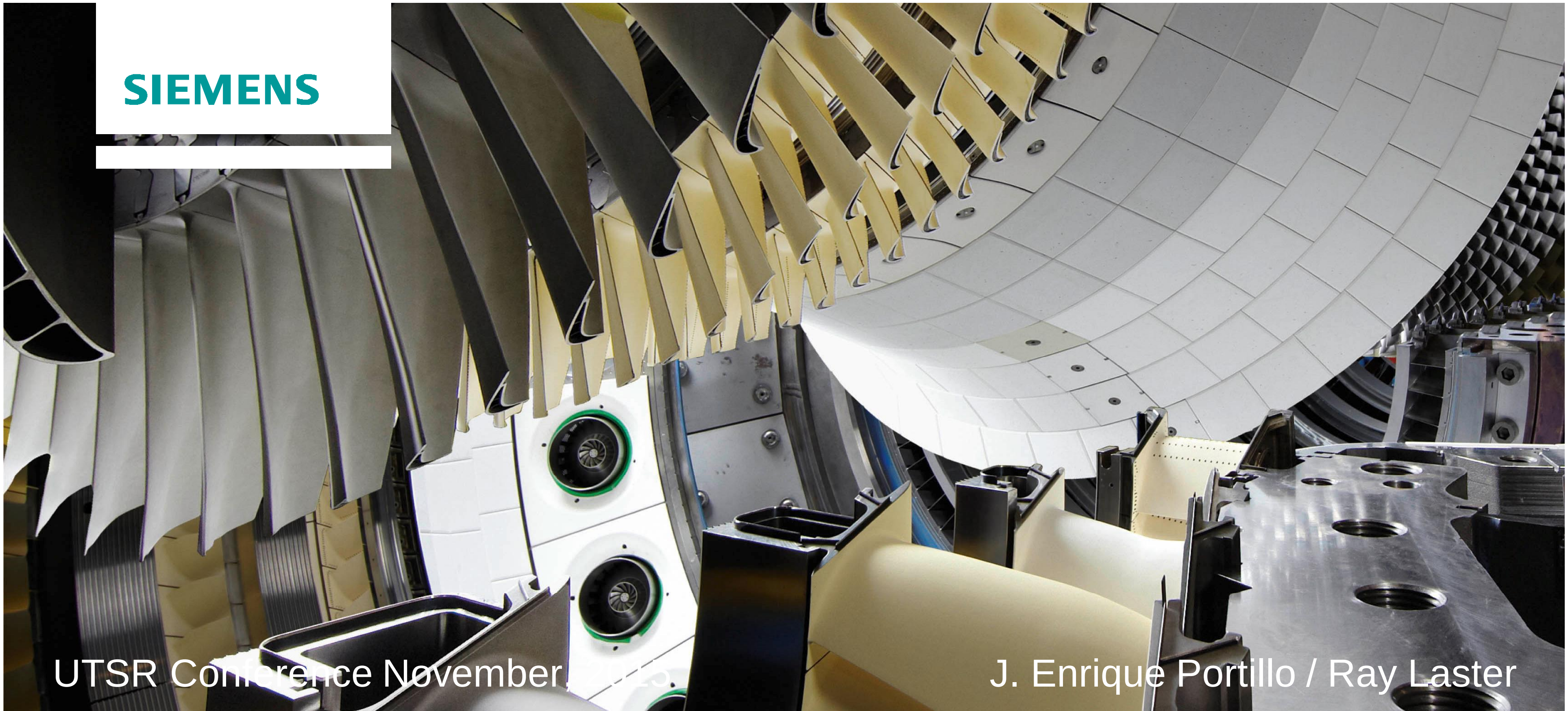

UTSR Conference November, 2015

J. Enrique Portillo / Ray Laster

Low NOx Combustor design for η > 65% CC

>> Project Overview

http://siemens.com/energy/power-generation/gas-turbines

Low NOx Combustor Design for η > 65% CC Program Overview

Content of Today's Presentation

Towards a 65% CC system

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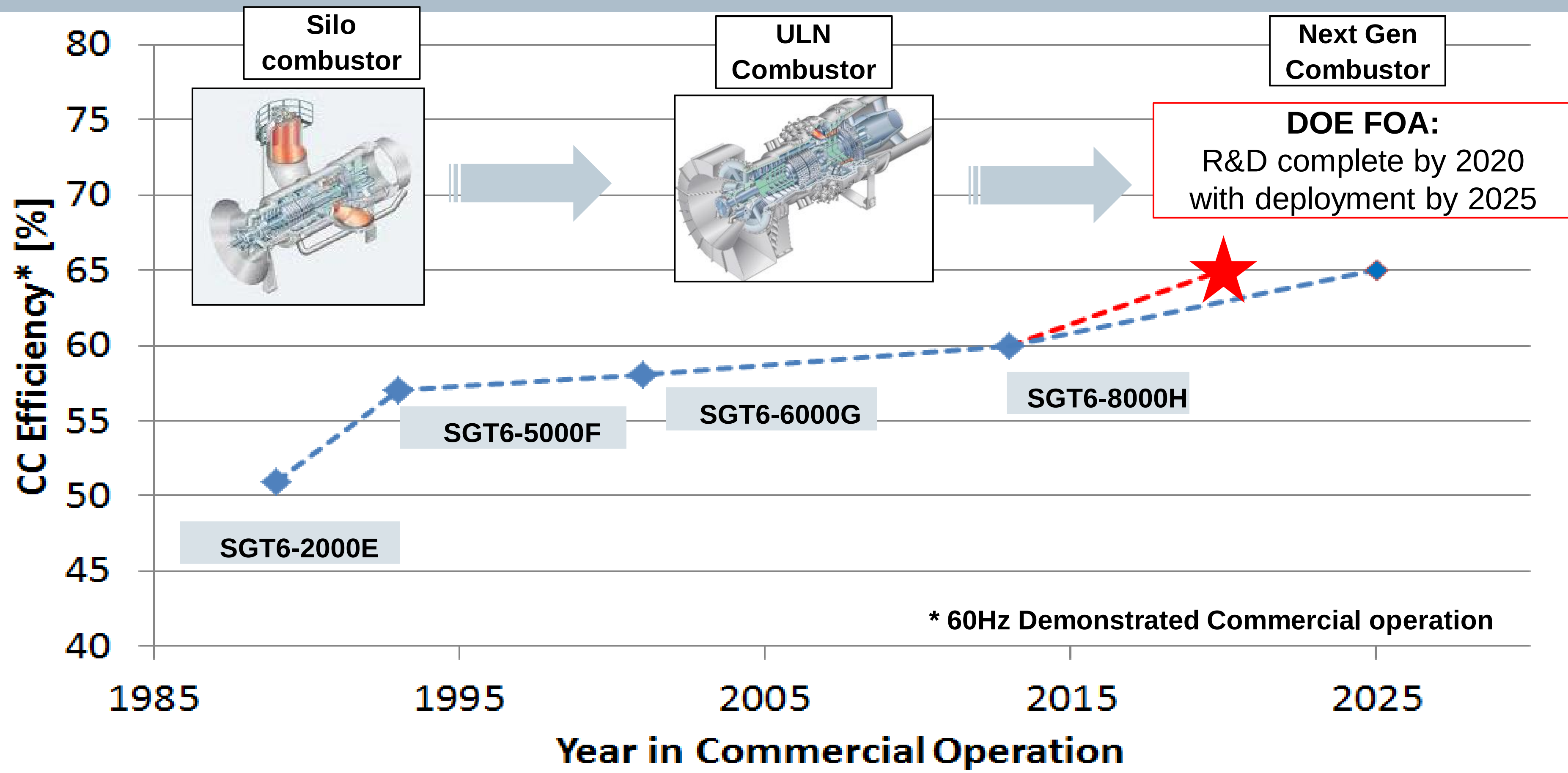
