IAGT
Industrial Application of Gas Turbines

IAGT 2015 SYMPOSIUM

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# LOW EMISSIONS COMBUSTION SYSTEM RETROFITS FOR MATURE FRAME GAS TURBINE POWER PLANTS

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**Banff, Alberta, Canada - October 2015**

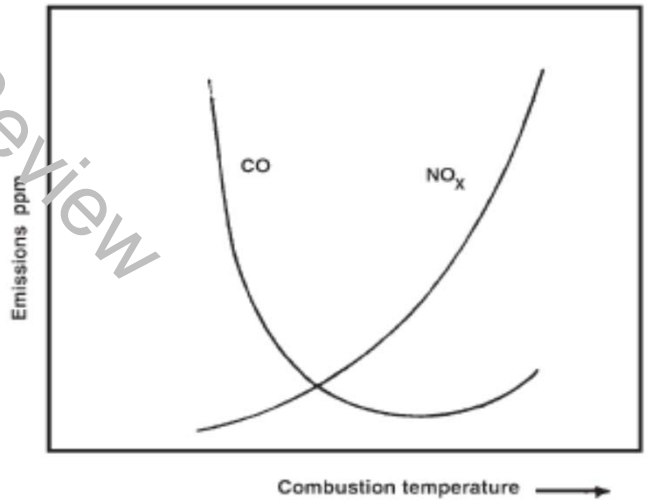
# Agenda

- NOx, CO & Combustion Fundamentals
- LEC-III® System
- Fr7B Low Emissions Conversion Case Study
- Analytical Approach
- Results and Summary

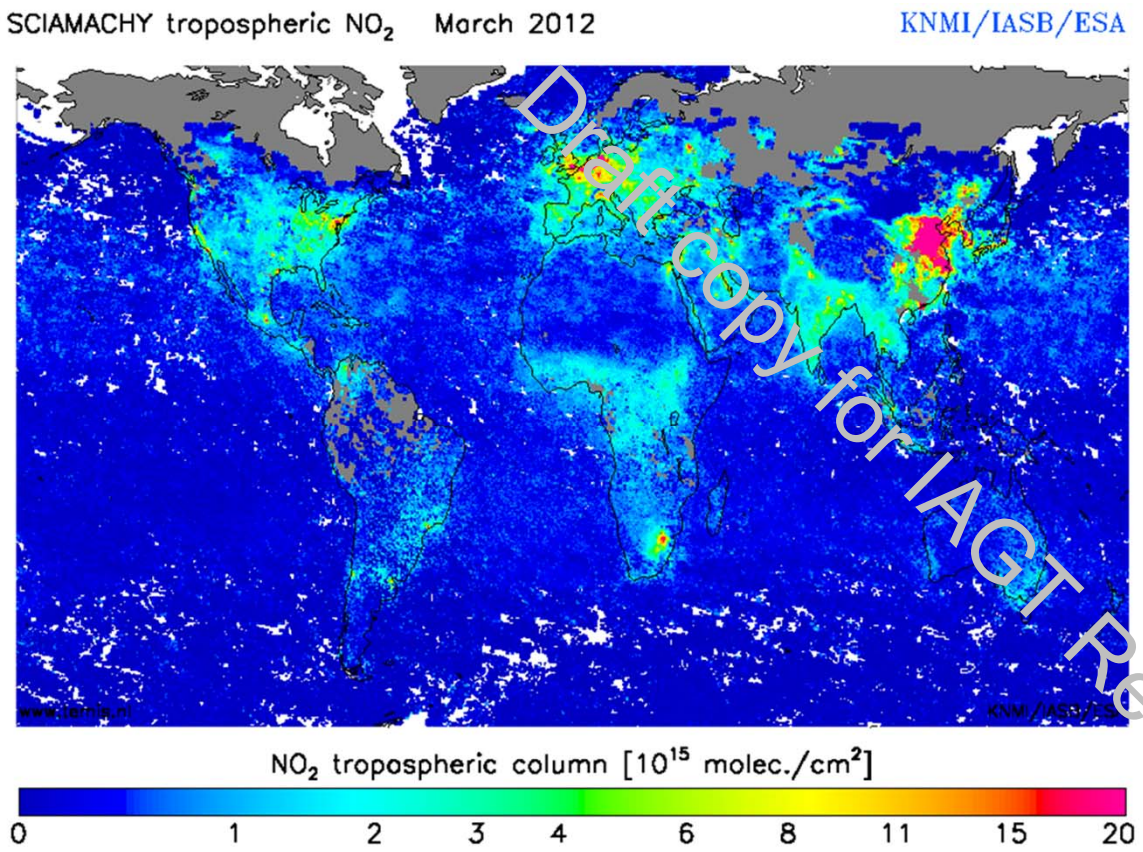
# Gas Turbine Combustion Emissions



- NOx & CO: combustion bi-products
  - Limited by regulations
  - US: EPA, EU: EEA,
  - CA: AQMS, BLIERS, …..etc
- NOx generation:
  - High firing temperature
- CO generation:
  - Typical at low load.



