)

- "*Alternative Control Techniques Document – NOx Emissions from Stationary Gas Turbines*" EPA-453/R-93-007
- Equations to Estimate TIC, AOC, and CR
- 80% - 90% Reduction Equivalent to Reducing to 2 ppmv from 10 ppmv or 20 ppmv

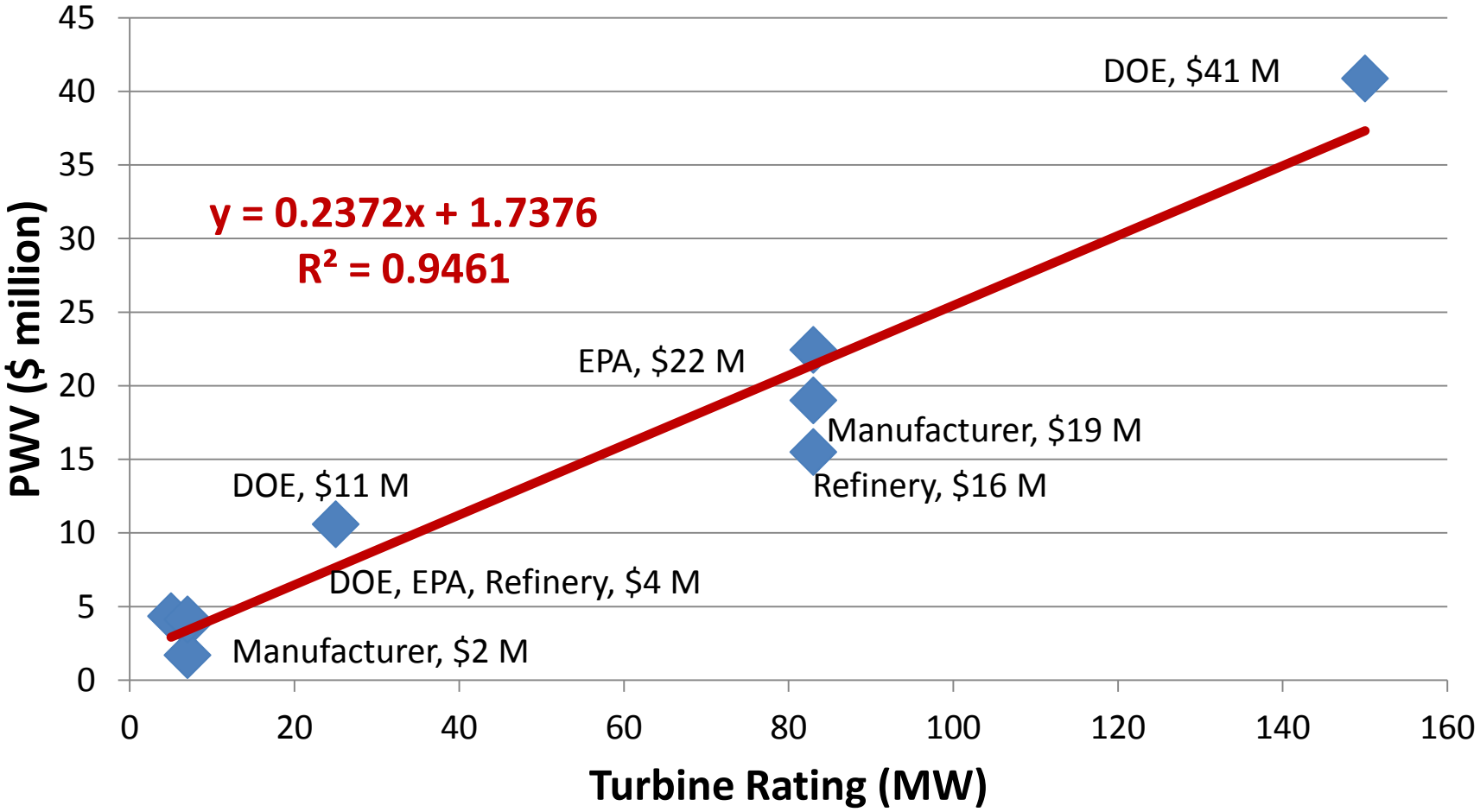
Development of Cost Data

DOE's Information

(Present Worth Value)

- "*Cost Analysis of NOx Control Alternatives for Stationary Gas Turbines*", November 5, 1999
- TIC and AOC for 5 MW, 25 MW, and 150 MW Gas Turbines
- 80% - 90% Reduction Equivalent to Reducing to 2 ppmv from 10 ppmv or 20 ppmv