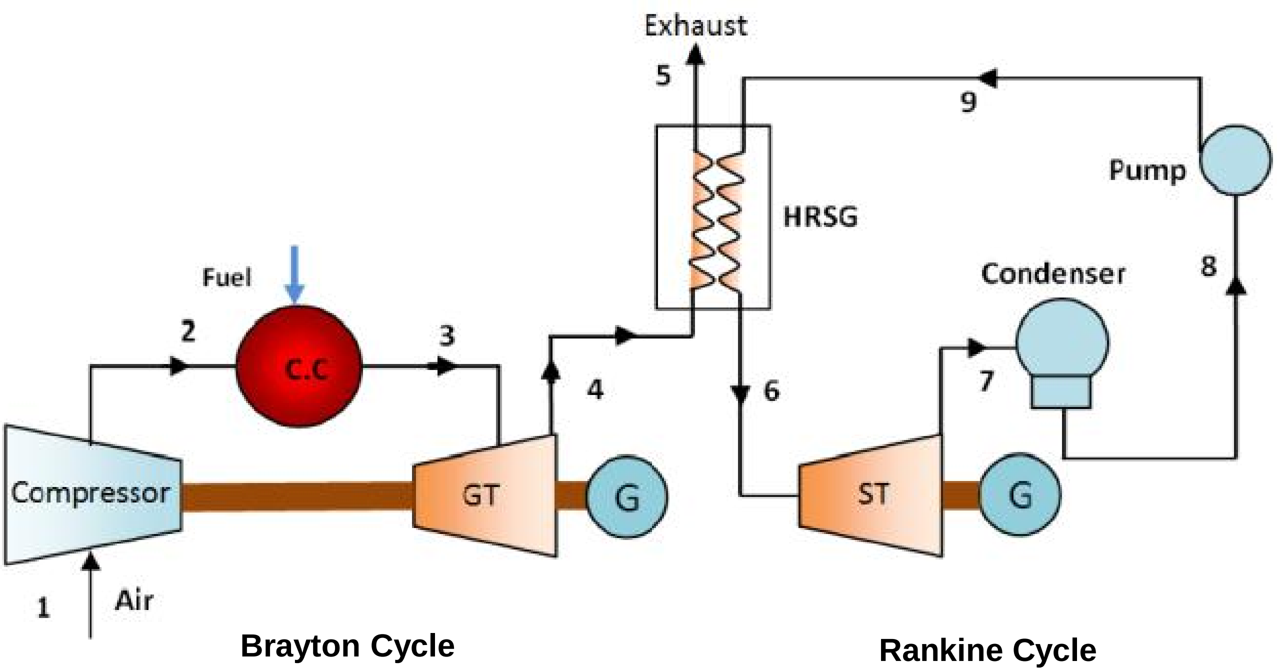


DOE targets are driving a step change in GT combustion technology

Towards a 65% CC system



Source: Ibrahim et. al (2012)

Brayton Cycle

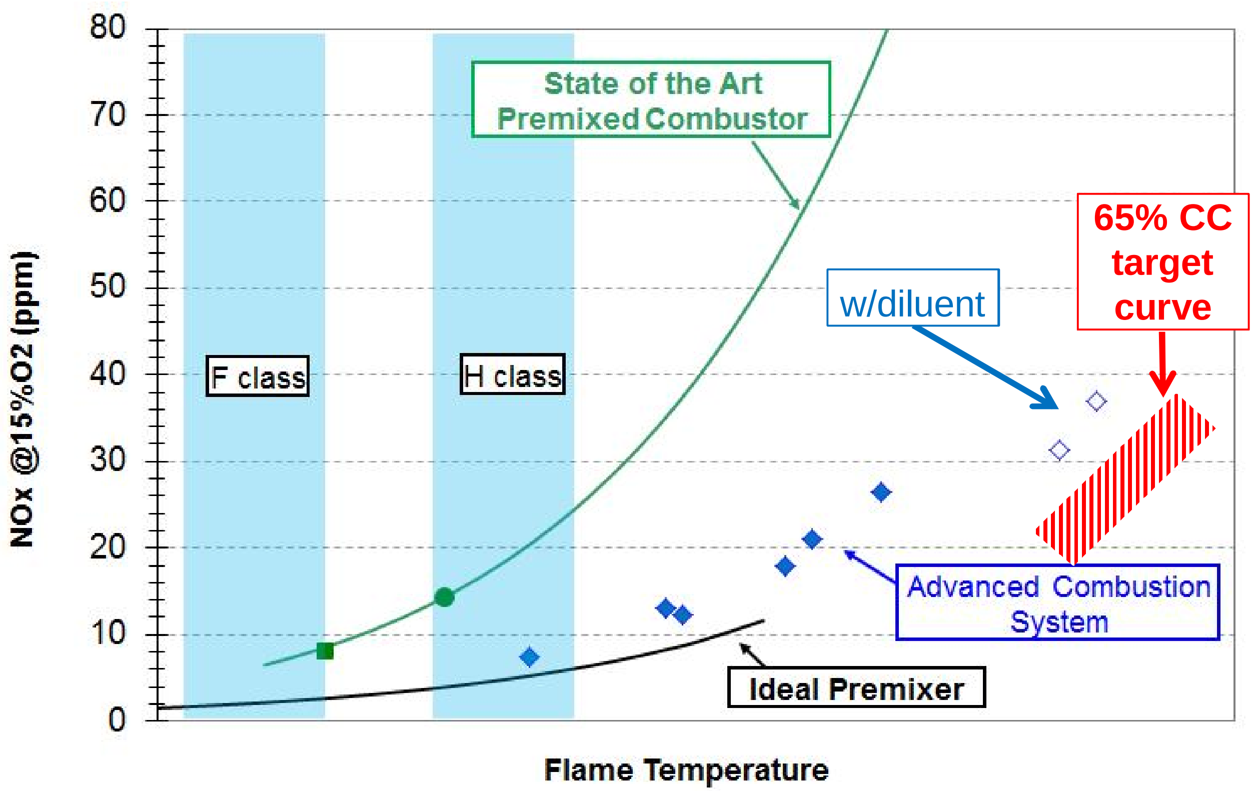
- Plant output and efficiency improved by raising the top of the cycle
- i.e. **Higher firing temperature** and **pressure**.