# NOx & CO Pollution






GT Pollution Control

- Post Treatment: Exhaust SCR can be impractical and/or costly

or

- Pre-Treatment: Water / Steam injection can be costly

or

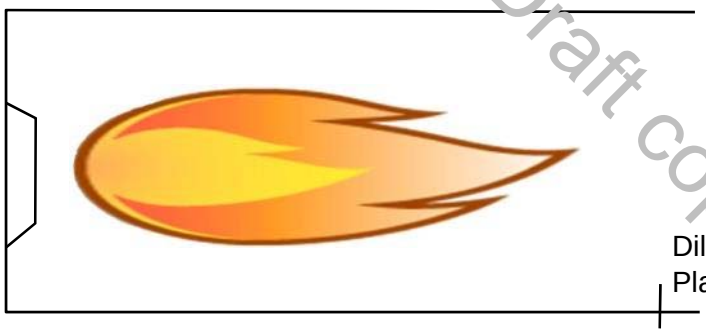
- Combustion Pre-Mix

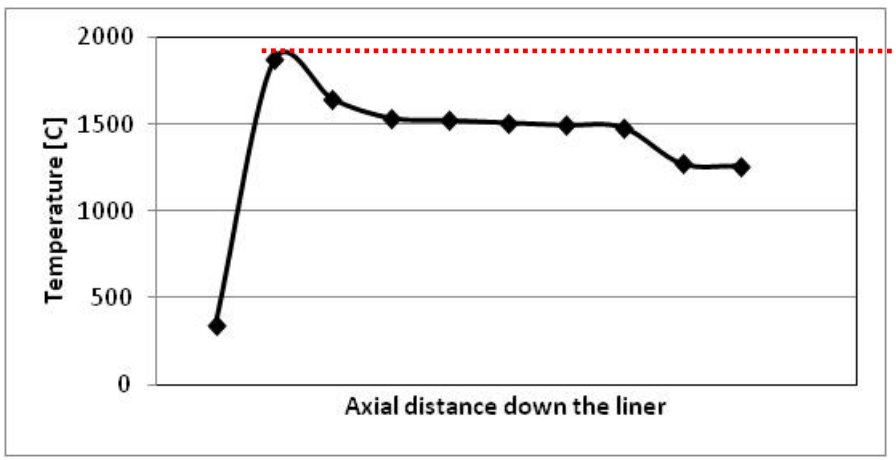
http://www.esa.int Photo: KNMI/IASB/ESA .

**NOx emissions – A global issue**

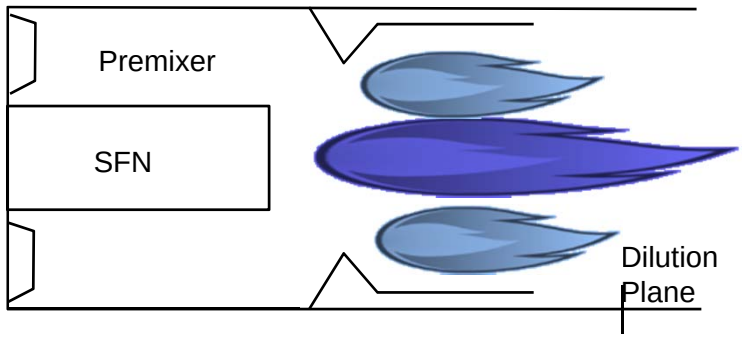
# Combustion Concept

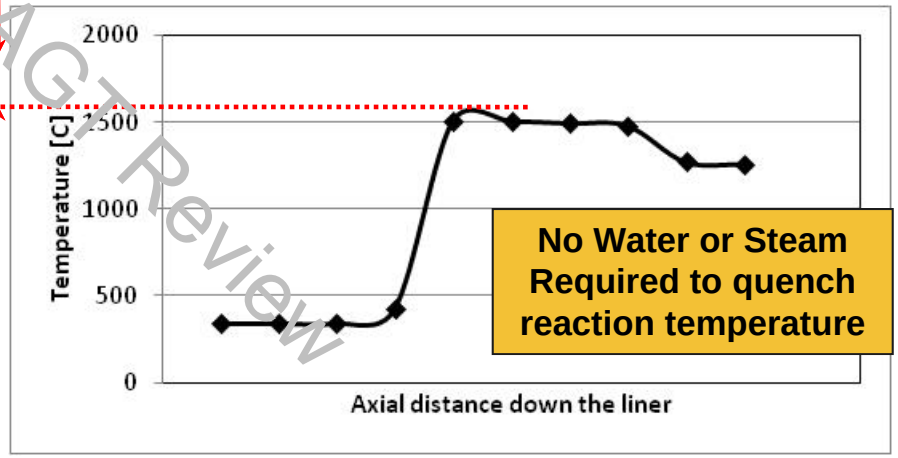
## Diffusion Burning (Single Body Nozzle)




## Premix Burning (LEC-III ® or DLN-1)






**Premix Combustion : Lower reaction temperatures : Lower NOx & Saves water!**

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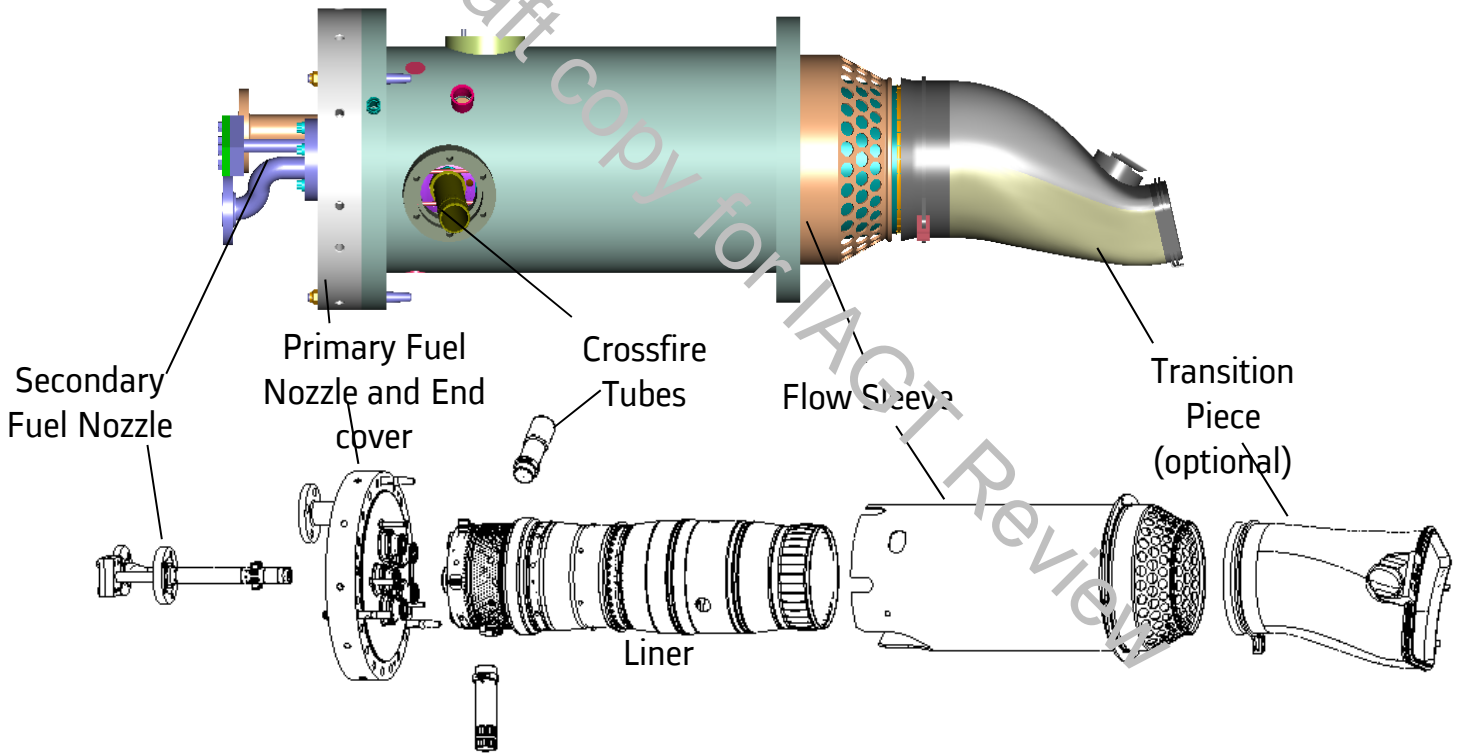
# LEC-III® Combustion System

