Cheng Low NOx (CLN®)

State-of-the-Art Emissions Control Technology

Introduction to CLN Technology
Metric 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 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

IPT TIMELINE

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.**
1984 - 1988	**IPT develops five additional Cheng Cycle installations in California: Frito-Lay, Sunkist Growers, Hershey Chocolate, SRI International, and Loma Linda University.**
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

Germany KB-7 – DLE to CLN Conversion - Operational April 2006

Project Status

SRI – KB5 - CLN Demonstration Project Status

1) Currently IPT has achieved sub 19 mg/m3 NOx and CO at 1035 Deg C (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,

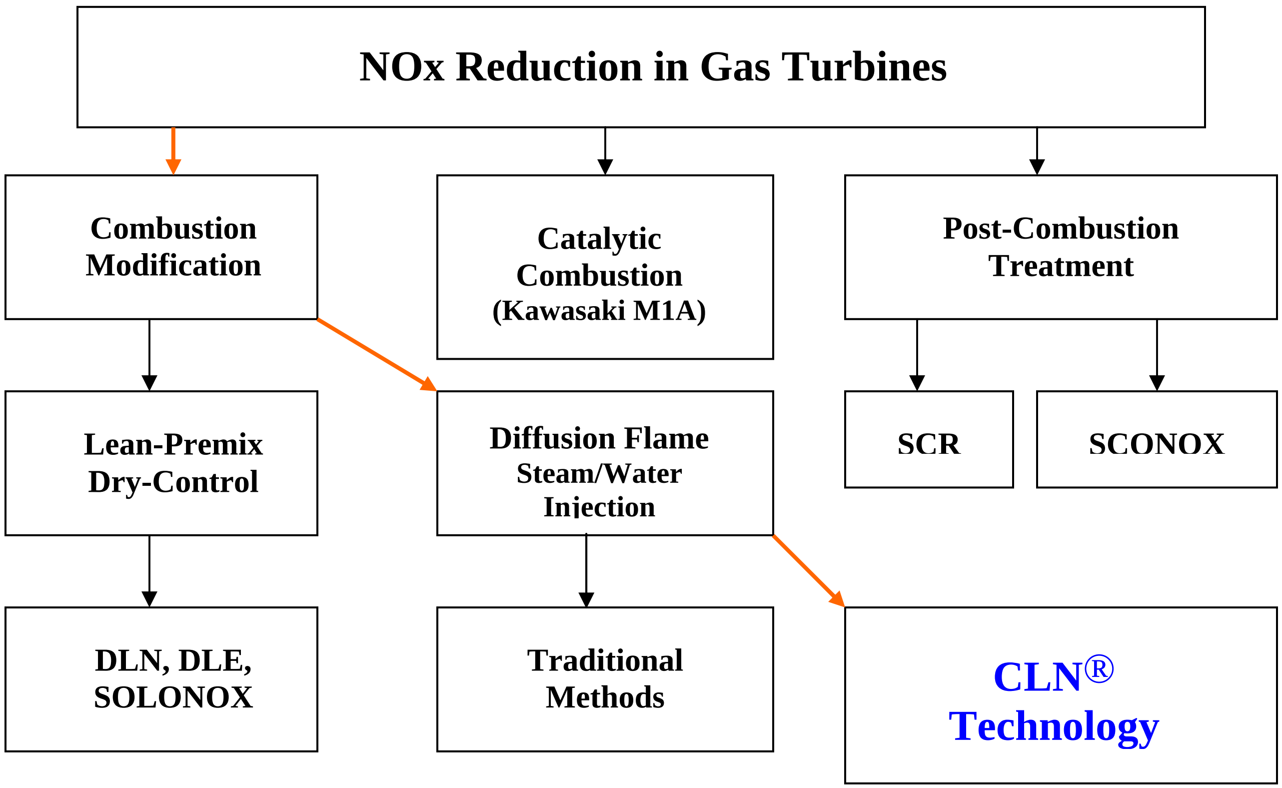
Germany – KB7 - CLN Demonstration Project Status

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 1057 Deg C (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