Rankine Cycle

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

>65% CC efficiency targets Firing Temperature > 1700ºC

Siemens Solution to Program Challenge: Combustion Development



Combustion Technology "jumps" are required to shift NOx curve right

Enablers: Decrease CCLA
Combustion Cooling & Leakage Air

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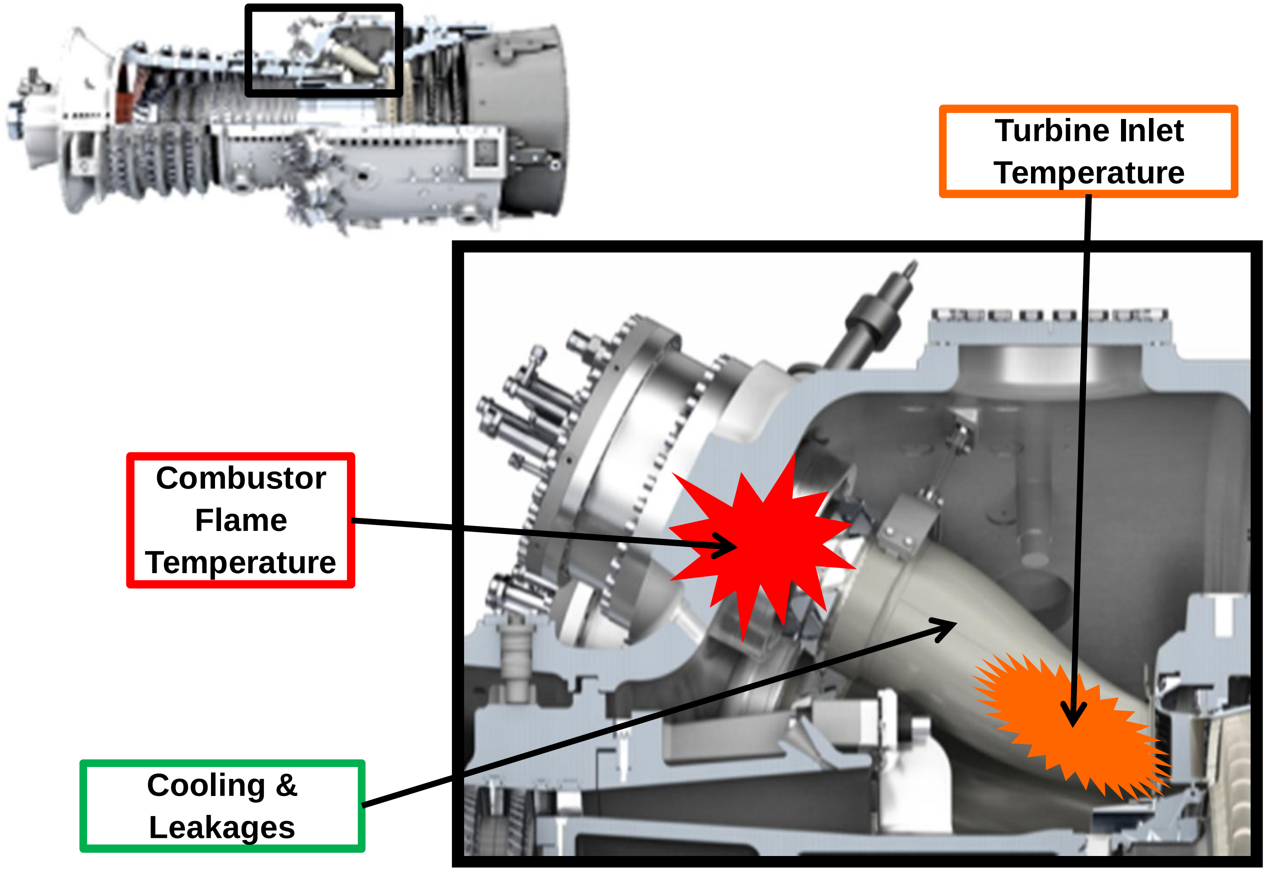