PWV of SCR for Gas Turbines



Proposed BARCT Cost Effectiveness @ 2 ppmv

Incremental Cost Effectiveness with SCR

Unit Rating Profile (MW)	**2000/2005 BARCT Level** (lbs/mmscft)	**PWV** ($M)	**Emission Reduction from 2000/2005 BARCT** (tpd)	**CE for 2014 BARCT** ($/ton)
(a)	(b)	(c)	(e)	(f)
59	62.27	15.7	0.210	8,210
46	62.27	12.6	0.310	4,472
30	62.27	8.9	0.200	4,851
23	62.27	7.2	0.140	5,631
83	62.27	4.8 (d)	0.600	870
No Turbines/Duct Burners = 21 No of Cogen Units = 12		**Total PWV = $97.68 M**	**Total Reductions = 4.14 tpd**	**Average CE = 2,692 $/ton (g)**

(a) All gas turbines and all SCRs at the refineries were installed ≥ 25 years ago

(b) 2000/2005 BARCT Level from Table 1 of Rule 2002

(c) PWV = (0.2372 x MW) + 1.7376

(d) Costs for additional SCR catalysts to get from 10 ppmv to 2 ppmv

(e) Emission Reduction = Emissions @ 2000/2005 BARCT Level – Emissions @ 2 ppmv
where Emissions @ 2000-2005 BARCT Level = 2011 Fuel Gas Usage (mmscft/yr) x 62.27 (lb/mmscft)
Emissions @ 2 ppmv = 2011 Emissions x (2 ppmv / 2011 NOx Level in ppmv)

(f) CE = PWV/Emission reductions from 2000-2005 BARCT = (c)/(e x 365 x 25)

(g) CE (DCF Method) = $2692 per ton. CE (LCF Method) = $4500 per ton for 25 years life and 4% interest rate

Refinery Sector Review for FCCUs

(Summary from January 22, 2014 WGM)

Proposed BARCT for FCCUs

(Summary from January 22, 2014 WGM)

- 2 ppmv NOx
- Control Technology
  - SCR
  - LoTOx
  - NOx Reducing Additives in combination with SCR or LoTOx
- Implementation Schedule
  - 2017 to 2020
  - May Consider Synchronization with Refinery's Turnaround Schedule

Proposed BARCT Cost Effectiveness @ 2 ppmv

Incremental Cost Effectiveness with SCR or LoTOx

(Summary from January 22, 2014 WGM)

Equipment	**2005 BARCT Level**	**Incremental PWV** ($M)	**Incremental Emission Reduction from 2005 BARCT Level** (tpd)	**CE for 2014 BARCT** ($/ton)
	(a)	(b)	(c)	(d)
FCCUs with SCR	85% reduction	13	0.43	3,444
FCCUs with LoTOx	85% reduction	- 14	0.43	- 3,521