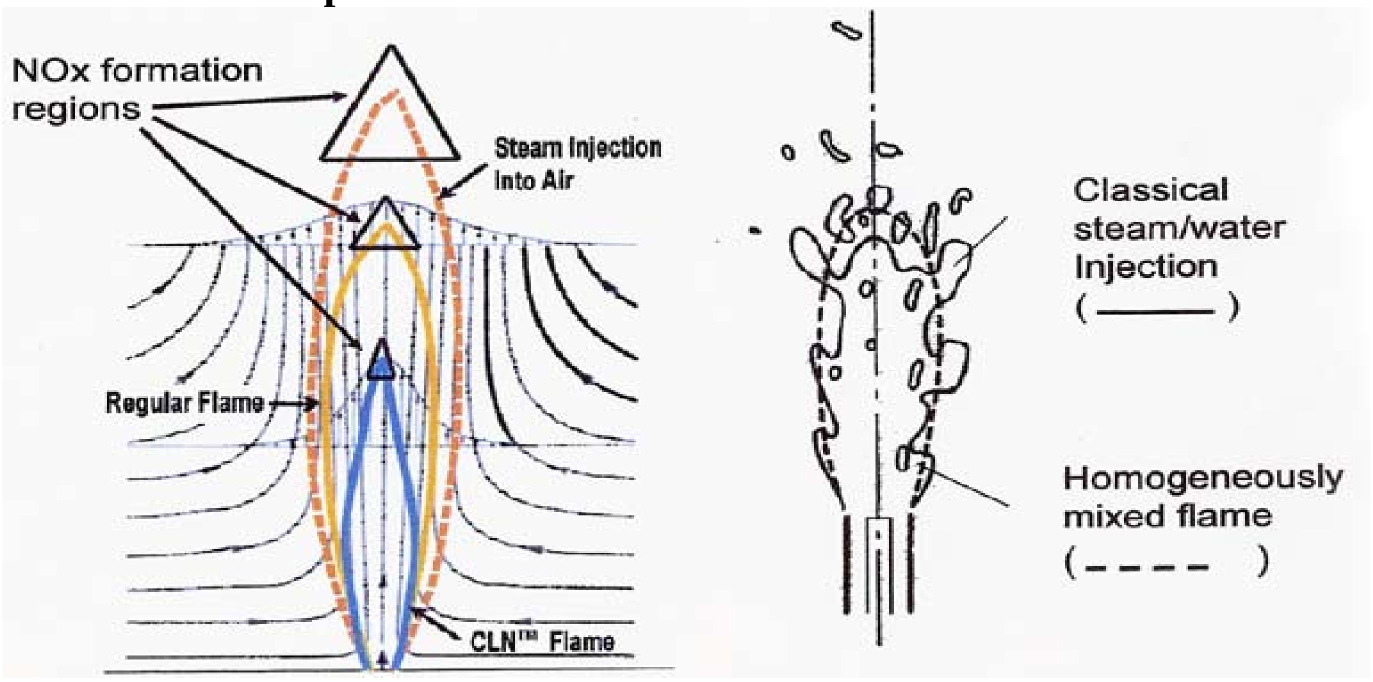
Available NOx Reduction Technologies



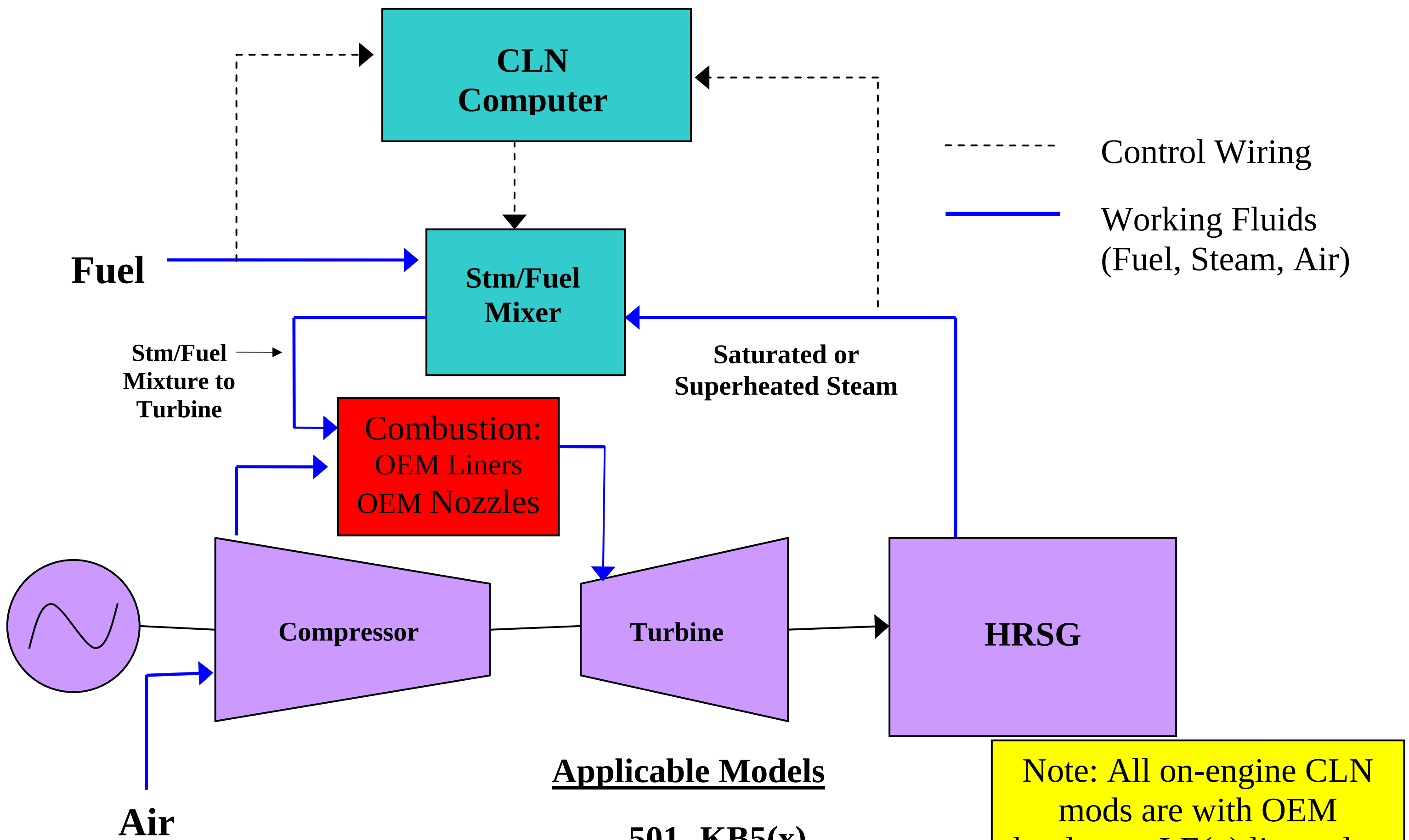
Principal of CLN®

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**



<u>CLN® System Block Diagram</u>



<u>Applicable Models</u>

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

Note: All on-engine CLN mods are with OEM hardware: LE(x) liners, low Btu fuel nozzles, and fuel manifolding

