Low NOx Combustor design for $\eta > 65\%$ CC

>> Project Overview
Low NOx Combustor Design for $\eta > 65\%$ CC

Program Overview

Content of Today’s Presentation

1. Towards a 65\% CC Efficient Power Plant
2. Enablers & Challenges for Low NOx Combustion
3. Combustion Technology Development
4. Conclusions & Next Steps
Towards a 65% CC system

DOE targets are driving a step change in GT combustion technology
Towards a 65% CC system

>65% CC efficiency targets Firing Temperature > 1700ºC

**Brayton Cycle**
- Plant output and efficiency improved by raising the top of the cycle
- i.e. Higher firing temperature and pressure.

**Rankine Cycle**
- Plant output and efficiency improved with better utilization of GT Exhaust energy.
- i.e. Higher bottoming steam temperature and pressure.

Source: Ibrahim et. al (2012)
Combustion Technology “jumps” are required to shift NOx curve right
Enablers: Decrease CCLA
Combustion Cooling & Leakage Air

How it works
- TIT needs to be fixed to meet performance
- Air used for cooling is used in combustion instead
- Lower equivalence ratio
- Lower NOx
  → Limited by material temperatures

Decrease CCLA → Lower Flame Temperature → Better emissions
Enablers: Increase Premixing Quality

How it works

- Uniform mixing in combustion process
- Avoid local “hot spots” in the combustion process
- No local flames at high equivalence ratios
- Lower NOx
  → downside is combustion dynamics

Increase premixing → Avoid Hot Spots → Better emissions
Enablers: Decrease Residence Time

How it works

- Decrease time of hot gases in the combustion chamber
- Hot gases are producing NOx
- Lower NOx

→ Limit set by time needed for complete combustion

Decrease residence time → finish reactions quickly → Better emissions
Siemens Solution to Program Challenge: Combustion Development

Enablers

- Lower CCLA

Lower cooling air consumption allows lower flame temps for fixed TIT
Siemens Solution to Program Challenge: Combustion Development

**Enablers**

- Lower CCLA
- Increase premixing quality
- Decrease residence time
- Diluents

**Residence time reduction & premixing allow lower NOx at flame temperature**

State of the Art Premixed Combustor

Advanced premix

Low residence time

Advanced Combustion System

Ideal Premixer
Siemens Solution to Program Challenge: Combustion Development

Enablers
- Lower CCLA
- Increase premixing quality
- Decrease residence time
- Diluents

Technology Challenges
- Decrease Cost
- Life (metal temperatures)
- Thermoacoustic stability
- Turndown
- Fuel Flexibility
- Modeling …!!

Residence time reduction & premixing allow lower NOx at flame temperature

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**Objective:**
- Phase 1: Conceptual aero & mechanical design

**Target:**
- Low NOx at TIT > 1700°C to enable for $\eta = 65\%$

**Enablers:**
- Enhanced premixing
- Lower residence time
- Advanced cooling

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**DOE PHASE 1 Concept Feasibility**

- Chemical Reactor Network
- CFD benchmarking
- Thermoacoustics
- Autoignition
- Detailed Mechanical prototype design

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**Conceptual implementation of enablers into 65% CC system**
Emission Potential of Proposed Combustion Technology

Combined Enablers
- Improve combustion premixing level
- Decrease residence times
- NOx at 65% CC conditions becomes a reachable target

Low NOx emissions is a realistic target at $\eta \sim 65\%$ TIT’s
Calibrated CRN models used for conceptual system design at phase 1
Modeling: CFD

**Phase 1: Assessment of CFD as a design tool → identify gaps for Phase 2**

**DOE-H2 rig:**

Simultaneous high speed PIV, OH-PLIF and emissions

**Status & Future Work**

- Single JICF model validated with DOE-H2 program data
- RANS & LES
- Compare combustion model and identify calibration parameters
- Assess modeling of mixing in various combustion zones
- Assess run times/cost for various size models

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Low order tools guide conceptual design. High order tools detailed design.

Modeling: Thermoacoustics

### Status & Future Work
- IFD and HFD mode shapes via low order modeling
- Low order unsteady heat release models needed → stability analysis
- Stability inputs used for system optimization needed
- Higher order acoustics needed for detailed design
Status & Future Work

- CH4 not a risk for high pressure ratios (PR)
- Risk of autoignition increases with premixed higher hydro carbons (HHC) in NG
- Correlations differ from each other. More evaluation needed.

No issues identified for pure CH4. Further development needed for HHC
Technology Development Process to develop new burner concepts

- **TRL3**
  - Proof of Concept
  - Labscale test (Universities)

- **TRL4**
  - Technology Feasibility at Engine cond.
  - Full scale test at ATM/HP conditions

- **TRL5**
  - Ready for Component design
  - Full scale test at high-pressure

- **TRL6**
  - Engine Ready Design Test
  - Full scale test at engine conditions

**COST + Validity**

**Feedback from test results → starting iteration loop**

**Simulation tools for transferability between test configurations**

**Increasing TRL level increases testing fidelity and expense**
## Development needs for a Phase 2

<table>
<thead>
<tr>
<th>Model</th>
<th>Application</th>
<th>Areas of Opportunity / Needs</th>
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| Chemical Reactor Network | - System aero design  
- Emission prediction                | - Mixing in flame area needs to be calibrated with experimental data  
- Need data sets that provide **mixing/emissions**                                      |
| CFD                  | - Parametric system aero design  
- Heat transfer  
- Detailed component aero design  
- Thermoacoustic prediction | - Combustion models need to be calibrated with experimental data (include strain)  
- Need data sets that provide **steady and unsteady** flame visualization |
| Thermoacoustics      | - Low order: system design  
- High order: component design | - Need advanced **$q'$ models** related to flow physics  
- Continue work on **self excited LES**                                              |
| Autoignition         | - Assess system operational limits                                      | - Need **better correlations** for NG with HHC (and FO)  
- Limited experimental data sets available                                               |

**Conceptual design → Phase 2 will require significant university collaboration to achieve targets**
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Thank You. Questions?

J. Enrique Portillo
Program Manager - DOE Low NOx Combustor Design for 65% CC
Energy / America / Materials & Technology

4400 Alafaya Trail
Orlando, FL 32826

Phone: +1 (407) 736-2000

E-mail: juan.portillo@siemens.com
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