- Fleet Leader ~50K Hrs
- +1.2M fleet fired hours
- +9000 starts in fleet

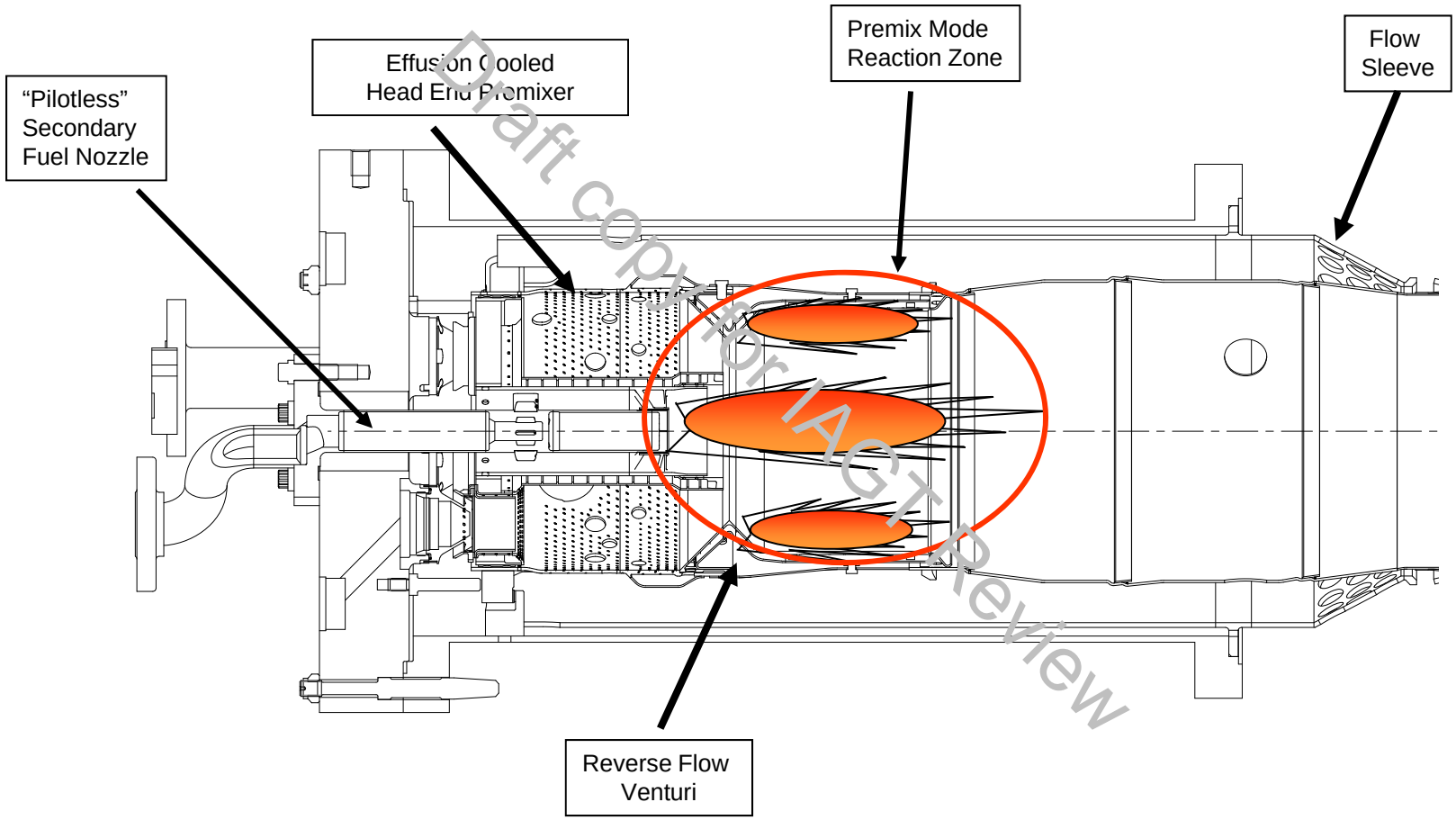
- 24,000 FFH / 900 FFS






**Sub-5 PPM NOX Consistently Achieved**

# LEC-III® Technology Features



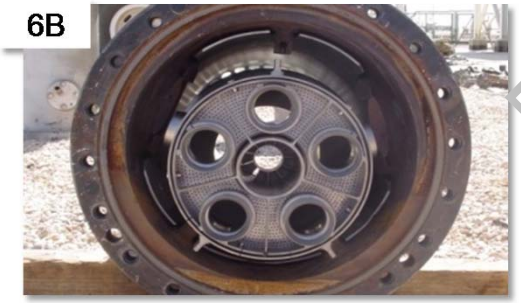



**Improved Mixing Allows Stable Ultra-low Emissions**

# LEC-III® – Over 3.6 GW Installed

# LEC-III® Experience

6B



9E & 7E

501B6 & D5

| Company | Location | GT Frame | # of Installations | Dates of Install(s) | Type |
|---|---|---|---|---|---|
| BTEC | Mississippi, USA | 7B/E | 3 | 1999 | Conversion |
| BTEC | Georgia, USA | 7E | 6 | 2000 | Conversion |
| TransAlta | Alberta, CAN | 7EA | 1 | 2001 | Drop In |
| GWF Power | California, USA | 7EA | 1 | 2003 | Drop In |
| DOW | Texas, USA | 7EA | 3 | 2003-04 | Drop In |
| DOW | Texas, USA | 6B | 1 | 2004 | Drop In |
| Roquette | France | 6B | 1 | 2004 | Drop In |
| ENEL | Italy | 9E | 1 | 2004 | Drop In |
| PDO | Oman | 6B | 3 | 2004-06 | Drop In |
| Calpine | Texas, USA | W 501D5 | 2 | 2005-07 | Conversion |
| NRG | Texas, USA | 7B-E | 8 | 2005-09 | Drop In |
| Air Liquide | Netherlands | 6B | 1 | 2006 | Drop In |
| Optim | Texas, USA | 7E | 5 | 2006-07 | Conversion |
| NRG | Texas, USA | 7EA | 2 | 2007 | Drop In |
| PDO | Oman | 6B | 2 | 2007 | Drop In |
| Dalkia | France | 6B | 1 | 2007 | Drop In |
| Tate & Lyle | France | 6B | 2 | 2007-09 | Drop In |
| Air Products | Texas, USA | 7EA | 1 | 2008 | Drop In |
| NV Energy | Nevada, USA | W501B6 | 4 | 2008-09 | Conversion |