How it works

- 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

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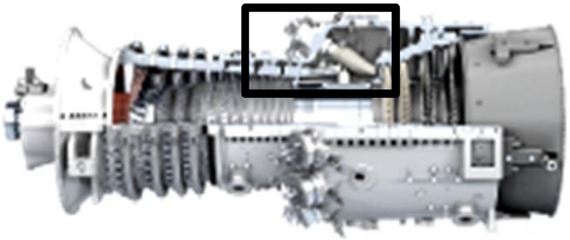
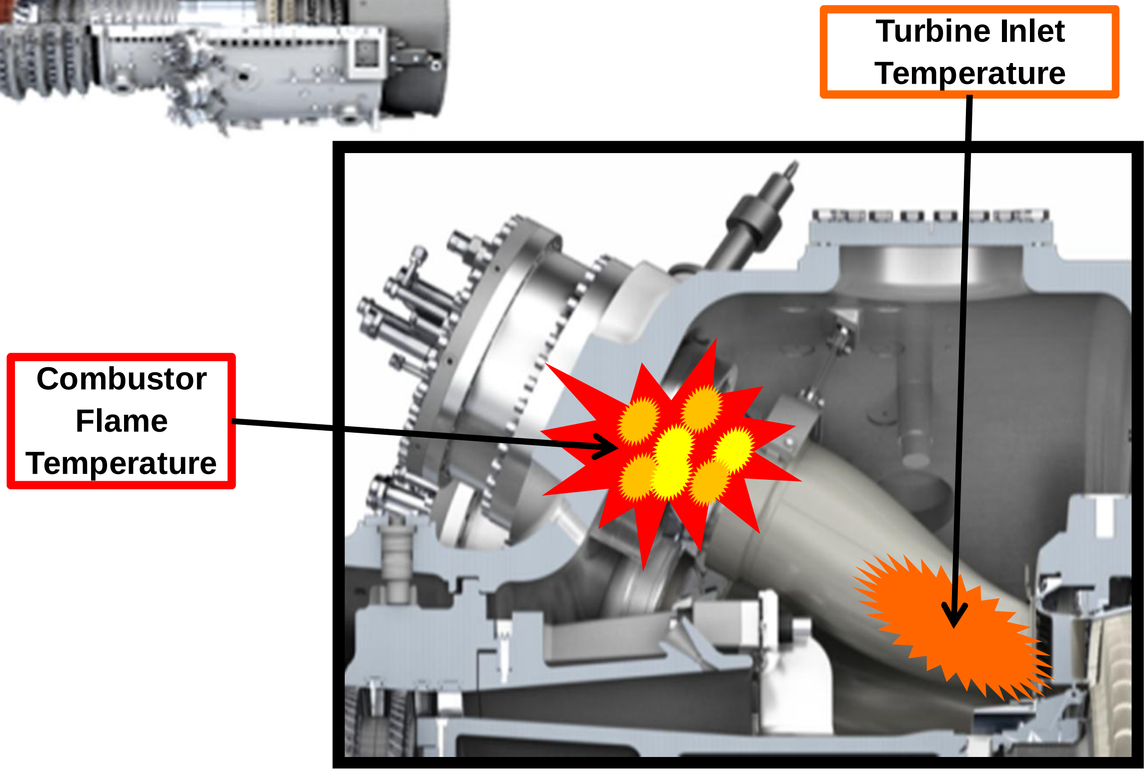