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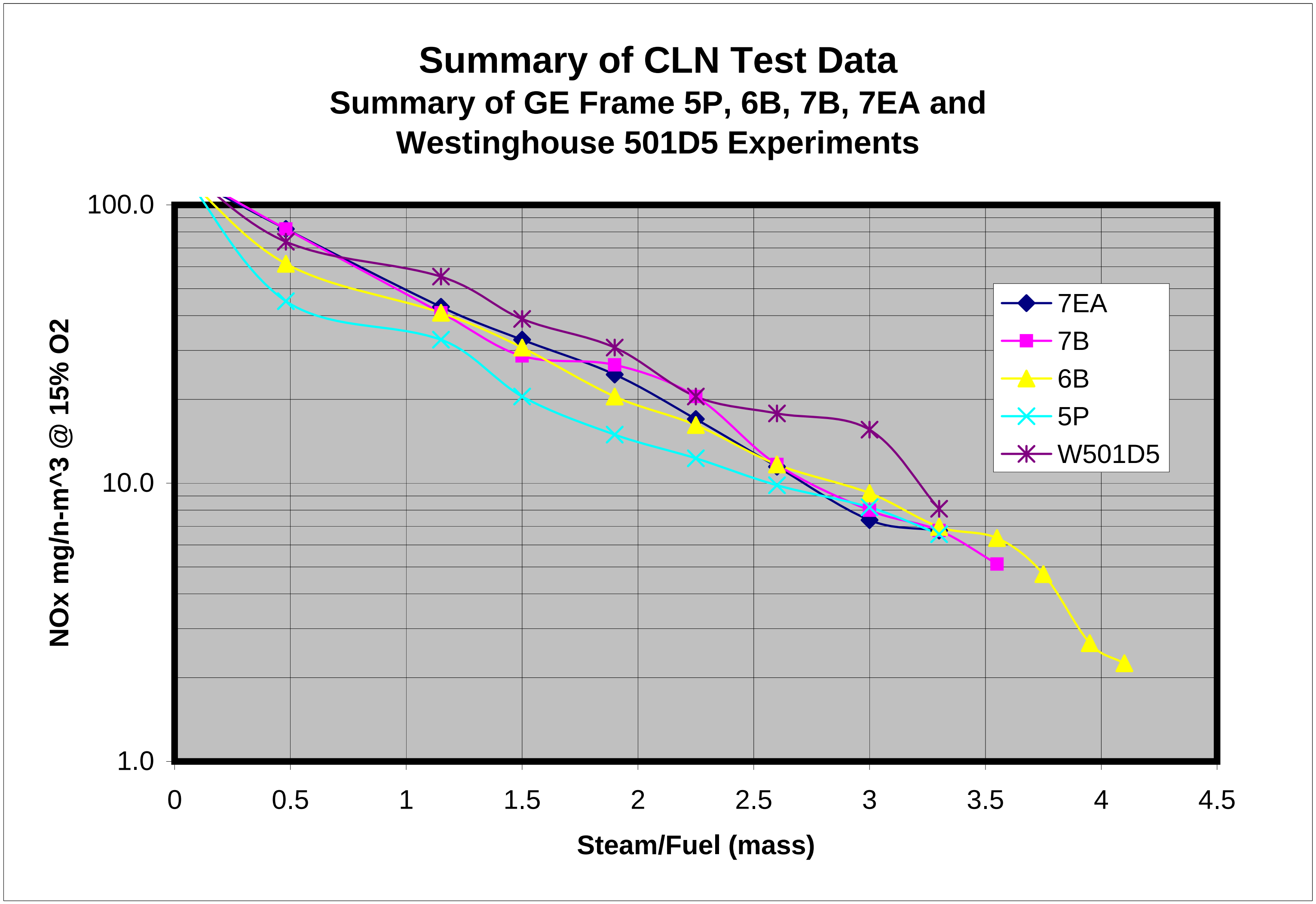
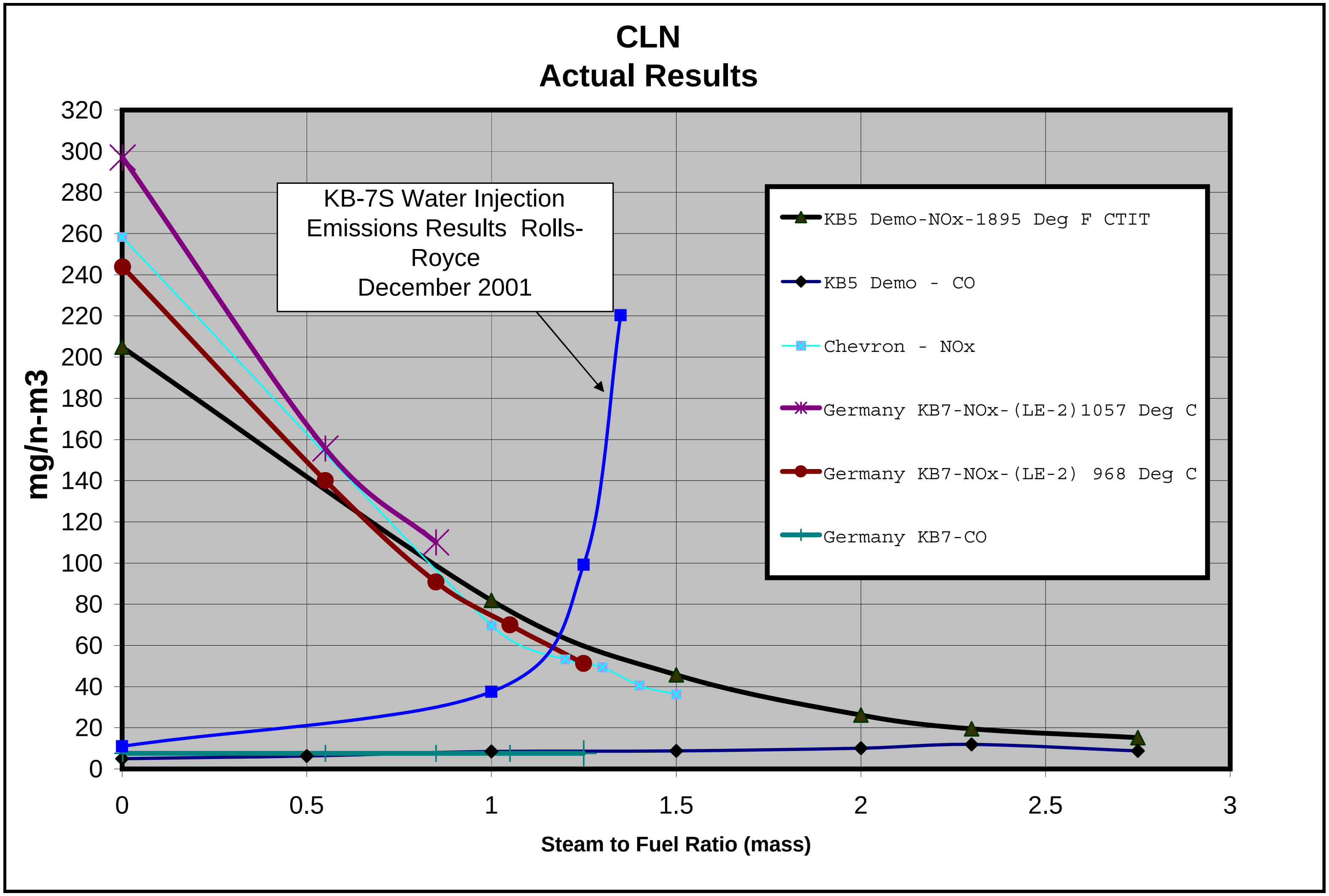
CLN Atmospheric Tests Results



