IGTI 2011

June 8th, 2011

WET COMPRESSION

What it ***Is***	What it ***Is Not***
8 to 25% (~12% 7EA) Power Augmentation at any wet bulb temperature above 45 °F	**Is not** traditional inlet air cooling, like a fogger or a chiller
"Complimentary Technology" -used in series w/ inlet cooling & other GT upgrades	**Is not** a system that limits your other options
Technology demonstrated for more than 10 years and >>300,000 fleet hours	**Is not** a new, untested concept
Applied to a wide range of GT's, aero and frame, for five GT OEMs	**Is not** a limited Application
Small droplets size, remain entrained in inlet air flow, reducing impingement	**Is not** damaging to compressor
GT OEMs have been Caldwell's *repeat* customers for Wet Compression	

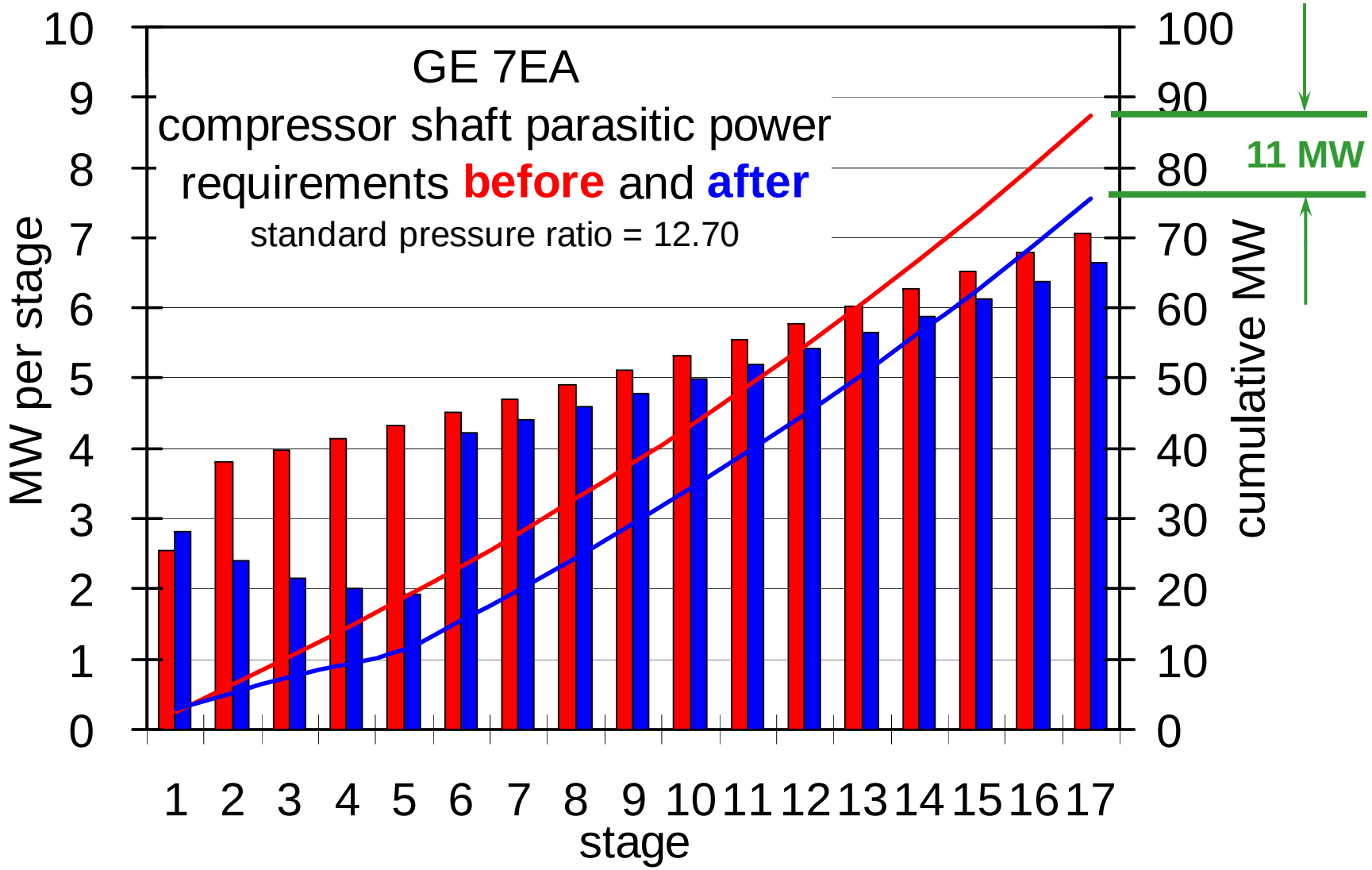
Four-fold effect:

- Water Inter-cools the CT compressor:
  - **COMPRESSOR EFFICIENCY DRAMATICALLY IMPROVED**
  - **Mass flow enhancement** (minor, but measurable)
  - **Lower CDT allows more fuel to be fired** (at constant firing temperature)

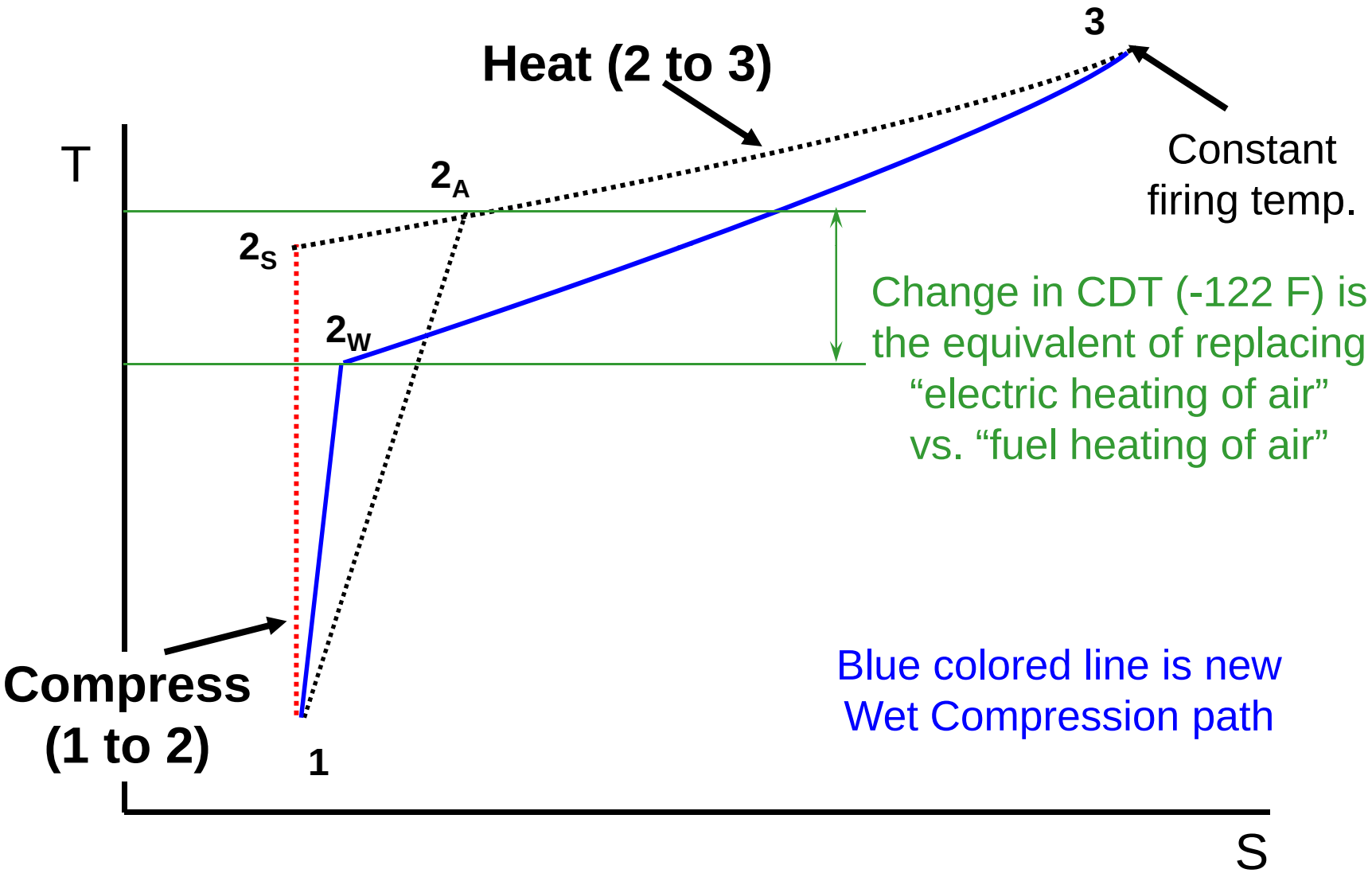
- Adiabatic Cooling of inlet air:
  - **Cools air to very near WBT @ bell-mouth**
  - Usually operated with an existing fogger or evap cooler upstream