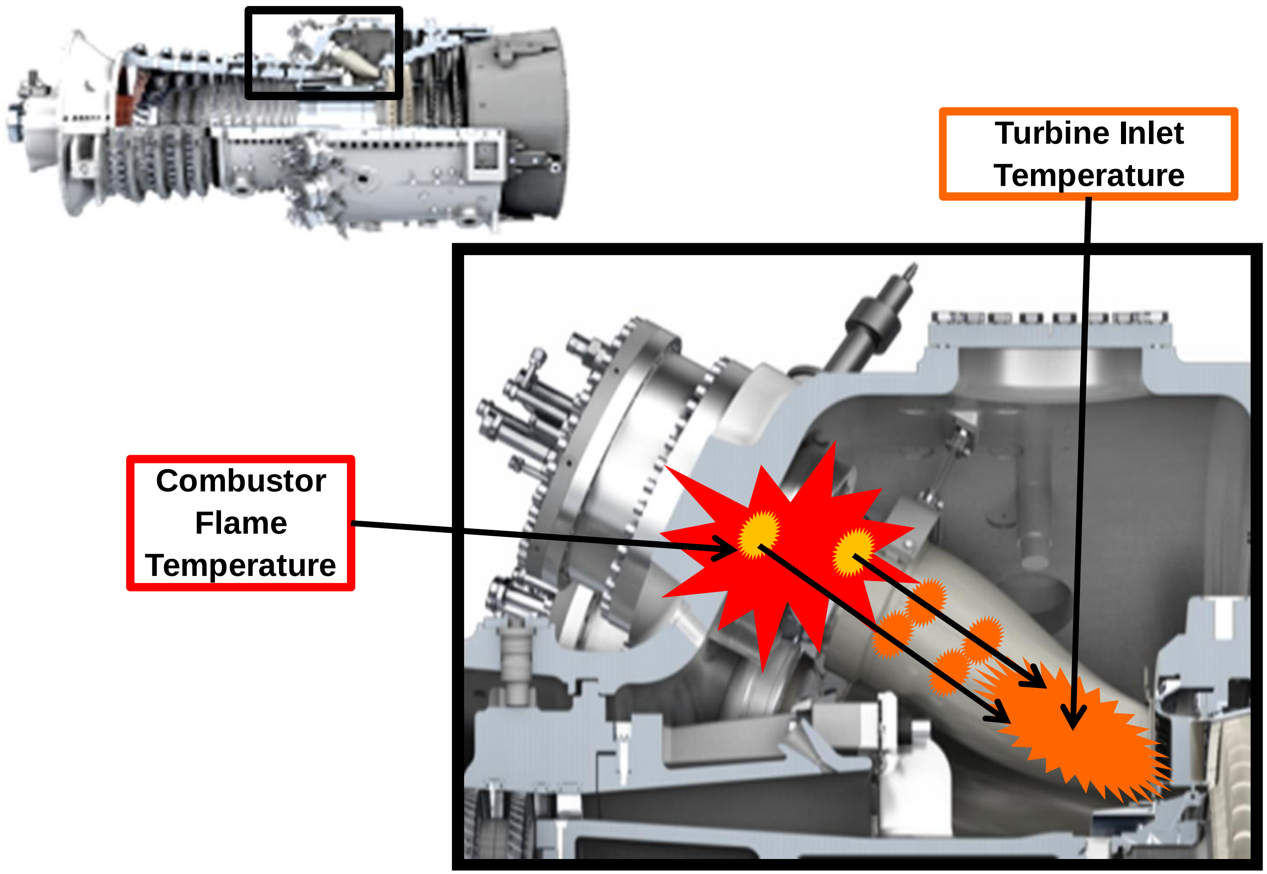
How it works

- 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

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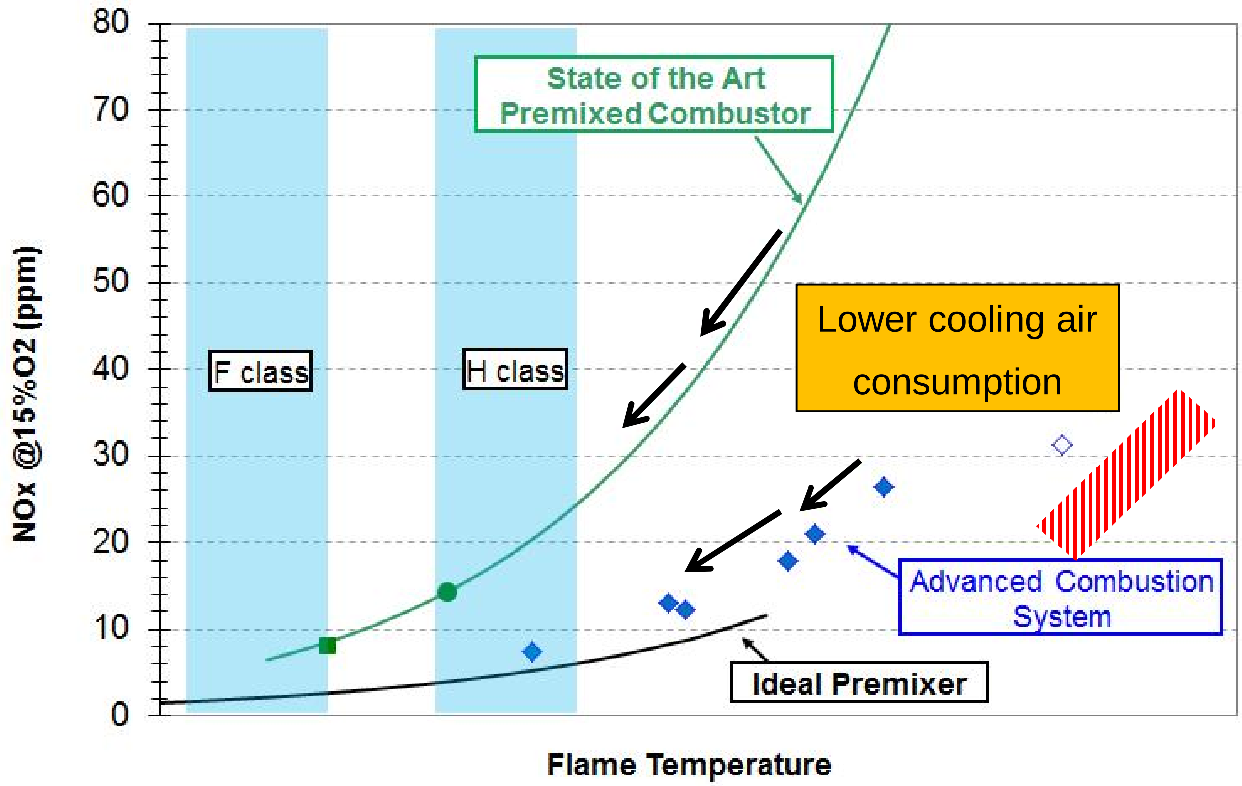
Enablers

- Lower CCLA



Lower cooling air consumption allows lower flame temps for fixed TIT

Siemens Solution to Program Challenge: Combustion Development

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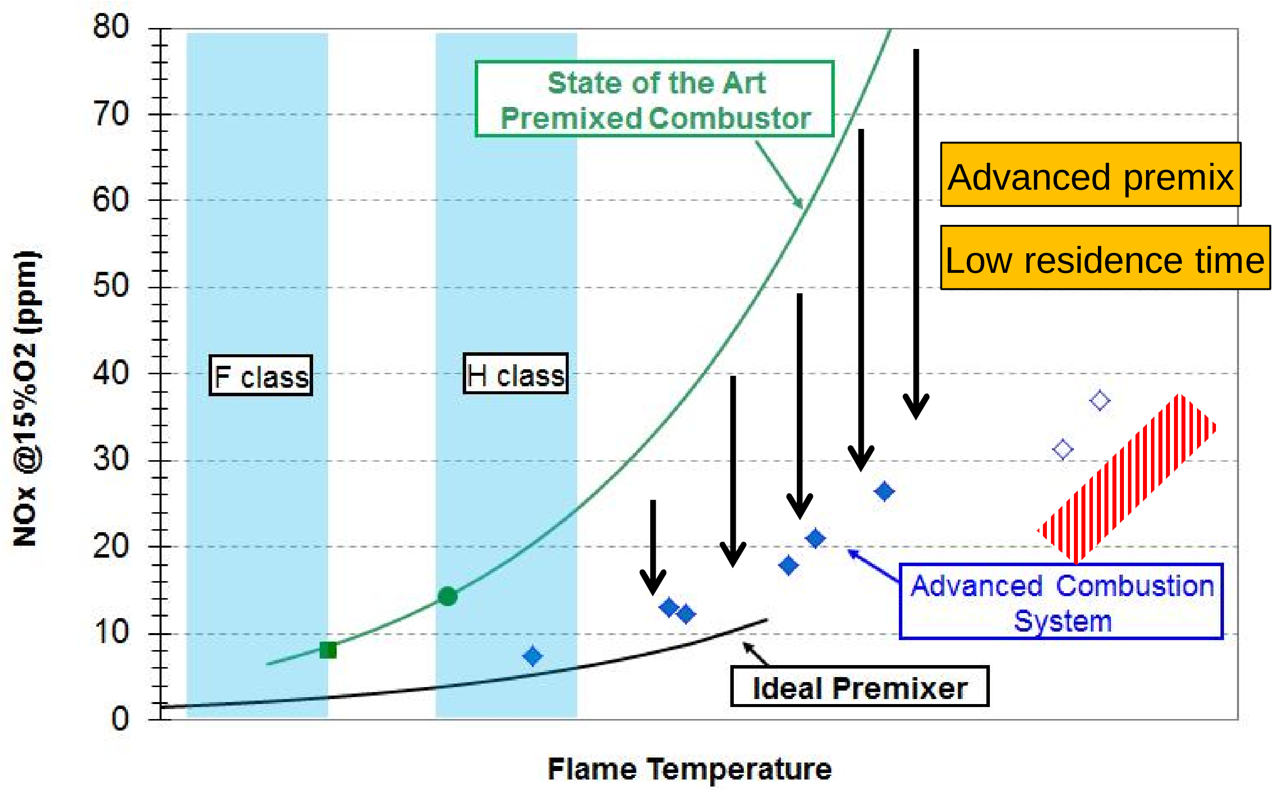
Enablers

