Cheng Low NOx (CLN®)
State-of-the-Art Emissions Control Technology

Introduction to CLN Technology
USA Version

Developed by:

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CLN Executive Summary

During the course of this presentation IPT will:

1) Describe in brief IPT’s corporate history and the Cheng Low NOx (CLN) technology development timeline
2) Provide a summary of the CLN Demonstration Projects and their current operational status
3) Describe the principles and benefits of the CLN technology
4) Show how the CLN technology is easy to implement and uses mostly stock OEM engine hardware
5) Describe in detail the benefits of CLN including:
   a) Lower NOx and CO
   b) Cheaper to implement than DLE, SCR, and sometimes water
   c) Increased power and peak (kW) shaving capability
   d) Decreased turbine fuel consumption
   e) Decreased CTIT at constant power resulting in turbine overhauls savings
1974   IPT founded by Dr. Dah Yu Cheng

1982 - 1983   IPT Co-Develops the Allison 501-KH dubbed the “Cheng Cycle”

1984   Startup of first commercial Cheng Cycle system startup at San Jose State University. Owned and Operated by IPT.


1986 – 1990   IPT licenses the Cheng Cycle technology to partners around the world: Kawasaki and Hitachi Zosen (Japan), ELIN (Europe), DETCO (Australia), and US Turbine (North America).

1991   IPT is acquired by its licensee ELIN, a large Austrian industrial holding company.

1999   Management Buy-Out

2003 - Present   IPT signs exclusive worldwide CLN License – Startup of first CLN Unit – Demo site operational February 2005.
Cheng Low NOx (CLN) Demonstration Site
SRI International Cogeneration Project
Operational Since March 2005
Project Status

SRI – KB5 - CLN Demonstration Project Status

1) Currently IPT has achieved 9.5 ppm NOx and CO at 1895 Deg F (CTIT) at 2.35 s/f ratio
2) Testing continues to achieve up to 4 to 1 Steam to Fuel Ratios
3) CLN has been operational for over 18 months without any problems
4) Liners tested: LE-2, LE-3.1, LE-3.2,

Germany – KB7 - CLN Demonstration Project Status

1) Became operational April 15, 2006
2) DLE conversion to CLN due to high DLE costs – Running LE-2 Combustion Liners
3) Site steam pressure limits steam-to-fuel ratio to .6 to 1 at 1935 Deg F (CTIT)
4) All expected emissions achieved

Potential CLN Retrofit Candidates

1) Those that want to convert from the OEM DLE to less costly low emissions system
2) Those looking to convert from water injected systems
3) Those looking to reduce emissions due to regulatory requirements
4) Those looking to voluntarily reduce emissions to sell the NOx and CO emissions offsets on the open market
5) New Installations requiring New Source Review emissions limits
Available NOx Reduction Technologies

NOx Reduction in Gas Turbines

1. Combustion Modification
   - Lean-Premix Dry-Control
     - DLN, DLE, SOLONOX

2. Catalytic Combustion (Kawasaki M1A)
   - Diffusion Flame Steam/Water Injection
     - Traditional Methods

3. Post-Combustion Treatment
   - SCR
   - SCONOX

CLN® Technology
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Principal of CLN®

CLN reduces emissions by mixing steam with natural gas prior to combustion in the turbine. CLN requires a homogeneous mixing of steam and fuel to enable the highest jet momentum by higher volume flow:

- to enhance the diffusion rate of oxygen
- to shrink the flame surface envelope
- to reduce or block N2 penetration into the flame structure
- to reduce residence time of N2 and O2 in the hot zone
- to reduce hot zone temperature
CLN® System Block Diagram

CLN Computer

Combustion: OEM Liners OEM Nozzles

Stm/Fuel Mixer

Saturated or Superheated Steam

Applicable Models

501- KB5(x)
501-KB7(x)
501-KH(x)
501-KC

Fuel

Stm/Fuel Mixture to Turbine

Control Wiring

Working Fluids (Fuel, Steam, Air)

Compressor

Turbine

HRSG

Note: All on-engine CLN mods are with OEM hardware: LE(x) liners, low Btu fuel nozzles, and fuel manifolding
Summary of CLN Test Data
Summary of GE Frame 5P, 6B, 7B, 7EA and Westinghouse 501D5 Experiments

![Graph showing NOx emissions vs. Steam/Fuel (mass) for different models: 7EA, 7B, 6B, 5P, and W501D5. The graph demonstrates the reduction in NOx emissions as the steam/fuel ratio increases. Each model shows a different trend line indicating varying levels of efficiency in NOx reduction.]

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On - Engine Test Results

CLN
Actual Results

KB-7S Water Injection Emissions Results Rolls-Royce
December 2001

Steam to Fuel Ratio (mass)
OEM Has Been Injecting Steam into the 501-K(x) Gas Turbine For Over 20 Years

<table>
<thead>
<tr>
<th>Rolls-Royce/Allison</th>
<th>Installation Design Manual Limits on Steam Injection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>501-KH</td>
<td>lbs/sec</td>
</tr>
<tr>
<td>501-KB7 and KB5</td>
<td>lb/lb</td>
</tr>
<tr>
<td>501-KB7 and KB5</td>
<td>lbs/sec</td>
</tr>
<tr>
<td>Typical CLN Range</td>
<td>lbs/sec</td>
</tr>
</tbody>
</table>
CLN Peak Shaving Capability

Effects of Adding CLN steam

Source: Roll-Royce/Allison Performance Program @ 100 Deg F CIT
All values are approximate

Constant CTIT Curves

Generator Rating = 4925 kW

2.0 S/F Ratio
Add 785 kW
12.5 ppm

1.5 S/F Ratio
Add 578 kW
20 ppm

.85/1 S/F Ratio
Add 321 kW
42 ppm

Assumed Generation (kW)

