Modeling Combustion In Pyrolysis Furnaces With Next Generation Low NOx Burners

Brad Adams, Qing Tang, Jinliang Ma
Reaction Engineering International

ACERC Conference

Provo, UT

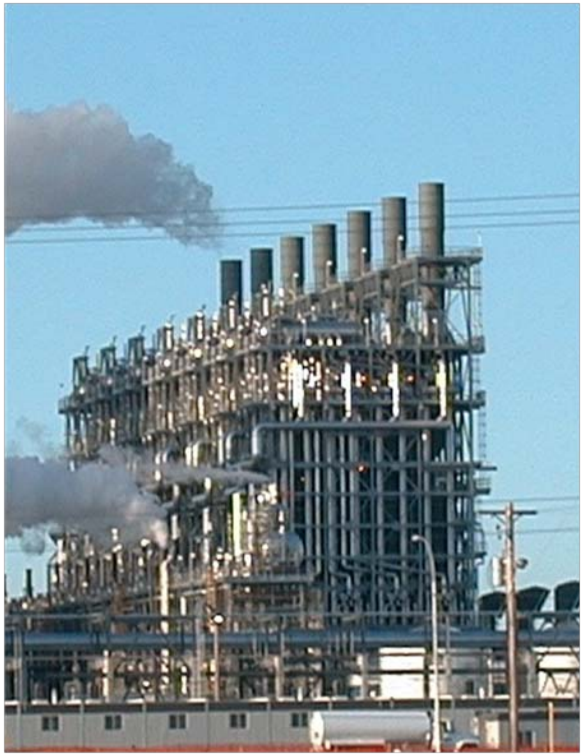
February 26-27, 2008

Acknowledgements

- Dr. David Brown, Shaw Energy & Chemicals (formerly Stone & Webster)
- John Zink Company, LLC
- PTTCH
  - PTT Chemical PLC, Map Ta Phut, Thailand
- National Science Foundation (NSF)
  - SBIR Phase II (DMI-0216590)
  - Program Manager: Dr. Errol B. Arkilic

Ethylene Cracking Furnaces

- Ethylene is major building block in petrochemicals (75 million metric tons per year)
- Key furnace performance issues:
  - Availability
  - Efficiency
  - Emissions (NOx, CO)
- Furnace performance depends on burner performance
  - Burners becoming more complex
  - Often a trade-off between low emissions and flame ‘quality’
- CFD can help evaluate new burner technologies