| Vattenfall SP | Germany | 6B | 1 | 2009 | Drop In |
| AES Elsta | Netherlands | 9E | 3 | 2009-10 | Drop In |
| BlueSky, CPU | China | 9E | 2 | 2011-12 | Conversion |
| Tampeeren | Finland | 6B | 1 | 2011 | Drop In |
| NRG Petronova | Texas, USA | 7E | 1 | 2012 | Conversion |
| WFEC | Oklahoma, USA | 7E | 1 | 2012 | Conversion |
| Helsingor | Denmark | 6B | 1 | 2012 | Conversion |
| GasCo | Abu Dhabi UAE | 6B | 1 | 2013 | Conversion |
| Hunstman Chem | Port Neches, TX | 6B | 1 | 2014 | Conversion |
| MPC- Henneng | China | 9E | 1 | 2014 | Conversion |
| NRG - Gilbert | NJ, USA | 7B | 4 | 2014-15* | Conversion |
| AEP-Comanche | Oklahoma, USA | W501B6 | 1 | 2015* | Conversion |
| 25 | | | 68 | | |



**Technology Platform – 1.2 Million+ fired hours and 9000 Starts**

# Agenda

- NOx, CO & Combustion Fundamentals
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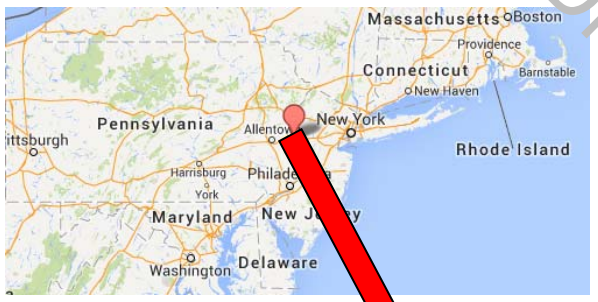
# Fr 7B Conversion Case Study

## Frame 7B LEC-III® Combustion Conversion




## Overview

- Combined Cycle Facility
- 4 x Frame 7B's GT's - CC or SC
- Began operation in 1974
- Units measured at (with water injection):
  - ~35 ppm NOx
  - 20-100 ppm CO
- HEDD Ruling : (High Energy Demand Day) Likely to close older peaking units due to tighter emissions cap

## Scope

Frame 7B Conversion to ultra low Nox

- Replace combustion system
- Remove liquid fuel system
- Remove water injection system
- Controls (Ovation) upgrade

# Fr 7B Conversion Case Study

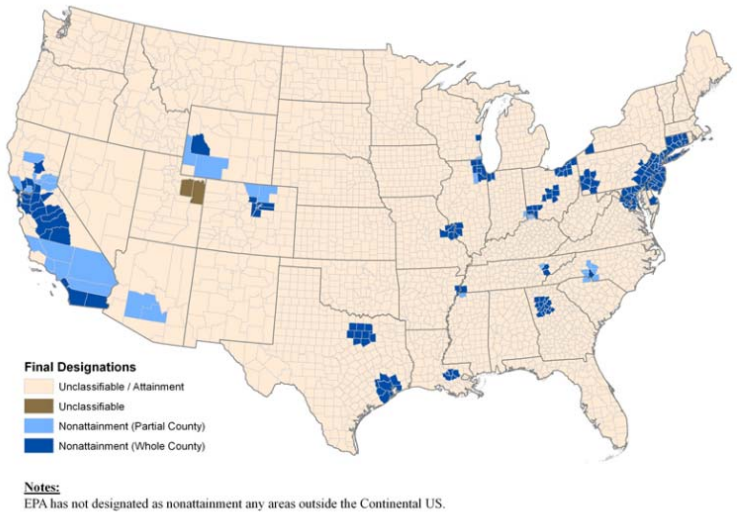
## High Electric Demand Day (HEDD)