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



Residence time reduction & premixing allow lower NOx at flame temperature

Siemens Solution to Program Challenge: Combustion Development

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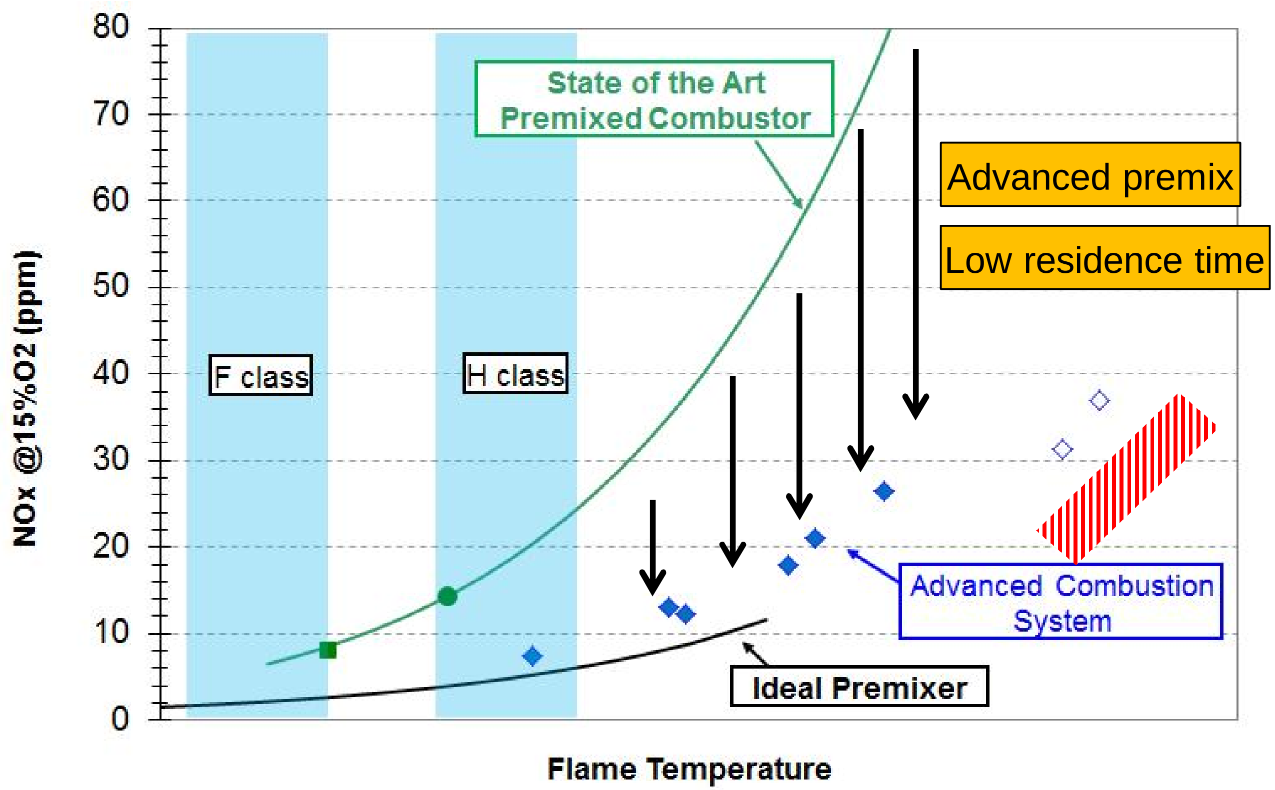
Enablers

- 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

DOE Phase 1 Project

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- **Objective:**
  - Phase 1: Conceptual aero & mechanical design
- **Target:**
  - Low NOx at TIT > 1700ºC to enable for η = 65%
- **Enablers:**
  - Enhanced premixing
  - Lower residence time
  - Advanced cooling

DOE PHASE 1
Concept Feasibility

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

Conceptual implementation of enablers into 65% CC system

Emission Potential of Proposed Combustion Technology

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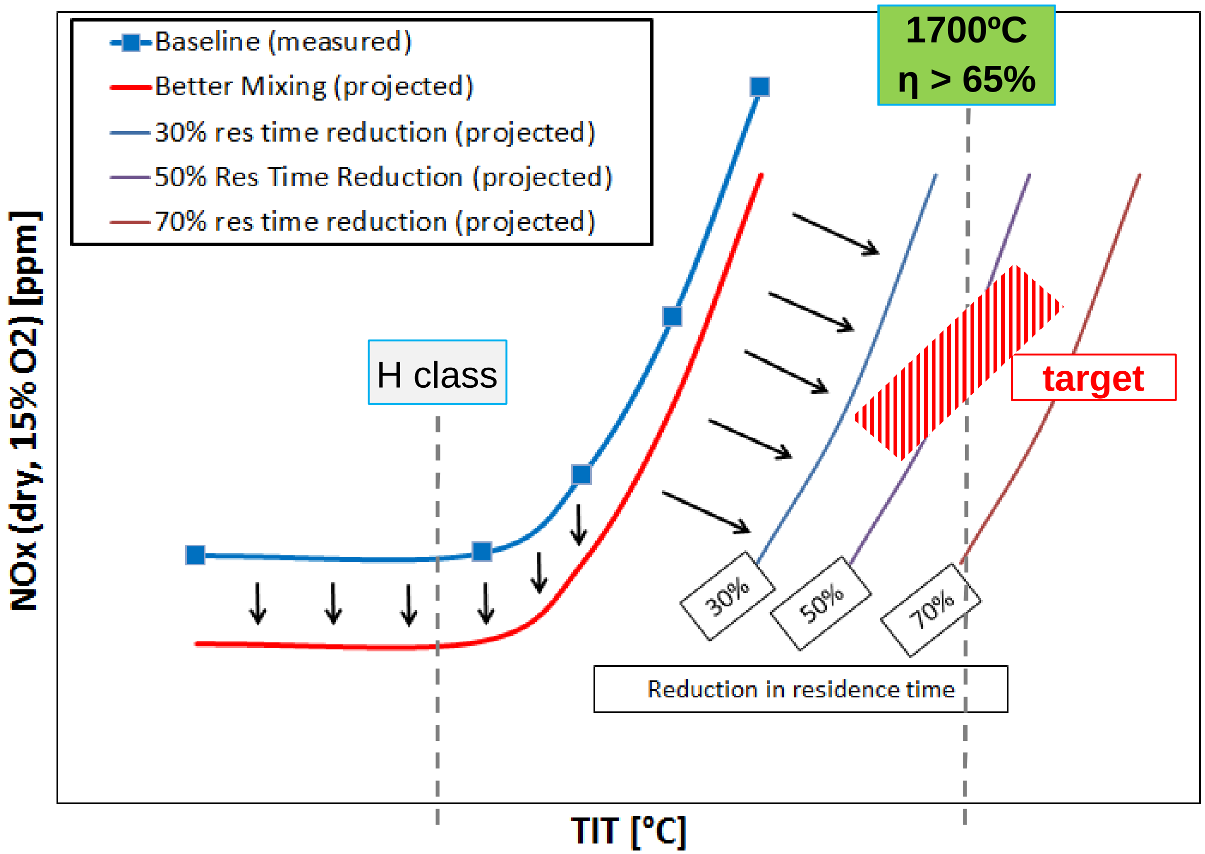
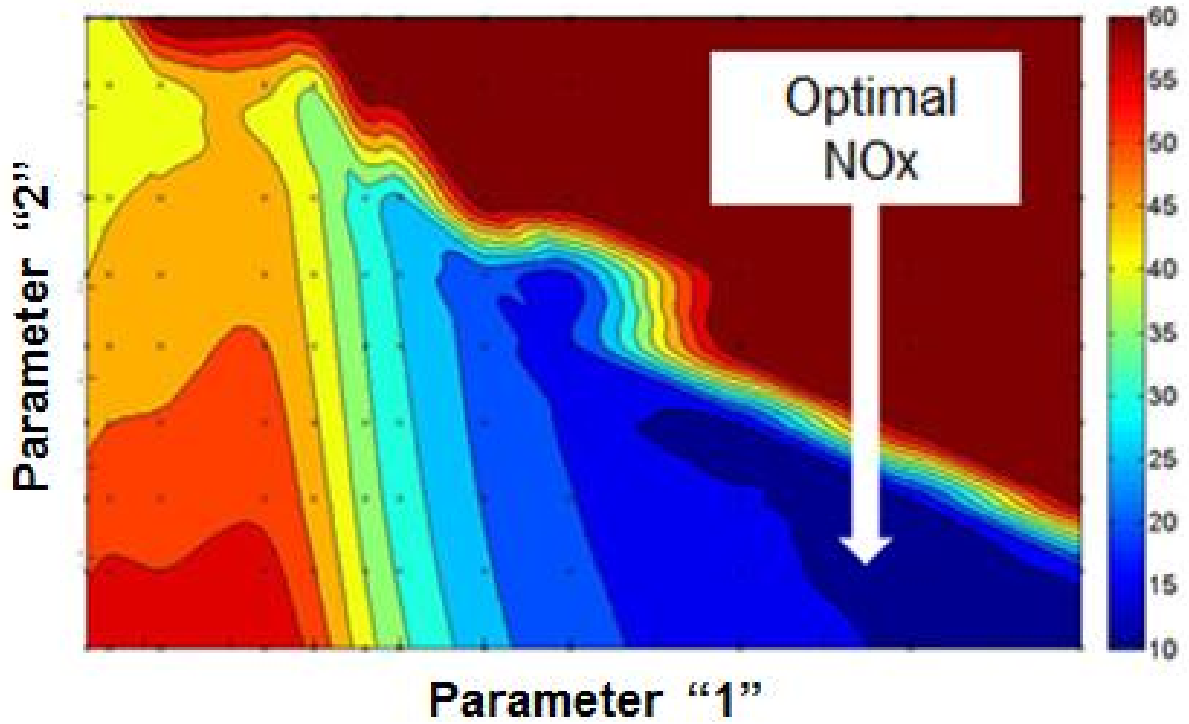