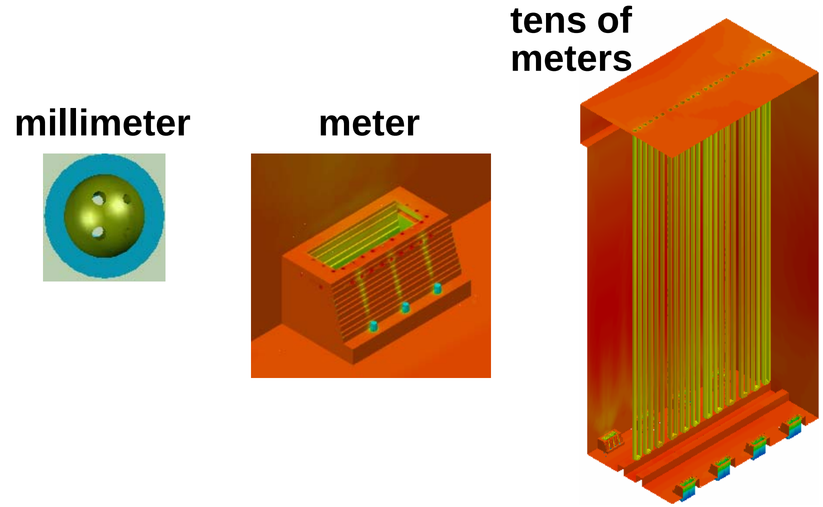


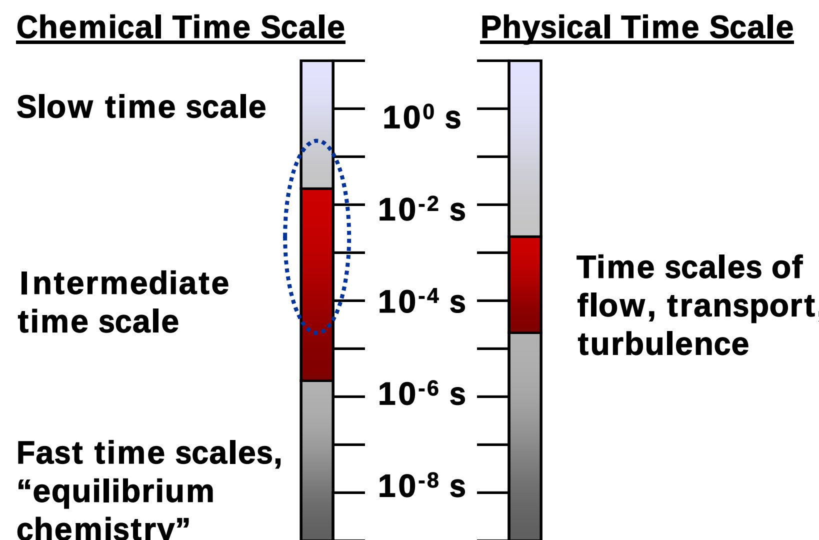
Key Furnace Combustion Elements

- Burners
  - Staged diffusion flames and/or lean premixed flames
  - Multiple fuels and firing rates (turn down)
  - Low NOx emissions (30-60 ppm)
  - Flame profile and emissions are key
- Process coils
  - High radiant efficiency (~45%)
  - Heat flux profile and heating uniformity
- Refractory
  - Limited heat loss (~2-4%)
  - Variable temperature & emissivity

Cracking Furnace Modeling Challenges

- **Scales!**
  - Geometric resolution
  - Jet velocities
  - Chemistry vs turbulent mixing
- **Input accuracy (GIGO)**
- **Trade-off between accuracy and turn-around time**
  - Grid refinement
  - Chemistry accuracy
  - Convergence





Furnace Model Requirements

- **<u>Grid resolution</u> (for detailed burner geometry, fuel jets, multiple fuel mixing zones, process tube heat transfer)**
- **<u>Sub-models</u> for:**
  - **Fuel-lean, premixed, turbulent combustion**
  - **Turbulence-chemistry interactions**
  - **Finite-rate kinetics for ppm-level NOx, CO**
  - **Variable surface properties**
  - **Gas-wall-tube heat transfer**
  - **Fire-side - process-fluid thermal coupling**

- **<u>Computationally efficiency</u> (for optimal run-time and memory usage)**

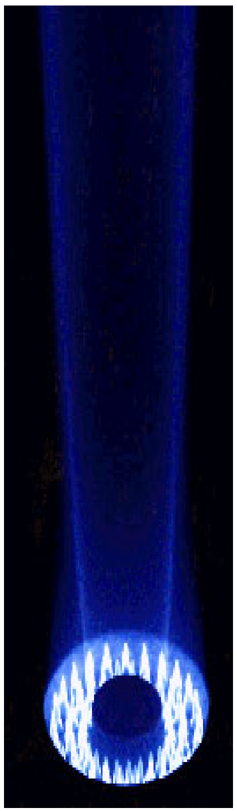
REI Software Evolution

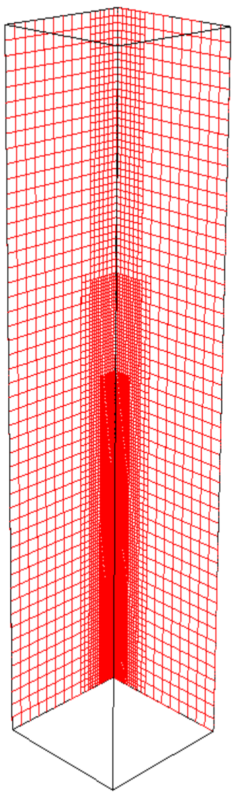
- 1991 ✓ Zone-type model with radiative heat exchange
- 1992 ✓ ***BANFF*** **models with 200,000 computational cells (flame quality, radiation, no NOx)**
- 1995 ✓ ***BANFF*** **models with 500,000 computational cells (flame quality, radiation, some NOx)**
- 2001 ✓ **Fluent-*BANFF* and *BANFF-BANFF* hybrid models with 1M + 800,000 cells (flame quality)**
- 2004 ✓ ***ADAPT*** **code with 1M+ computational cells**
- 2007 ✓ **Refined *ADAPT* code (chemistry, mixing models, turbulence-chemistry models, efficiency)**
- 2008+ ✓ **“More-refined” *ADAPT* code**