(a) 2005 BARCT level from Table 3 of Rule 2002

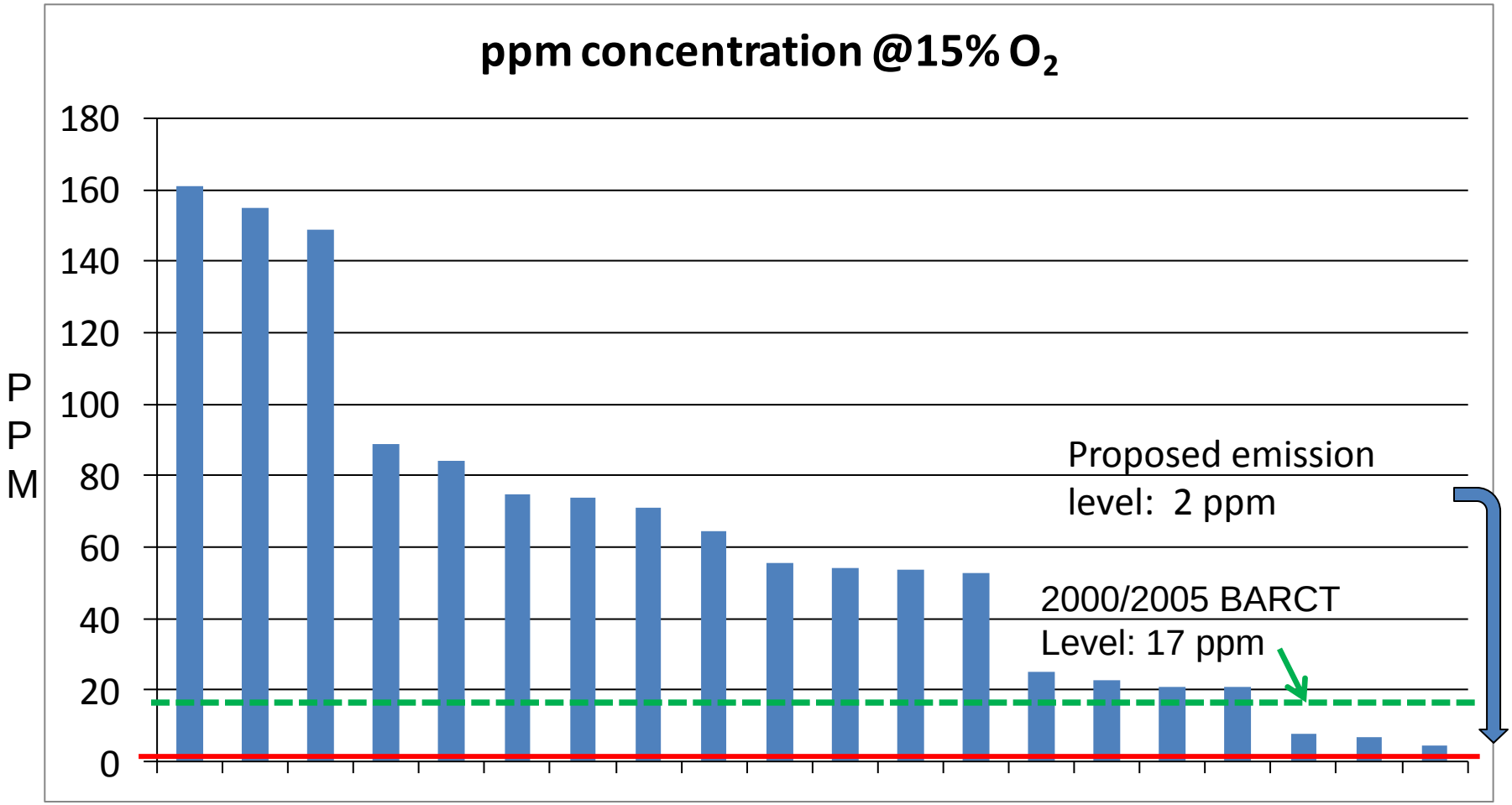
(b) Incremental difference in costs of control equipment for 85% reduction and control equipment for 2 ppmv

(c) Incremental emission reductions = Emissions @ 2005 BARCT – Emissions @ 2ppmv

(d) CE = (b)/(c*365*25) for DCF method. For LCF, CE = $5,700 -$5,900 per ton

Non-Refinery Sector Preliminary Analysis Gas Turbines

Non Refinery Gas Turbines (From 38 Facilities)



Cost Analysis for Gas Turbines

- Onshore gas turbines fired on natural gas
- Offshore (OCS) gas turbines fired on process gas or diesel
- Tier-1 Level 2000 (0.06 lb/mmBtu)
- Proposed BARCT level: 2 ppm @15% O_2
- For inlet NOx below 25 ppm, 2 ppm is achievable
- For inlet NOx above 25 ppm, 95% reduction is achievable
- Proposed Control technology: Selective Catalytic Reduction (SCR)

BARCT Emission Level

- Based on inlet concentration range for units emitting at or above 25 ppm (~50-160 ppm)

Inlet NOx @15%O2	BARCT Emission Level
< 25 ppm	2 ppm
At or above 25 ppm	95% Reduction*