On - Engine Test Results

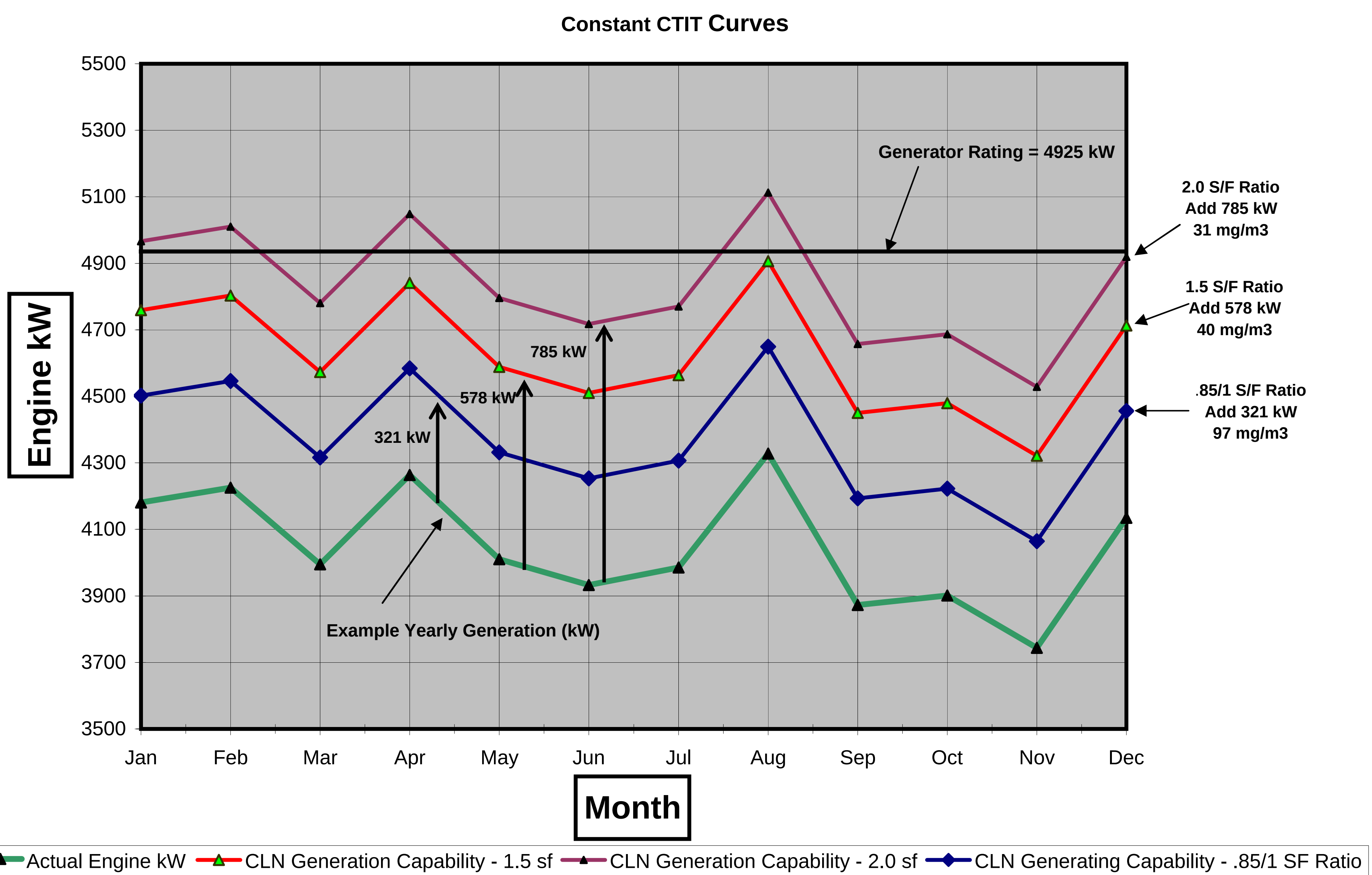


CLN Peak Shaving Capability

Effects of Adding CLN steam

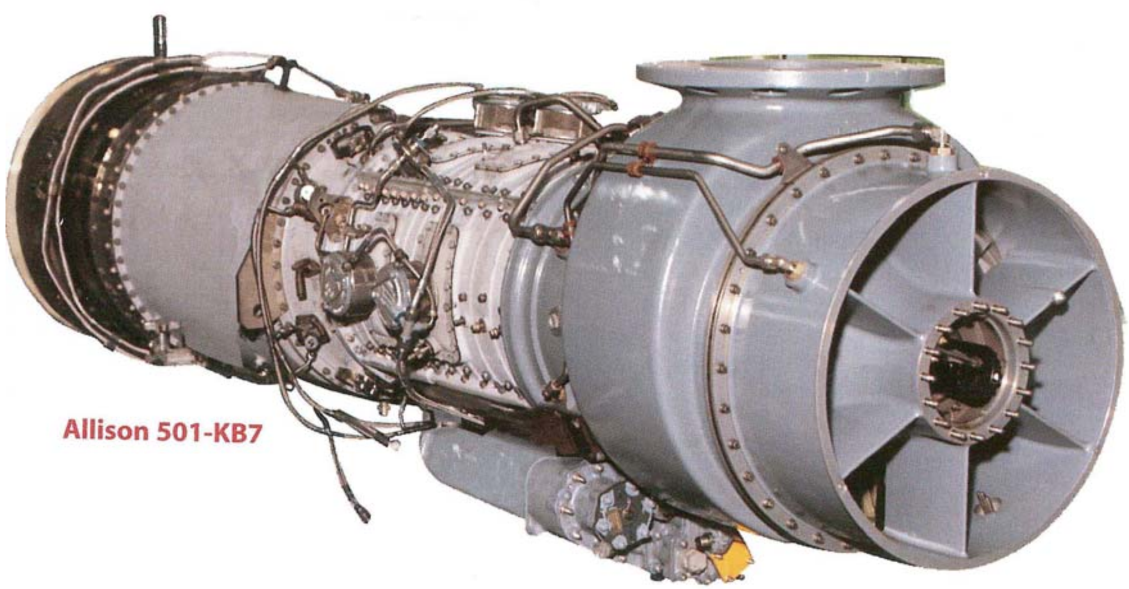
Source: Roll-Royce/Allison Performance Program @ 38 Deg C CIT

All values are approximate



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

Rolls-Royce/Allison			
Installation Design Manual Limits on Steam Injection			
Model	Units	Case Steam Limit	**Nozzle Steam Limit**
501-KH	kg/sec	2.72	.68
501-KB7 and KB5	kg/kg		2.0
501-KB7 and KB5	kg/sec		.68
Typical CLN Operating Range	kg/sec		.31 to .68
	kg/kg		.85 to 2.0