- Overall net impact ~ 9 - 13 MW on a GE 7EA, simple cycle

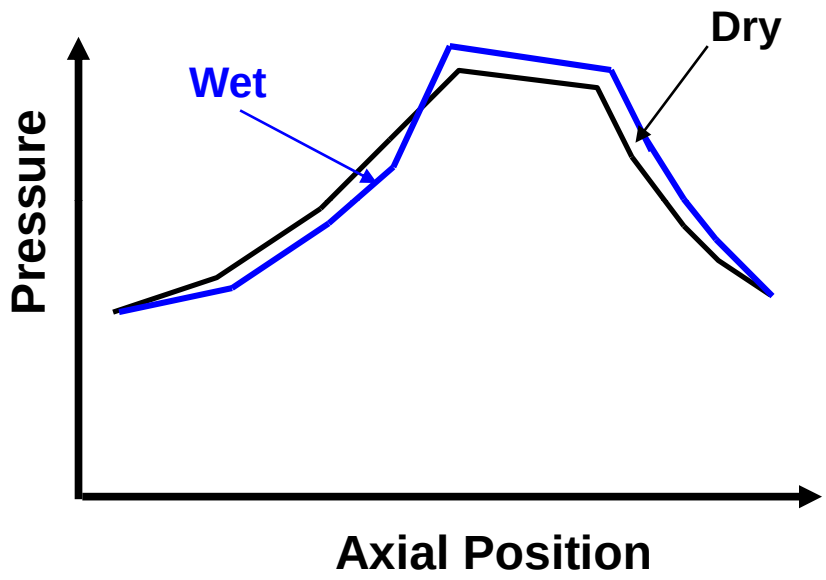
Compressor Efficiency Improvement



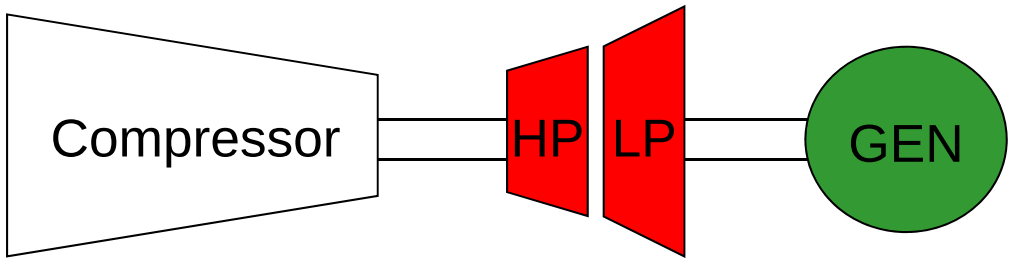
T-S Diagram of Compressor & Combustor



Wet Compression Effects on Stage Operating Pressure



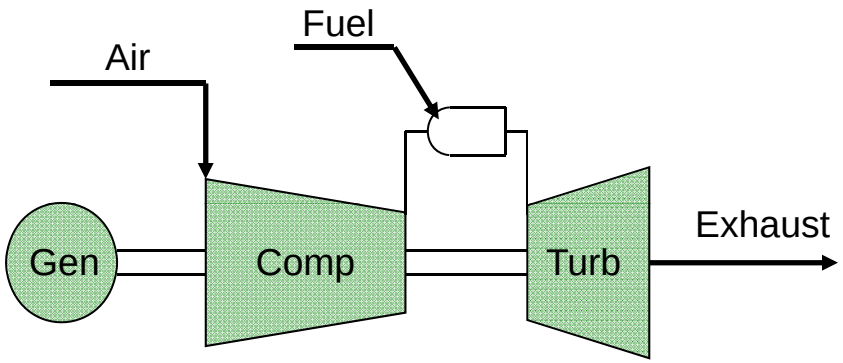
- Intercooling reduces front end compressor work
- Water and increased HP rotor speed increase mass flow and CDP
- Turbine pressure increased in all stages