* Further evaluation ongoing

- Implementation Schedule
  - 2017-2020

Cost Analysis for Gas Turbines

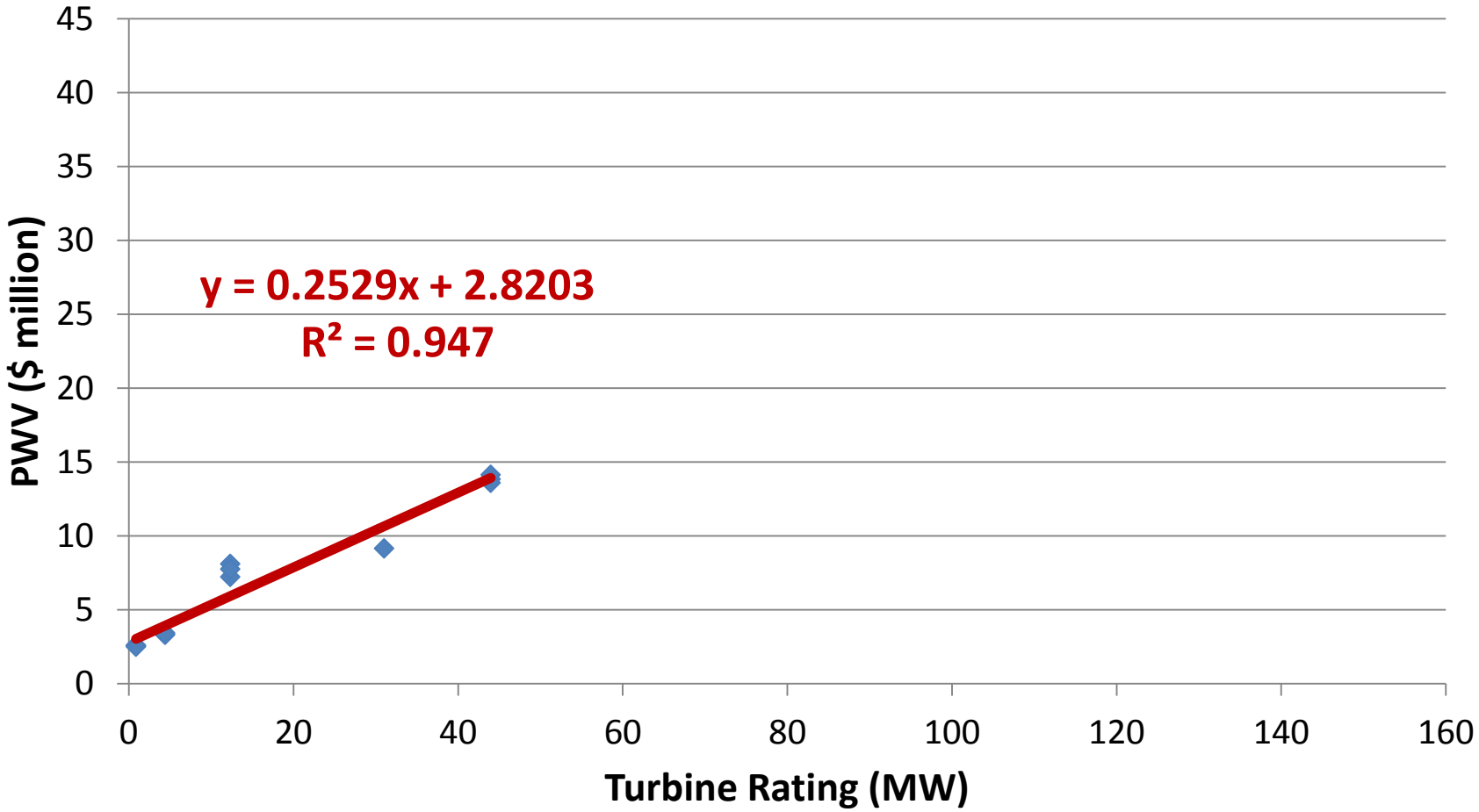
- SCR vendor equipment costs include:
  - Ductwork, NH_3 injection hardware, catalyst, PLC system, tempering air/mixing system, and CFD flow modeling
- Installation costs were calculated to be 200% of the equipment costs (400% for OCS)
- Total Installed Cost (TIC) includes equipment plus installation
- Vendor-supplied annual costs (AC) include NH_3 usage, catalyst replacement, and power.
  - Catalyst replacement every 3 years

Cost Analysis for Gas Turbines

- Present Worth Value (PWV) assumes a 4% interest rate and a 25-year equipment life
- PWV = TIC + (15.622 x AC)
- Emission Reductions (ER) for this category
  - 1.71 tons per day
- Cost Effectiveness = PWV / (ER x 365 x 25)
- Cost Effectiveness Range
  - DCF range: $3,100 - $26,000 / ton
  - LCF range: $5,000 - $42,000 / ton