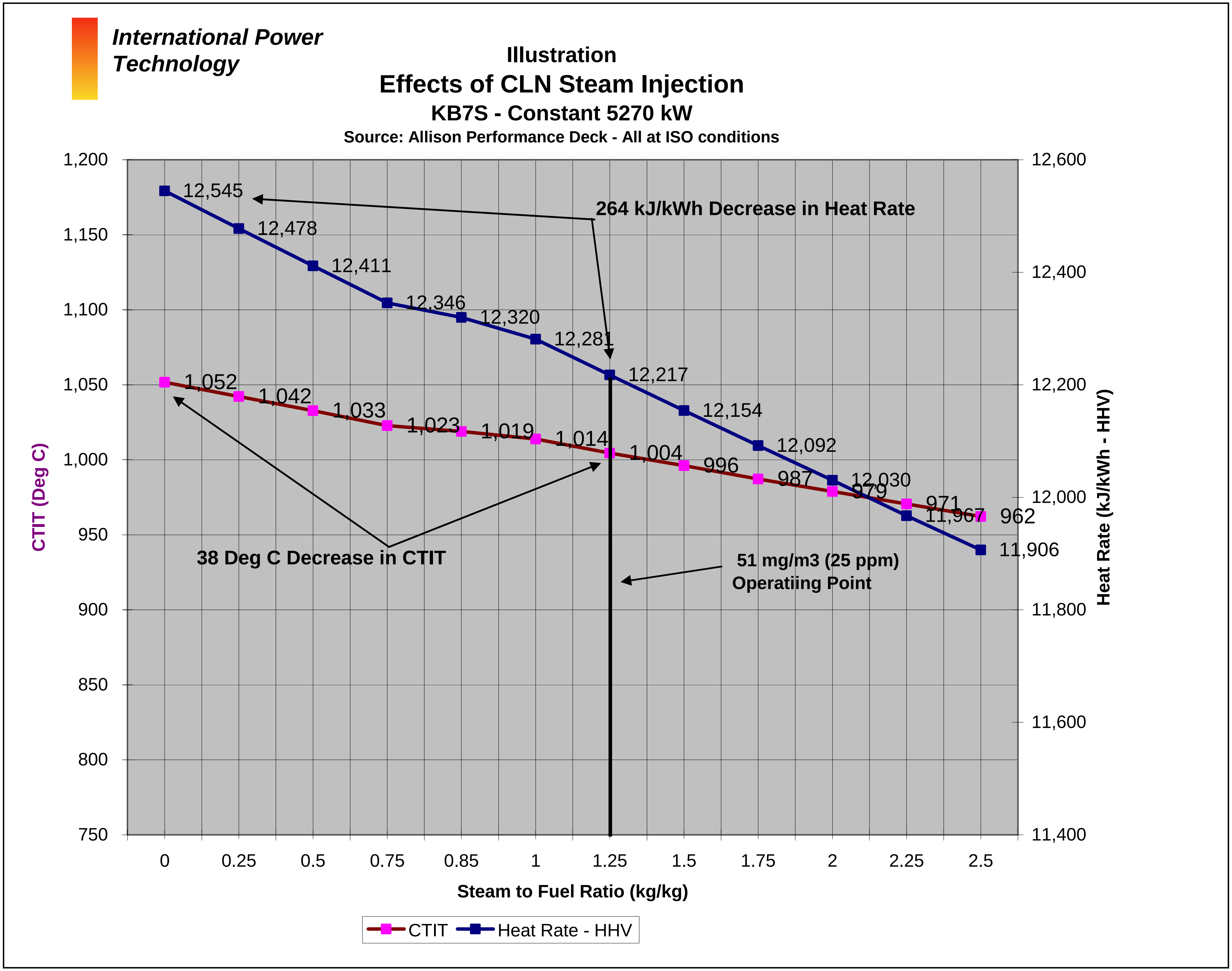


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Illustration
Effects of CLN Steam Injection
KB7S - Constant 5270 kW
Source: Allison Performance Deck - All at ISO conditions
264 kJ/kWh Decrease in Heat Rate
38 Deg C Decrease in CTIT
51 mg/m3 (25 ppm)
Operatiing Point
CTIT (Deg C)
Heat Rate (kJ/kWh - HHV)
Steam to Fuel Ratio (kg/kg)
CTIT
Heat Rate - HHV
12,545
12,478
12,411
12,346
12,320
12,281
12,217
12,154
12,092
12,030
11,967
11,906
1,052
1,042
1,033
1,023
1,019
1,014
1,004
996
987
979
971
962
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
12,600
12,400
12,200
12,000
11,800
11,600
11,400
0
0.25
0.5
0.75
0.85
1
1.25
1.5
1.75
2
2.25
2.5