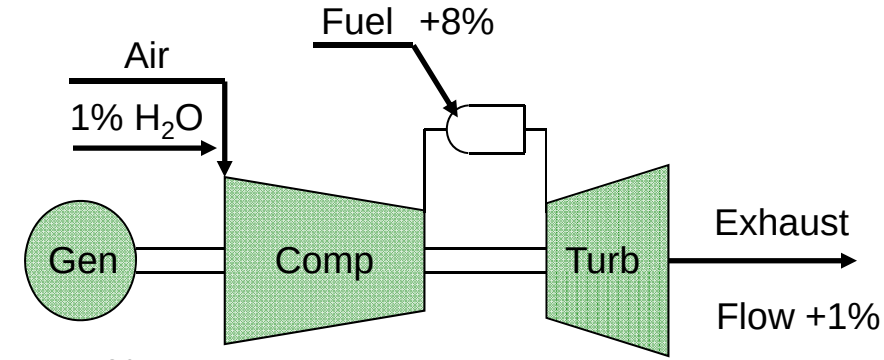
Two Stage Turbine

WC Cycle Performance Effects

Dry, Base Load Operation



Wet Compression - 1% Overspray



Pwr +9%

Flow +1%

Enthalpy +1%

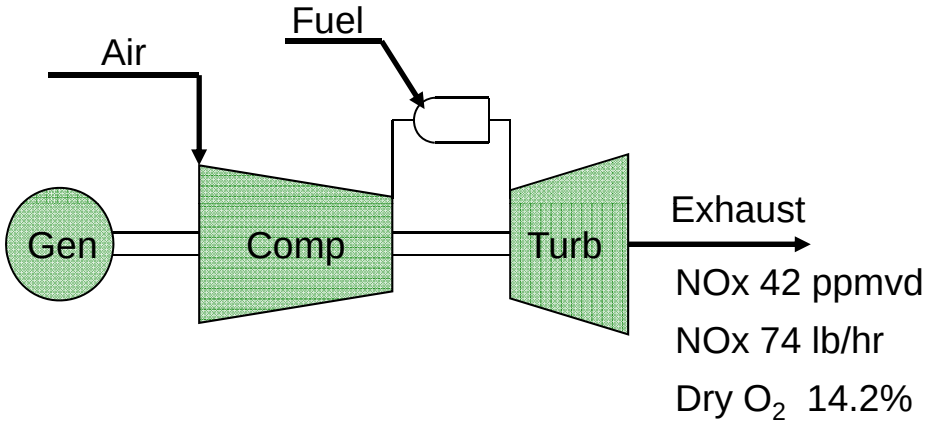
Energy + 2%

2560	

Estimated Cycle Performance Effects:	
CT Power	11.8%
CT Heat Rate	-1.0%
CT Fuel Flow	10.7%
CT Exhaust Flow	0.0%
CT Exhaust Energy	?%
Steam Production	2.0%
STG Power	2.0%
Duct Burner Flow	?%

WC NOx Emission Effects

Dry Base Load Operation



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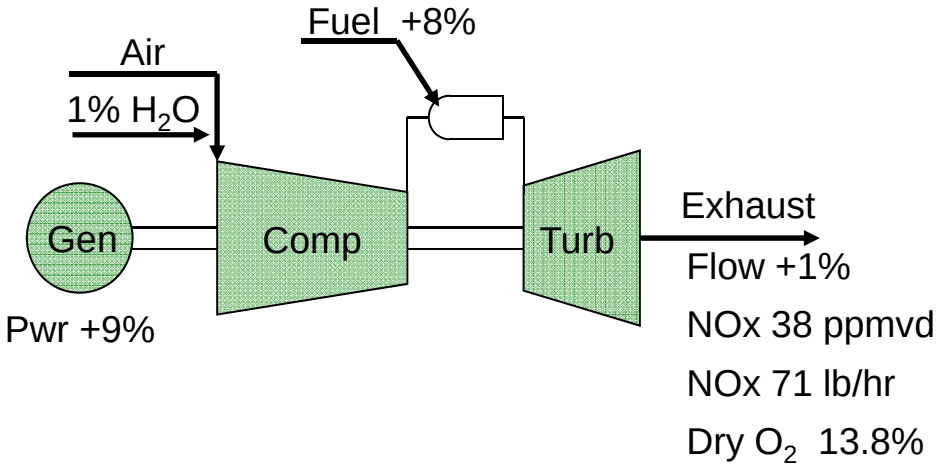