Peaking plants typically cause elevated ozone concentrations in the following conditions:

- Elevated Temperatures
- Elevated Electricity Demand

HEDD restrict NOx Emissions on hot days

- Older units only profitable on hot days
- Older units would be limited to cold day operations




Nonattainment Areas for 2008 Ozone Standards

Source: EPA
http://www.epa.gov/ozonedesignations/2008standards/final/finalmap.htm

**Peaking Plants Must Reduce Emissions**

Source: https://www1.eere.energy.gov/wip/solutioncenter/pdfs/tap_webinar_20080717_mcnevin.pdf

# Conversion Project Scope

**Combustion System**

- Remove Diffusion Flame – Dual Fuel
- Install LEC-III® Combustion System – Gas Only



Old

New

# Conversion Project Scope

**Fuel Delivery System**

- Removal of Water Injection & Fuel Oil Systems
- New gas skids
- New Fuel Manifolds



Old

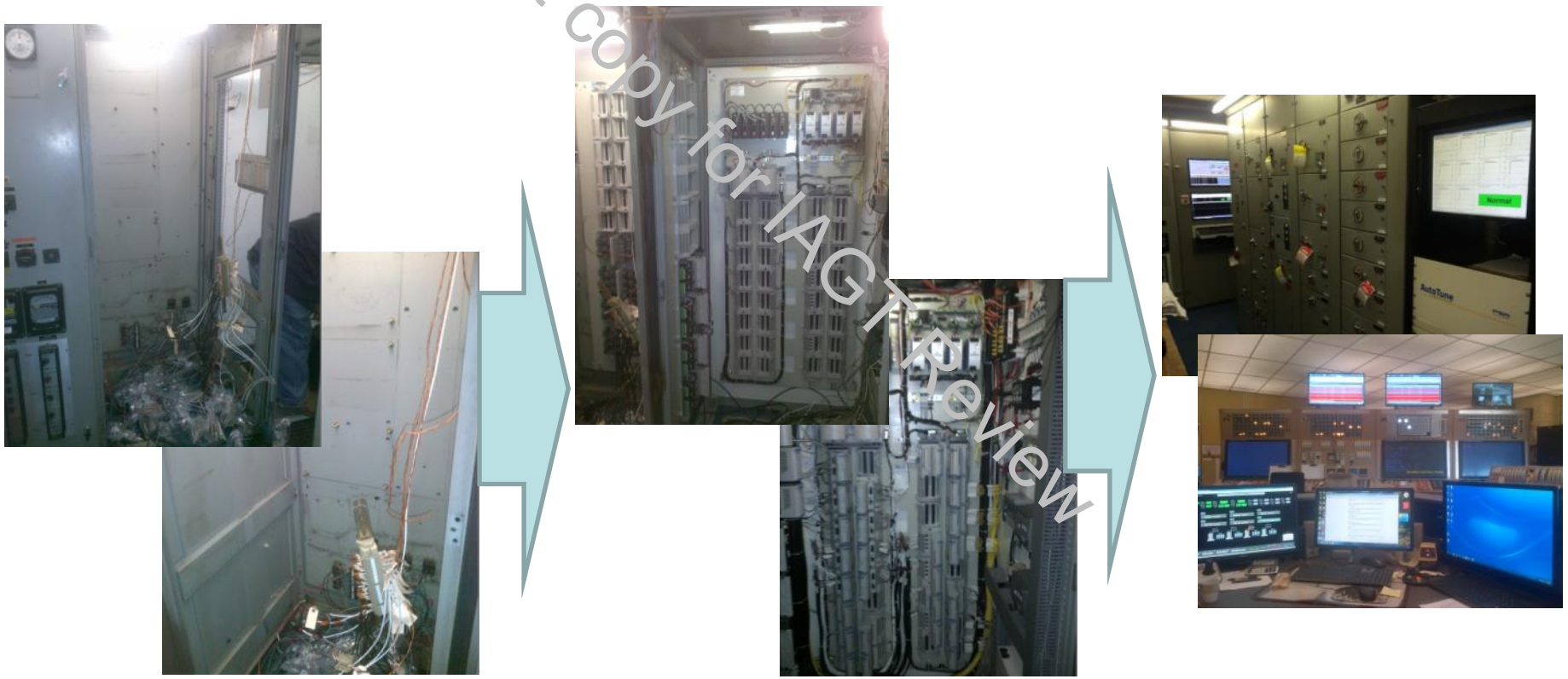
New

# Conversion Project Scope

## Control System

- Upgrade of Control System to Ovation™ platform
- New HMI in Control Room

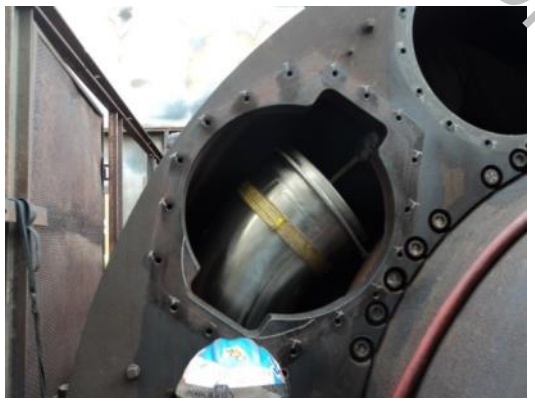




# Conversion Project Scope

## Conversion Complete





New

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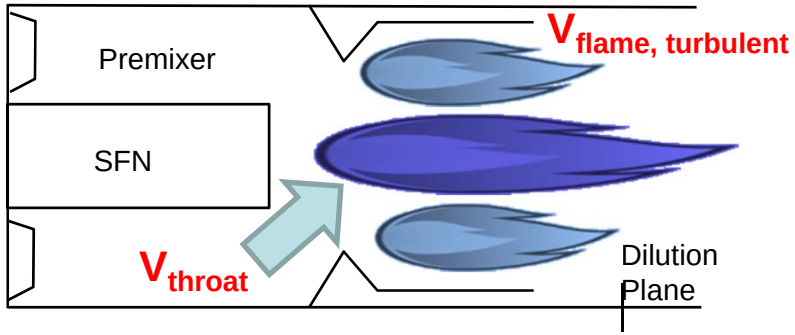
# Challenges – Flashback avoidance