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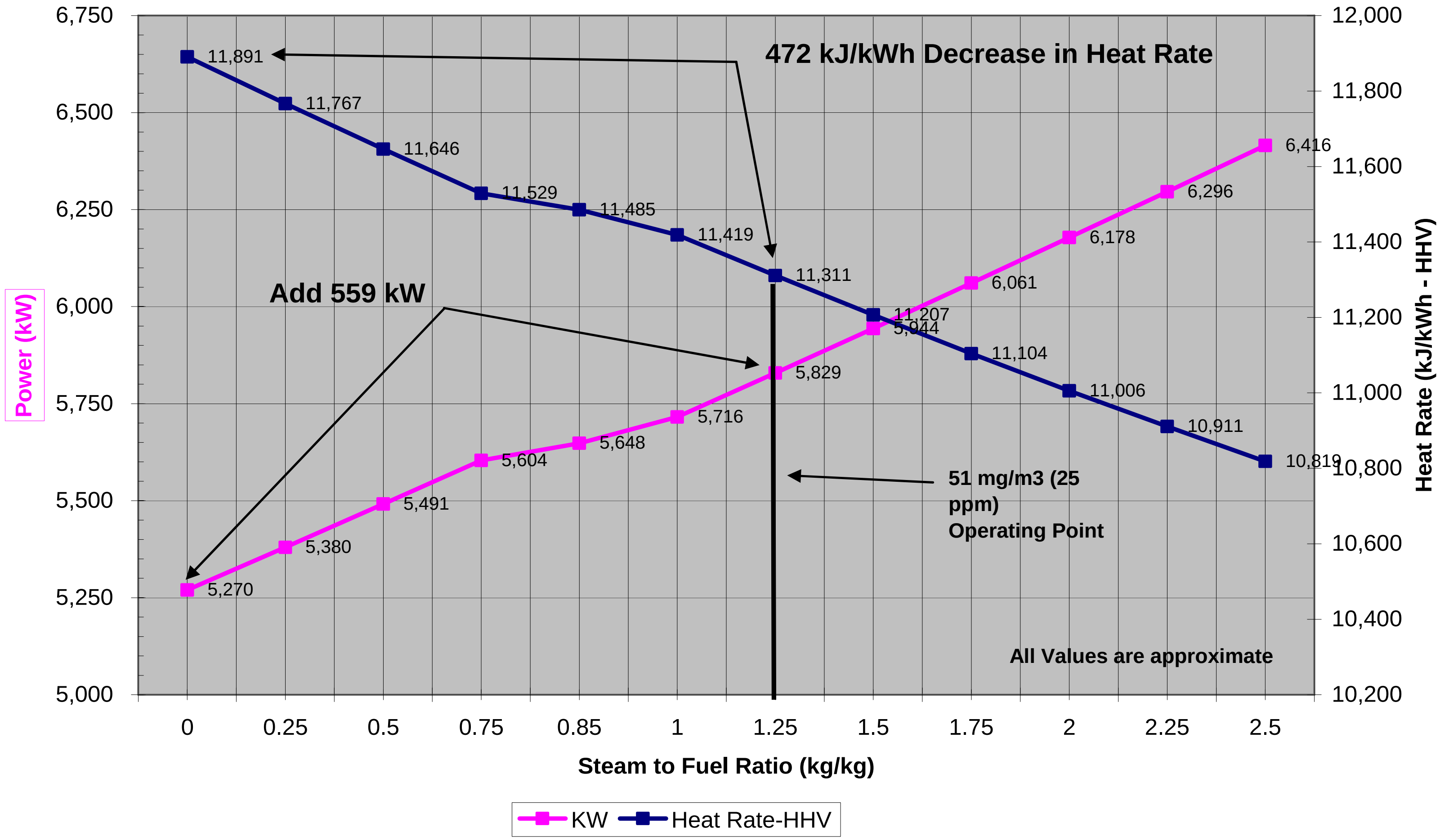