Estimated Emission Effects:

- CT NOx reduced 10 to 20 percent in conventional diffusion flame combustion systems on a dry volumetric PPM basis corrected to 15% oxygen
- Mass emission rates are reduced by approximately half as much since oxygen content is reduced with wet compression.
- Dry low NOx emissions levels are affected by combustion system dynamics and may require tuning to hold NOx PPM constant or slightly increase emission rates. Mass emissions will increase due to the oxygen correction.

Environmental Benefits: 7EA

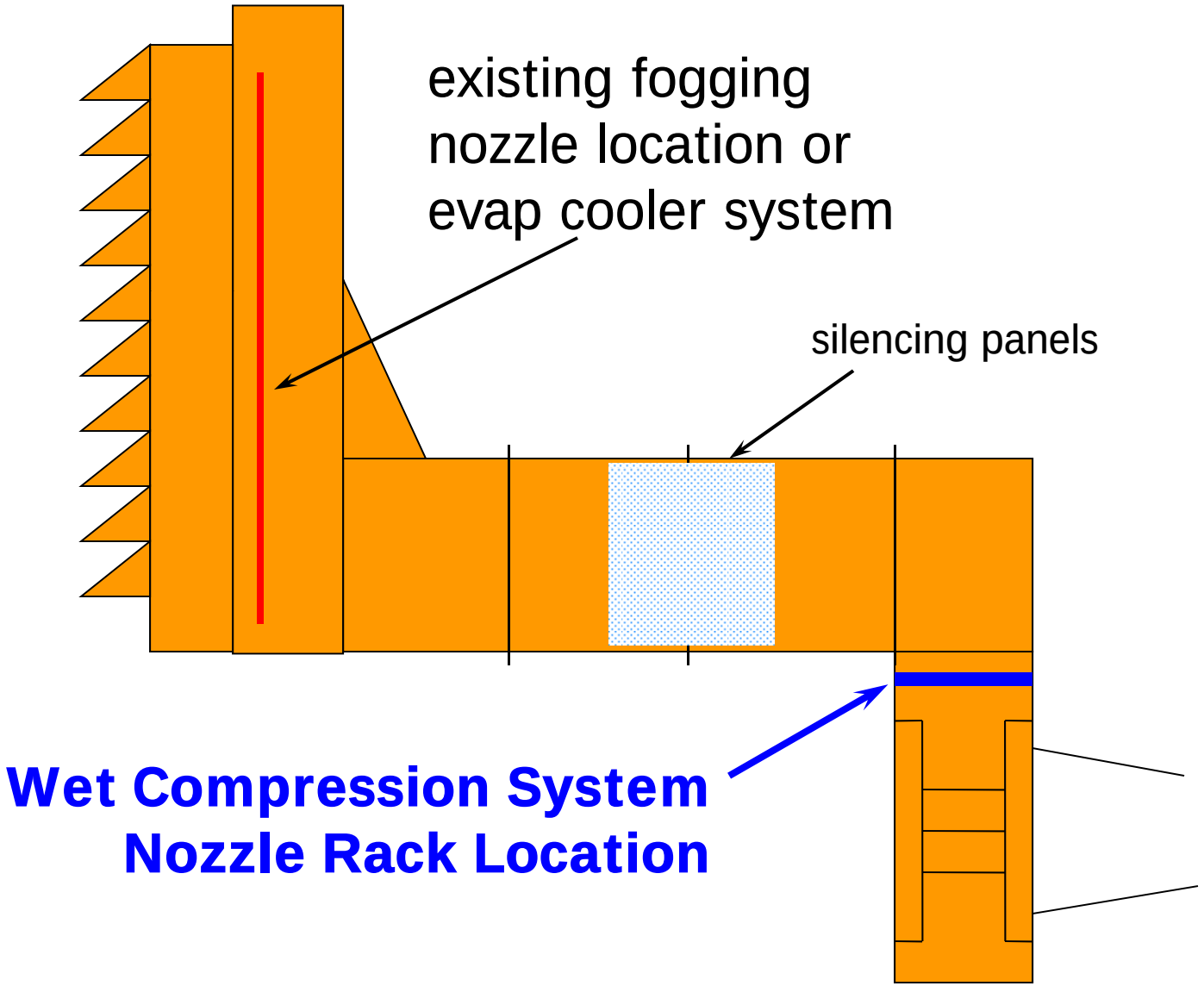
- Improves SC HR ~4%.
- Reduces NOx PPM
  - on conventional diffusion (WI / SI) burners; and
  - requires integration with dry-low NOx burners