- **Flashback avoidance:**
  - Flame flashback into the premixer prevented by maintaining:

$$V_{throat} >> V_{flame,\ turbulent}$$

Premix Burning (LEC-III® or DLN-1)




  - LEC-III® hardware previously used for 7B/E and 7E/EA units
  - 7B running conditions decreases $V_{throat}$ due to lower:
    - compressor air flow
    - compressor discharge temperature
  - Flashback was identified as a risk item early on in the project
  - 7B compressor pressure ratio was found to be lower than the 7E/EA
    - Net effect is 7B $V_{throat}$ to $V_{flame,\ turbulent}$ ratio similar to 7EA

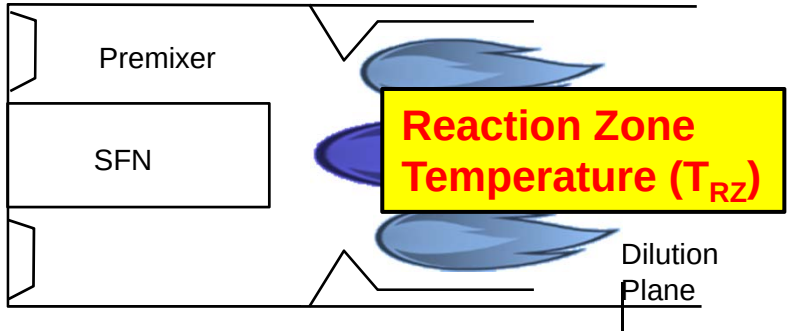


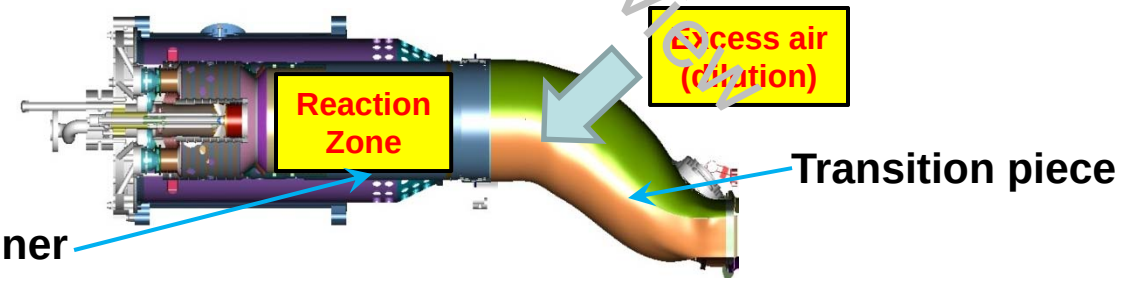
**Flashback was a risk item, mitigations were ready but not needed**

# Challenges – Dilution air injection

- **Dilution air injection:**
  - LEC-III® Reaction Zone Temperature ($T_{RZ}$) precisely set by:
    - Dilution air hole sizing
  - Allows exact tuning to $NO_x$ and CO emission targets
  - 7B $T_{RZ}$ target similar to previous 7B/E and 7E/EA applications
  - 7B lower firing temperature increased the amount of dilution air
  - Needed to identify injection location between the reaction zone region and the exit of the transition piece

Premix Burning (LEC-III® or DLN-1)



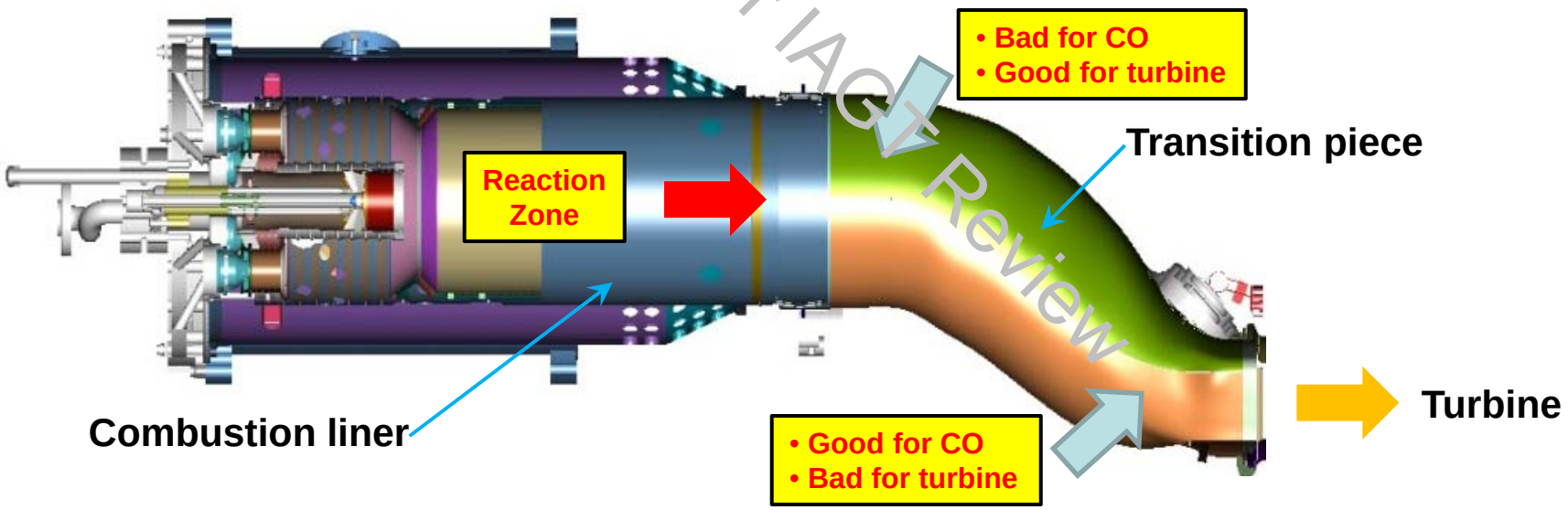




**We have a lot of excess air, where/how are we going to use it?**

# Challenges – Dilution air injection (cont.)

- **Dilution air injection conundrum:**
  - "Early" dilution air introduction
    - After the reaction zone
    - Poor CO characteristic
    - Good turbine inlet profile
  - "Late" dilution air introduction
    - Before the transition piece exit
    - Good CO characteristic
    - Poor inlet temperature profile