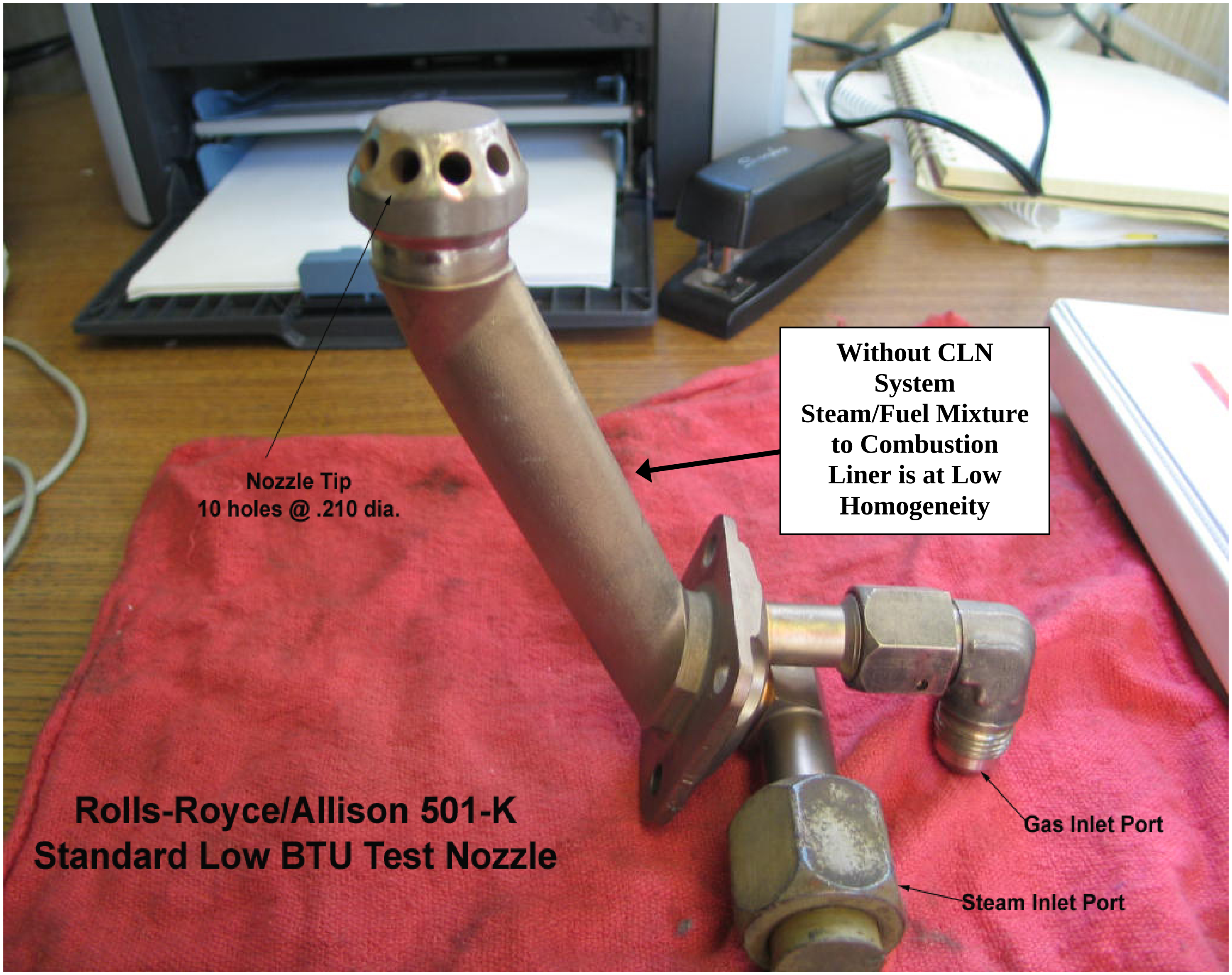
Illustration
Effects of CLN Steam Injection
KB7S - Constant CTIT @ 1925