207EA, duct-fired, pre-fit w/ evap cooling

Emissions	Before	with WC	delta
Gas Turbine Emissions (total for 2 units) - burning gas fuel			
NOx as NO2	65	73	7.4
CO	110	110	0.0
UHC as CH4	19	20	0.6
Duct Burner Emissions (total for 2 units) - burning gas fuel			
NOx as NO2	33	37	3.6
CO	18	18	0.0
UHC as CH4	11	11	0.4
Plant Total Emissions			
NOx as NO2	20	22	**2.2**
CO	128	128	**0.0**
NH3	27	27	**0.8**

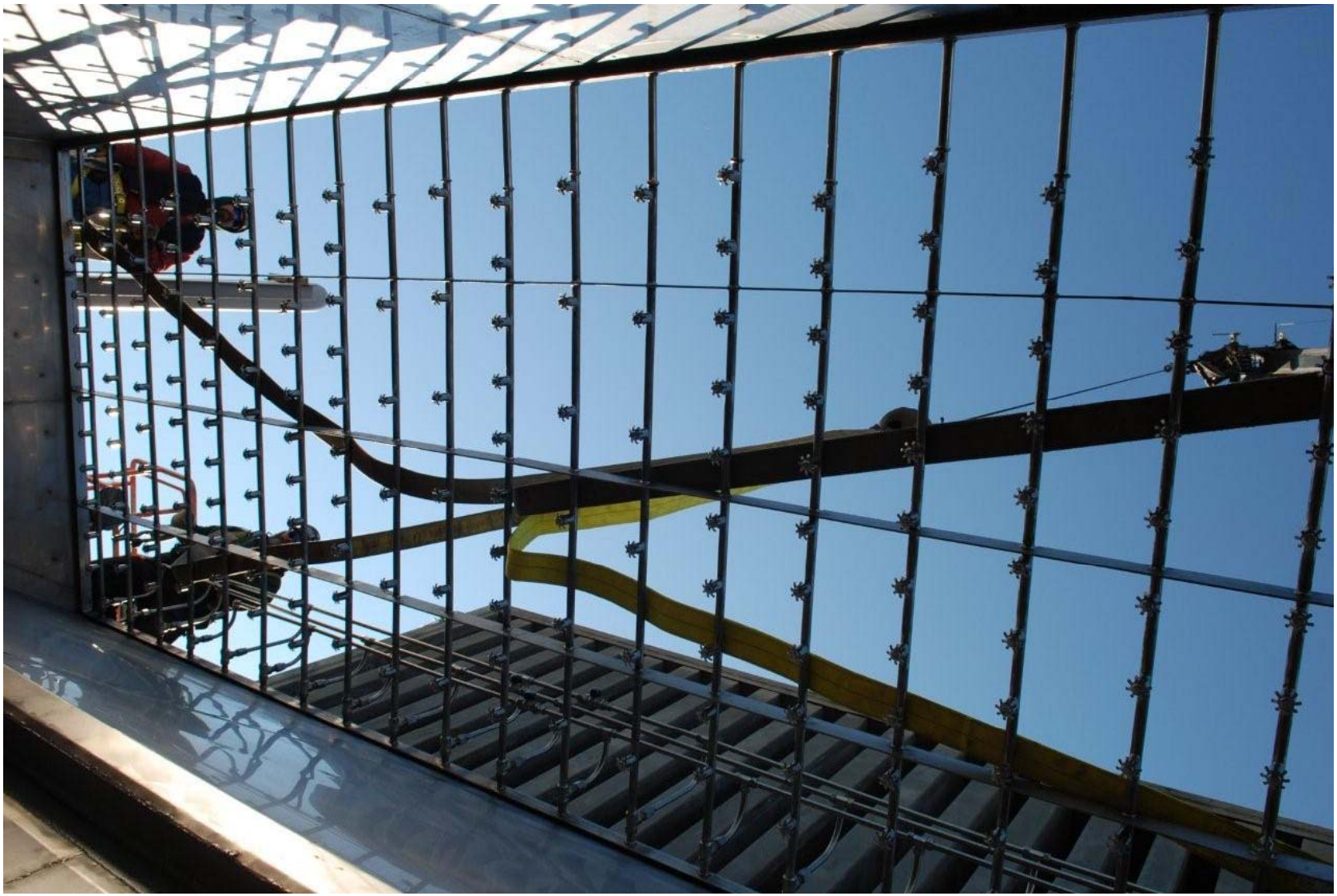
- **Overall NOx usually limited by SCR system**
- **Increase in “Criteria Pollutants” << 40 TPH trigger for NSR**