Combined Enablers

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

Low NOx emissions is a realistic target at η~65% TIT's

Modeling: Chemical Reactor Network



Status & Future Work

- Model calibrated with DOE-H2 high pressure test data
- Low order tool that allows large parametric variations
- Applied at system level
- Needs to be calibrated for new technology (need data!)

Calibrated CRN models used for conceptual system design at phase 1

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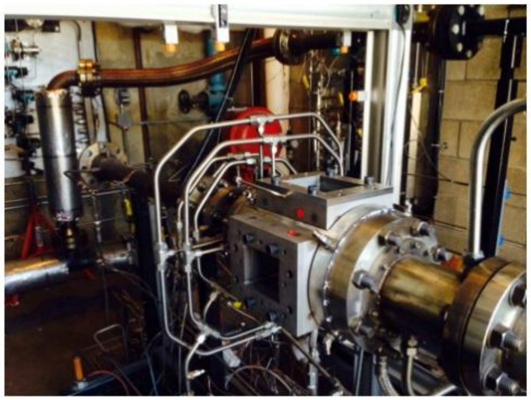
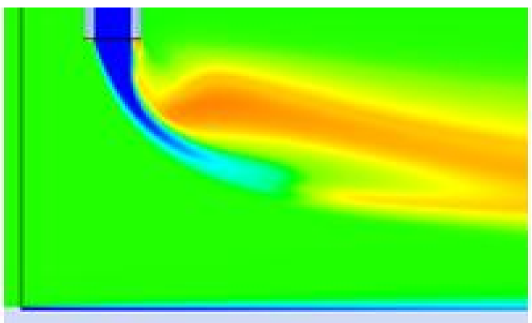
Modeling: CFD

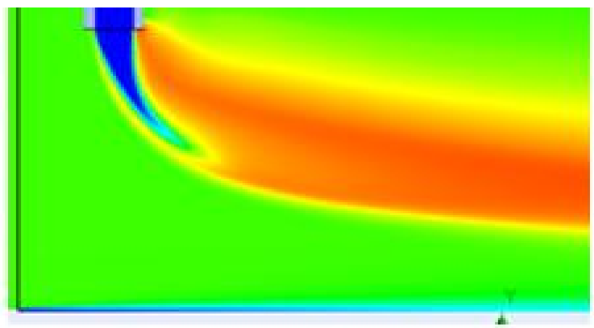


DOE-H2 rig:

Simultaneous high speed PIV, OH-PLIF and emissions



FGM w/ CH4 and



2Step w/ CH4 and

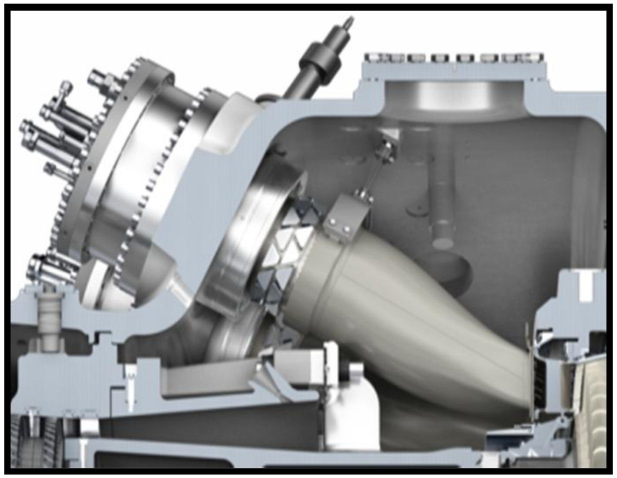
Status & Future Work

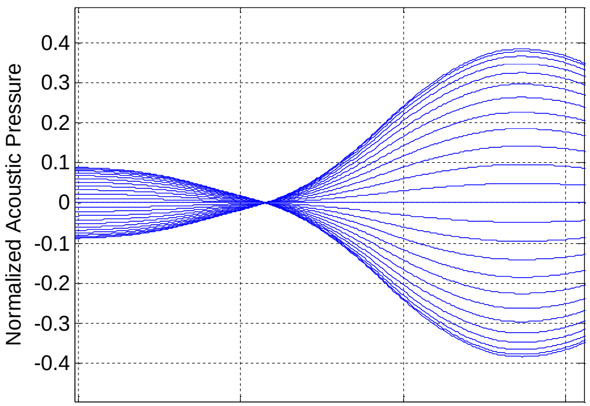
- Single JICF model validated with DOE-H2 program data
- RANS & LES
- Compare combustion model and identify calibration parameters
- Assess modeling of mixing in various combustion zones
- Assess run times/cost for various size models