Actual Engine kW
CLN Generation Capability - 1.5 sf
CLN Generation Capability - 2.0 sf
CLN Generating Capability - .85/1 SF Ratio
Illustration
Effects of CLN Steam Injection
KB7S - Constant 5270 kW
Source: Allison Performance Deck - All at ISO conditions

213 Btu/kWh Decrease in Heat Rate
59 Deg F Decrease in CTIT
42 ppm Operating Point

All values are approximate
Effects of CLN Steam Injection
KB7S - Constant CTIT @ 1925
Source: Allison Performance Deck - all at ISO conditions

Illustration

378 kW Increase
406 Btu/kWh Decrease in Heat Rate
All Values Are Approximate

42 ppm Operating Point
25 ppm Operating Point
15 ppm Operating Point

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Heat Rate (Btu/kWh - HHV)
Power (kW)
OEM Nozzle Used on Nozzle Steam Injected 501-K(x) Engines

OEM Currently Mixing Steam and Fuel Prior to Entering Combustion Liner

Without CLN System
Steam/Fuel Mixture to Combustion Liner is at Low Homogeneity

Rolls-Royce/Allison 501-K Standard Low BTU Test Nozzle

Nozzle Tip
10 holes @ .210 dia.

Gas Inlet Port
Steam Inlet Port
Standard OEM LE-2 Test Liner

Test Liner
Rolls-Royce/Allison Standard
LE-2 Combustion Liner Assembly

- Fuel Nozzle Insertion Point
- Igniter Hole
- Crossover Tube
- Barrel Section
- Dilution/Cooling Holes
- Transition Section
- Burner Outlet Temp Measurement Holes
Standard OEM Test Liner – LE-3.2
## Cycle Efficiency and Overall Cost - Water vs. Steam Injection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Water Injection</th>
<th>CLN Steam @ Constant kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTIT</td>
<td>Deg F</td>
<td>1895</td>
<td>1895</td>
</tr>
<tr>
<td>SF Ratio</td>
<td>steam-water/fuel</td>
<td>1.0</td>
<td>1.15</td>
</tr>
<tr>
<td>Constant kW</td>
<td>kW</td>
<td>4,059</td>
<td>4,060</td>
</tr>
<tr>
<td>Heat Rate</td>
<td>Btu/(kWe*hr) - LHV</td>
<td>12,122</td>
<td>11,381</td>
</tr>
<tr>
<td>Fuel Flow</td>
<td>mmbtu/hr - LHV</td>
<td><strong>49.20</strong></td>
<td><strong>46.21</strong></td>
</tr>
<tr>
<td>Fuel Flow</td>
<td>lb/hr</td>
<td>2409</td>
<td>2263</td>
</tr>
<tr>
<td>Unit Cost of Fuel</td>
<td>$/mmbtu</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Cost to Operate</td>
<td>$/hr</td>
<td>-410</td>
<td>-385</td>
</tr>
<tr>
<td>Delta Fuel Costs</td>
<td>$/hr</td>
<td></td>
<td><strong>24.9</strong></td>
</tr>
<tr>
<td>Delta Efficiency</td>
<td>%</td>
<td></td>
<td><strong>6.08%</strong></td>
</tr>
<tr>
<td>Steam Flow</td>
<td>lb/hr</td>
<td>0</td>
<td>2592</td>
</tr>
<tr>
<td>Cost of D.B. Steam</td>
<td>$/hr</td>
<td>0</td>
<td><strong>25.9</strong></td>
</tr>
<tr>
<td>Delta Fuel and Steam</td>
<td>$/hr</td>
<td></td>
<td><strong>-0.98</strong></td>
</tr>
<tr>
<td>Overall Cost Difference</td>
<td>%</td>
<td></td>
<td><strong>0.24%</strong></td>
</tr>
</tbody>
</table>

**Conclusion**

Overall Cost to convert to CLN Steam Injection only slightly greater than water injection

Assumes:
1) non-fuel water injection cost are the same as steam injection costs
2) any boiler efficiency changes between water and steam are excluded
3) all values are from Rolls-Royce/Allison Performance Deck
4) all injection steam being produced from duct burner at 90% efficiency
5) benefits of increased combustion liner life not included

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### Type of Customer

<table>
<thead>
<tr>
<th>Type of Customer</th>
<th>Is CLN Profitable?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water to Steam only</td>
<td>Maybe</td>
<td>Depends on water/fuel ratio and life of liners</td>
</tr>
<tr>
<td>Have at least 15% extra steam available</td>
<td>Yes</td>
<td>Payback increases with decreased steam costs</td>
</tr>
<tr>
<td>Need extra power</td>
<td>Yes</td>
<td>Cost per kWh from CLN is less than adding additional generation</td>
</tr>
<tr>
<td>Need lower emissions</td>
<td>Yes</td>
<td>Cost of CLN emissions control is less than alternatives</td>
</tr>
<tr>
<td>Have DLE</td>
<td>Yes</td>
<td>DLE is very expensive - 14th stage bleed system has high heat rates</td>
</tr>
<tr>
<td>Have/need SCR</td>
<td>Yes</td>
<td>CLN is much cheaper than SCR</td>
</tr>
</tbody>
</table>
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**IN CONCLUSION**

1. Produces lower NOx and CO
2. Increase power output in excess of 785 kW
3. Reduces turbine heat rate and fuel consumption
4. Uses OEM fuel nozzles and combustion liners
5. Eliminates the need for SCR and DLE systems
6. Increases hardware lifetime: reduced firing temperature and better flame pattern
7. Eliminates water injection