Wet Compression Nozzle Location



Array Manifold 7EA

Manifold Installation



WCT Nozzle Spray Pattern

Cardinal Cogen - GE Frame 6B

	No Wet Compression	With Wet Compression
Ambient dry bulb	58°F	59°F
Ambient wet bulb	52°F	52°F
Compressor Inlet Air Temp	57.9°F	52°F
Compressor Discharge Pressure	153 psig	158 psig
Compressor Discharge Temp	664°F	614°F
Gas Flow	6.1 lb/sec	6.6 lb/sec
Theoretical Firing Temp	2023 °F	2023 °F
Turbine Exhaust Temp	1029 °F	1017 °F
Turbine Power Output	35.3 MW	38.6 MW

Duct Work Treatment 6B

Wet Compression Arrays 6B

WCT Skid On Test

Rolls Royce ISI SKID

Table 1: Performance Comparison of Various Combustion Turbines							
Combustion Turbine	Siemens W501FC	Siemens V84.2	GE LM2500 PE	GE Frame 6B	SWPC W501D5A	Alstom GT-24	GE Frame 7EA
Overspray, %	1.3	1.0	2	1	2	1.2	1.5%
Compressor Discharge Temperature Reduction, °F	90	50	Data not available	50	100	48	90
Fuel Flow Increase, %	N.D.	N.D.	4	8.2	13.2	5.5	11.5%
Change in Base Load Firing Temperature, ºF	No Change	No Change	No Change	No Change	No Change	No Change	No Change
CT Power Increase, MW	17	5.2	1.6	3.3	15	15.5	9
Steam Turbine Power Increase, MW	Simple Cycle	Simple Cycle	-.5	0.3 (est.)	2 (est.)	1.8(est.)	Simple Cycle
CT Heat Rate Improvement, %	N.D.	2	0	1	2	2	1.05%
NOx Info	-10%	N.D.	-14%	DLN	DLN	No Change	-54%

Wet Compression Experience

- Patented Wet Compression Technology
  - licensed from Dow Chemical
  - 10 years of continuous improvement
- > 300,000 hours of operating experience on more than 60 CTs

Engine	1st Installed	Engine	1st Installed	Engine	1st Installed
W501A	1995	GE 6B	2002	GT 24	2002
W501D5A	1997	LM2500	2003	GT 26	2004
W501D5	1999	**GE 7EA**	**2008**	RR T60	2009
V94	2001				
W501F	2004				

8 units and growing

Wet Compression Summary

- Significant **efficiency improvement**
- **<< 1 year payback**
- **Ambient Independent**: consistent, predictable power augmentation
- Short outage, low-impact installation
- > 300,000 hours of operating experience
- **Safe and Reliable** – no impact to Reliability, Availability, Maintainability (RAM)

Wet Compression Customers

Projects installed in: USA, South America, Africa, Europe, Asia, Australia