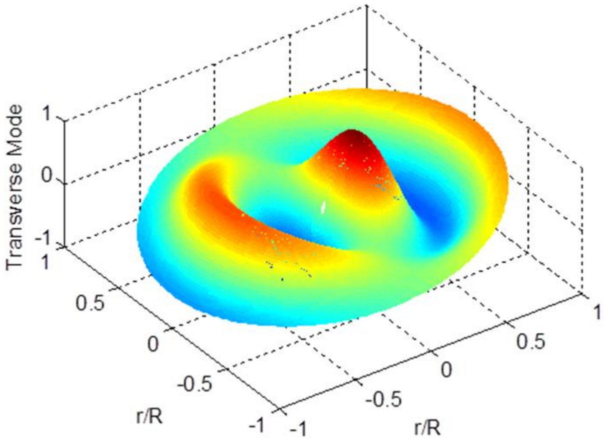
Phase 1: Assessment of CFD as a design tool → identify gaps for Phase 2

Modeling: Thermoacoustics

Longitudinal acoustic modes







Transverse acoustic modes

Status & Future Work

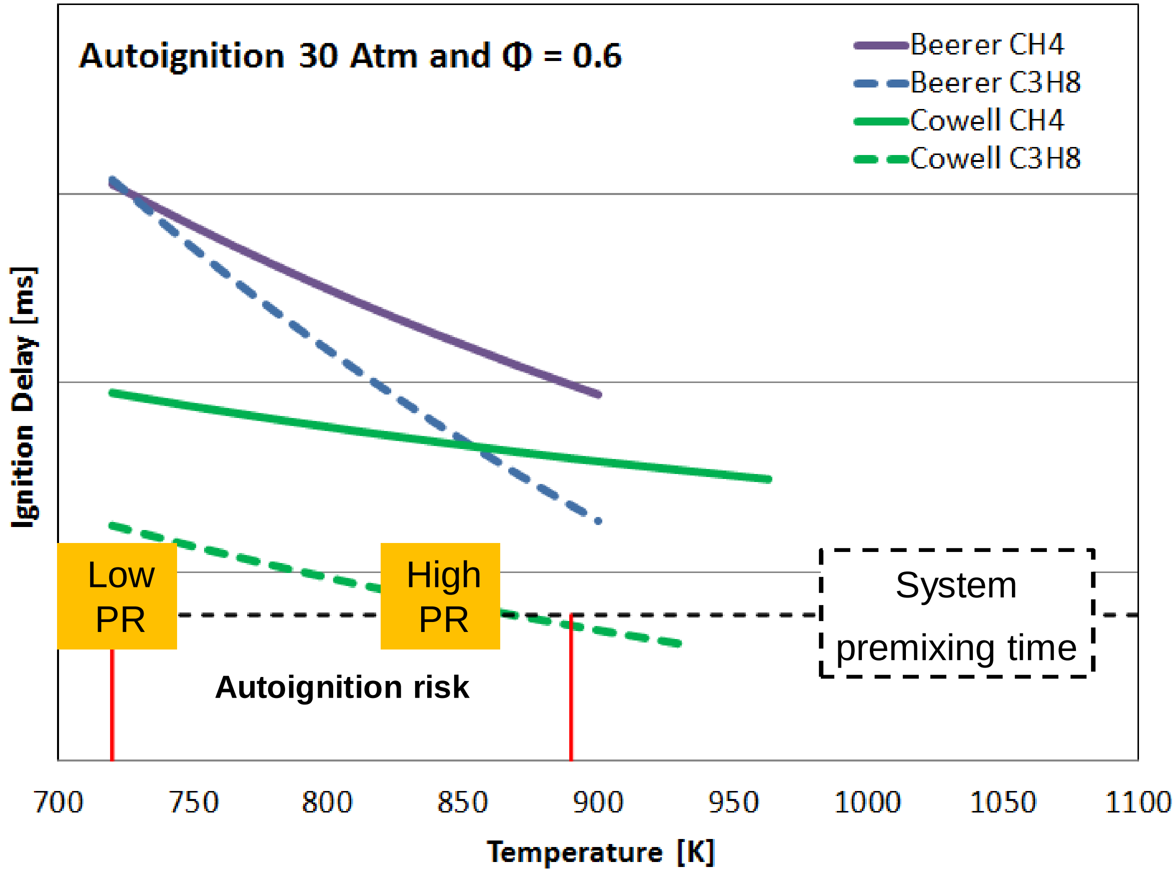
- IFD and HFD mode shapes via low order modeling
- Low order unsteady heat release models needed → stability analysis
- Stability inputs used for system optimization needed
- Higher order acoustics needed for detailed design

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

Modeling: Autoignition

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

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TRL3
- Proof of Concept
- Labscale test Athmospheric conditions

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

TRL5
- Ready for Compnent design
- Full scale test at high-pressure

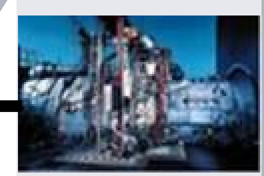
TRL6
- Engine Ready Design Test
- full scale test at encine conditions

COST + Validity

Labscale test (Universities)
- Investigate design hypothesis.
- Flame visualization
- Tool validation

Simulation tools for transferability between test configurations

Full scale High Pressure test (DLR Cologne)
- Screening test at full scale and high pressure.



Engine test
for technology validation

Feedback from test results
→ starting iteration loop

Increasing TRL level increases testing fidelity and expense

Development needs for a Phase 2

Model	Application	Areas of Opportunity / Needs
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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Answers for Energy.

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Thank You. Questions?

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