PWV of SCR for Non-Refinery Gas Turbines

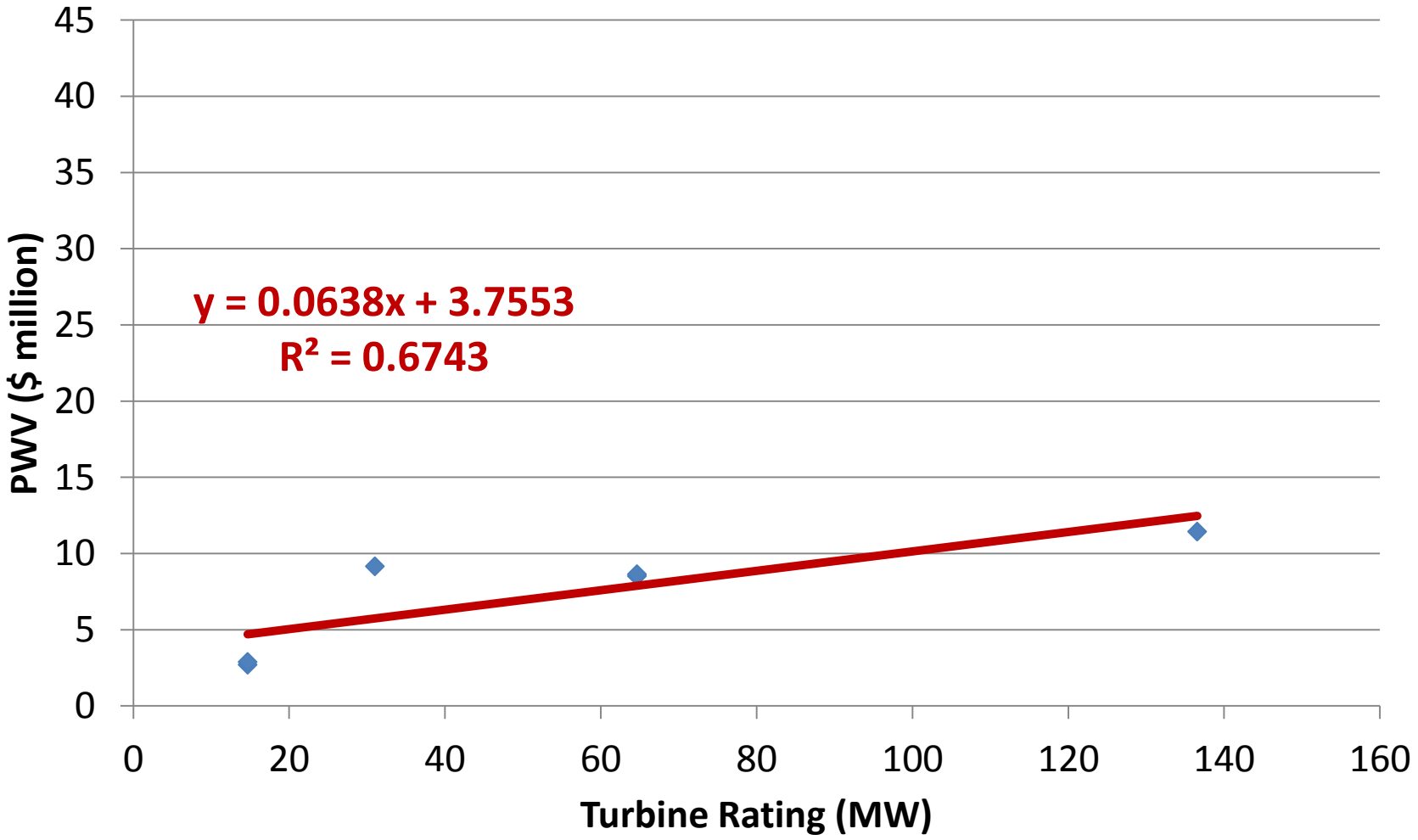
(Inlet ppm at or above 25 ppm to achieve a 95% reduction of 3-8 ppm)*



* Further evaluation ongoing

PWV of SCR for Non-Refinery Gas Turbines

(Inlet ppm below 25 ppm to achieve 2 ppm)



Proposed BARCT Cost Effectiveness

Unit Rating Profile Range (MW)	2000/2005 BARCT Level	PWV Range ($M)	Emission Reductions from 2000/2005 BARCT (tpd)	C.E. Range for 2014 BARCT ($/ton)
1-140	0.06 lb/MMBTU	3-14	1.71	$3,000 - $26,000 **Average: ($13,198/ton)**

* Cost Effectiveness LCF range: $5,000 - $42,000 / ton

Next Steps

- Complete BARCT Analysis
- Schedule next meeting April/May 2014
- Ongoing individual meetings to review BARCT

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