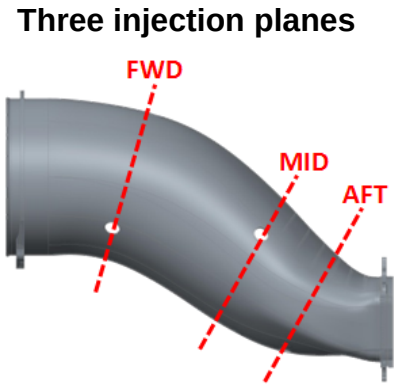


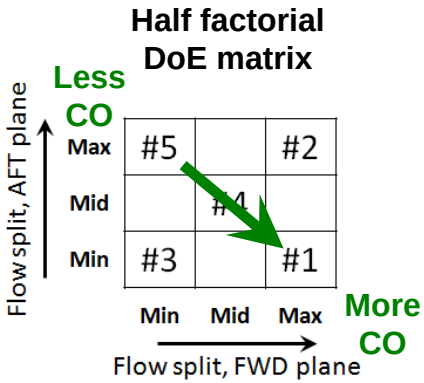


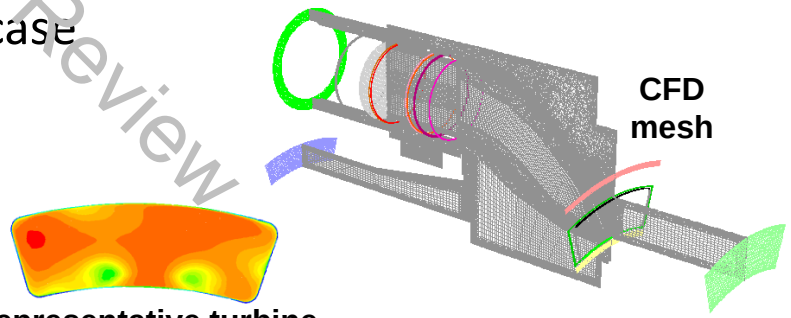

**How do we balance CO requirement and turbine life?**

# Solving the conundrum

- **Engineering approach:**
  1. Design of Experiments Used
     - Three injection planes defined on transition piece flowpath
     - Hole locations selected in known low stress regions
  2. Available air flow split according to a ½ factorial matrix (five cases)
  3. Five CFD runs performed to derive turbine inlet temperature
  4. Impact on turbine assessed for each case
  5. CO impact estimated for each case
  6. Final decision on dilution scheme




Representative turbine inlet temperature profile

**Sturdy DoE approach, turbine life and CO requirement balanced**

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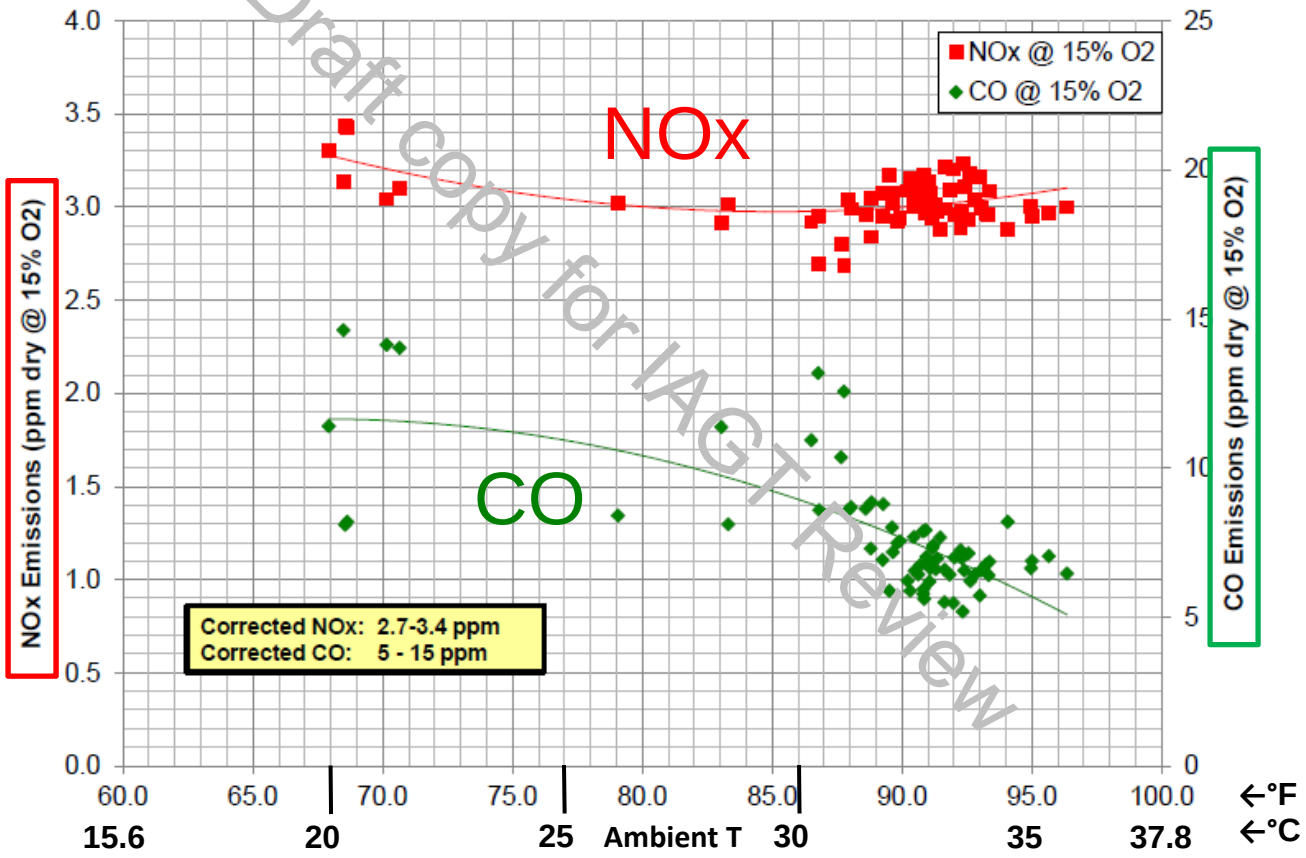
# Fr 7B – Conversion 1st Results