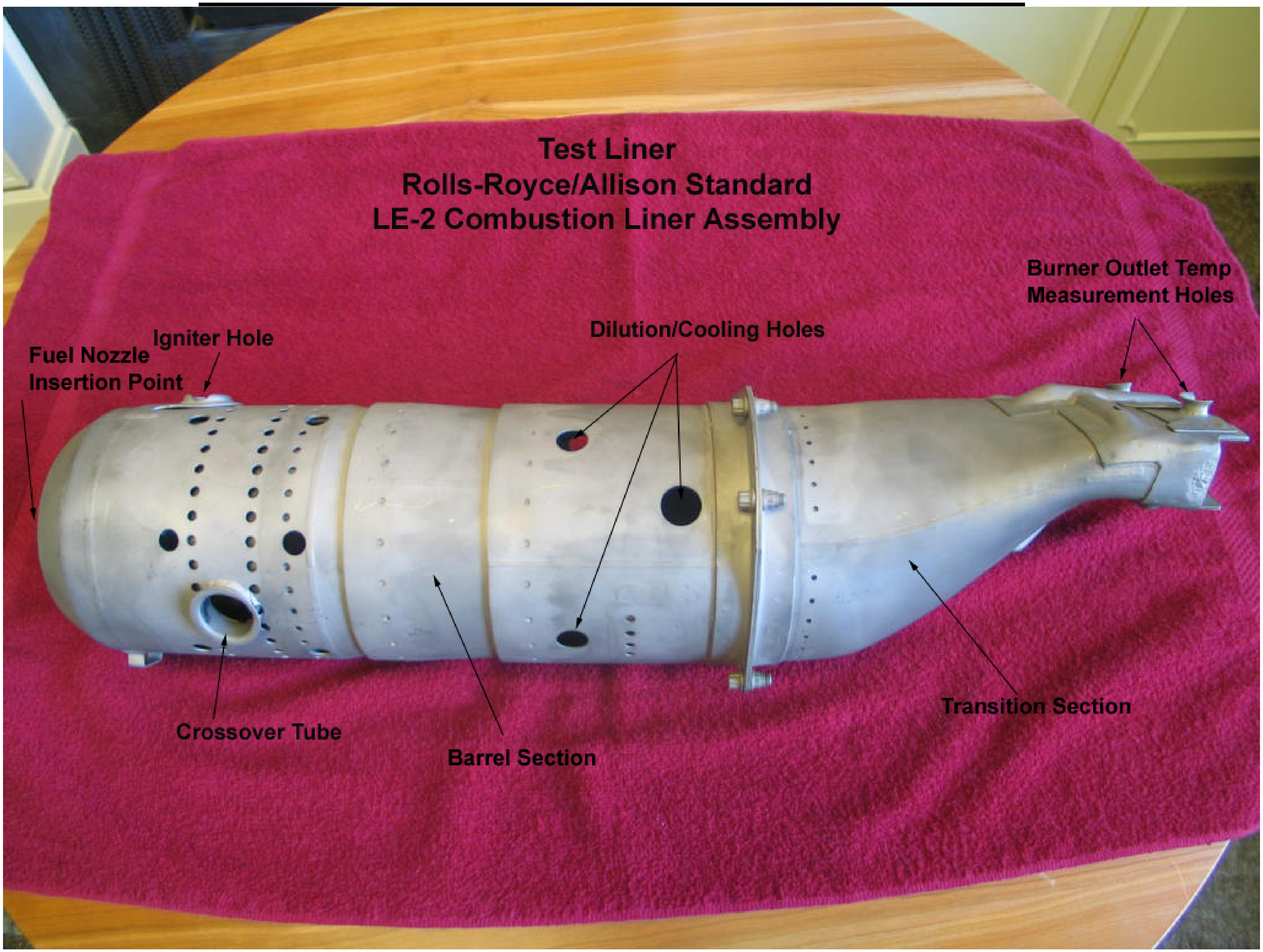
Source: Allison Performance Deck - all at ISO conditions



OEM Nozzle Used on Nozzle Steam Injected 501-K(x) Engines
OEM Currently Mixing Steam and Fuel Prior to Entering Combustion Liner



Standard OEM LE-2 Test Liner



CLN Test Liner – LE-3.2

Cycle Efficiency and Overall Cost - Water vs. Steam Injection

Parameter	Units	Water Injection	CLN Steam @ Constant kW
CTIT	Deg C	1035	1035
SF Ratio	steam-water/fuel	1.0	1.15
Constant kW	kW	4,059	4,060
Heat Rate	kj/(kWe*hr) - LHV	12,790	12,008
Fuel Flow	Gj/hr - LHV	**51.91**	**48.75**
Fuel Flow	kg/hr	1093	1026
Unit Cost of Fuel	$/Gj	7.5	7.5
Cost to Operate	$/hr	-433	-406
Delta Fuel Costs	$/hr		**26.3**
Delta Efficiency	%		**6.08%**
Steam Flow	kg/hr	0	1176
Cost of D.B. Steam	$/hr	0	**25.9**
Delta Fuel and Steam	$/hr		**0.39**
Overall Cost Difference	%		**-0.09%**

Conclusion

Overall Operating Cost of CLN Steam injection same as 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) alll 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

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

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IN CONCLUSION
CLN

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 and reduces wear and tear on combustion liners