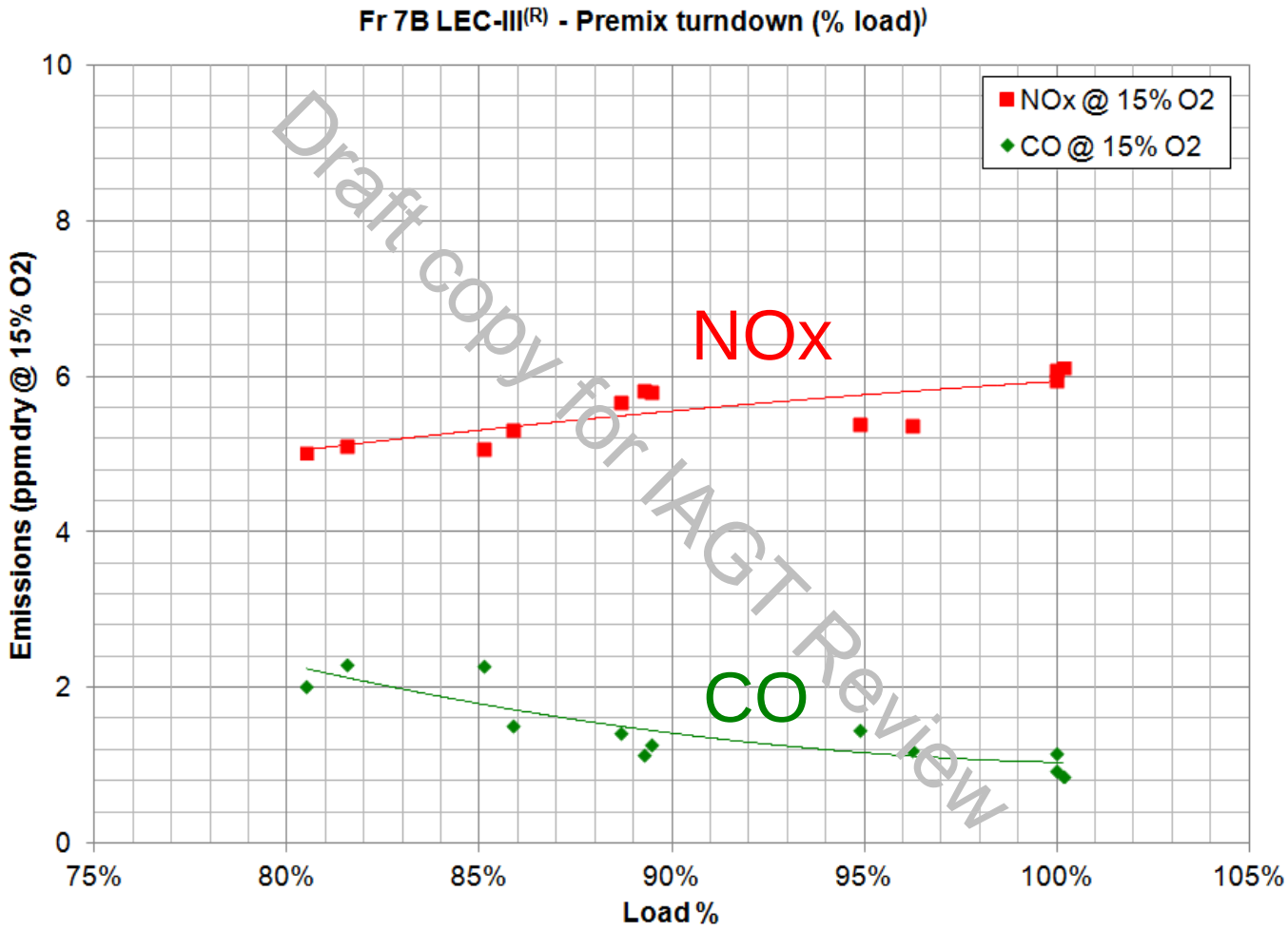
**First installation @ Baseload, across ambient temperature**

Firing temperature remains at 1005°C (1840°F)




**NOx: 35 ppm to <4 ppm | CO: 20-100 ppm to <15 ppm**

# Fr 7B – Conversion Final/Typical Results




**NOx: 35 ppm to 6 ppm | CO: 20-100 ppm to <3ppm**

# Summary

- Proven: Frame 7B Ultra Low Emissions Combustion System
- Performance: Sub 3-6 ppm NOx & Sub 15 ppm CO

→ No need to upgrade turbine firing temperature or turbine components

- LEC-III ® technology running since 2001
  - Sub 5ppm NOx & Sub 15ppm CO
  - Improved CI's: 24k OH or 900 Starts

- Platform Technology: Across multiple OEM's

- Control System Independent: (Mark, Ovation, Triconix, WDPF)