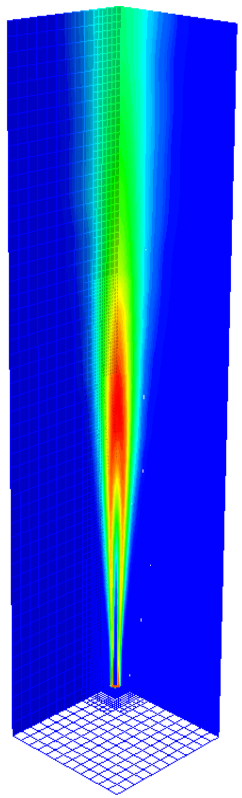
Laboratory-Scale Gas Burner

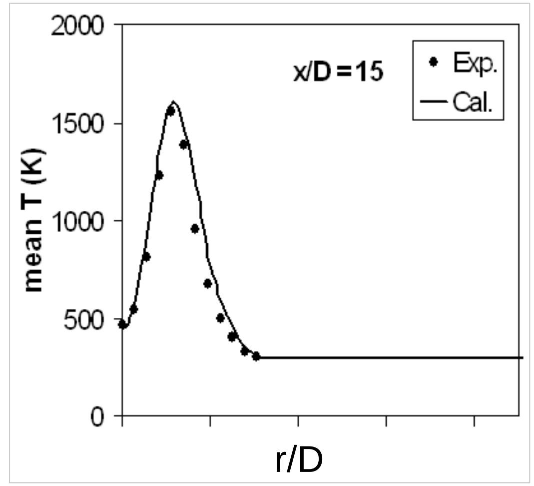
2004 Calculations

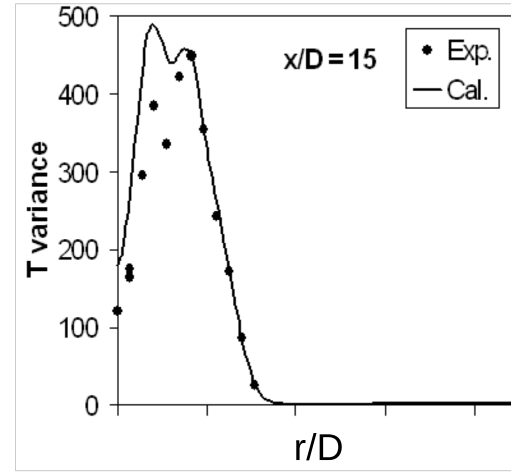
Sandia Piloted-Jet Methane Flame
(http://www.ca.sandia.gov/TNF)

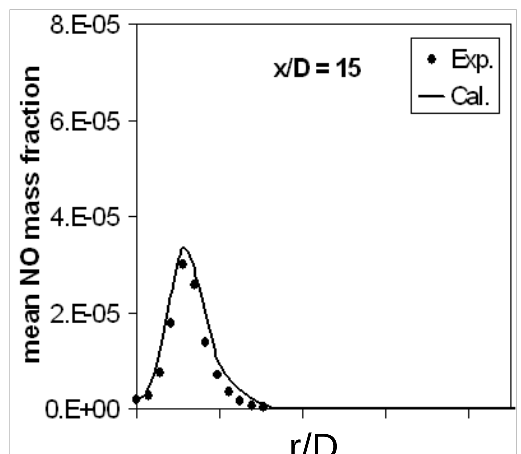


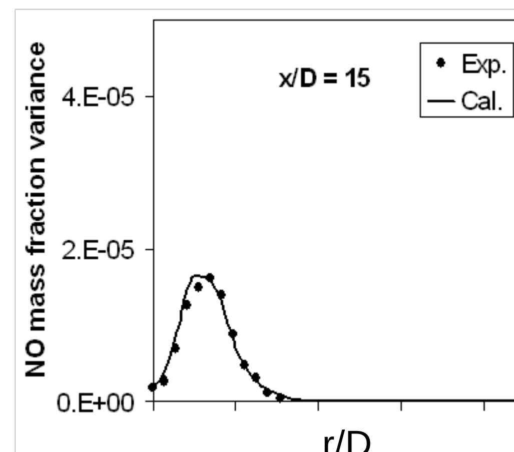








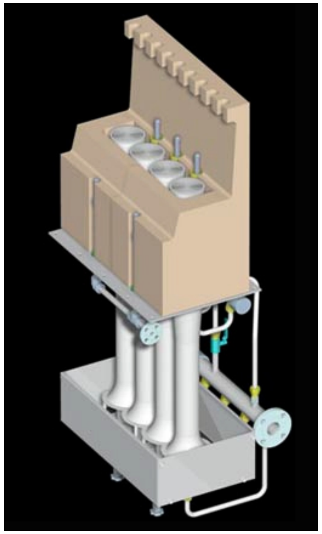


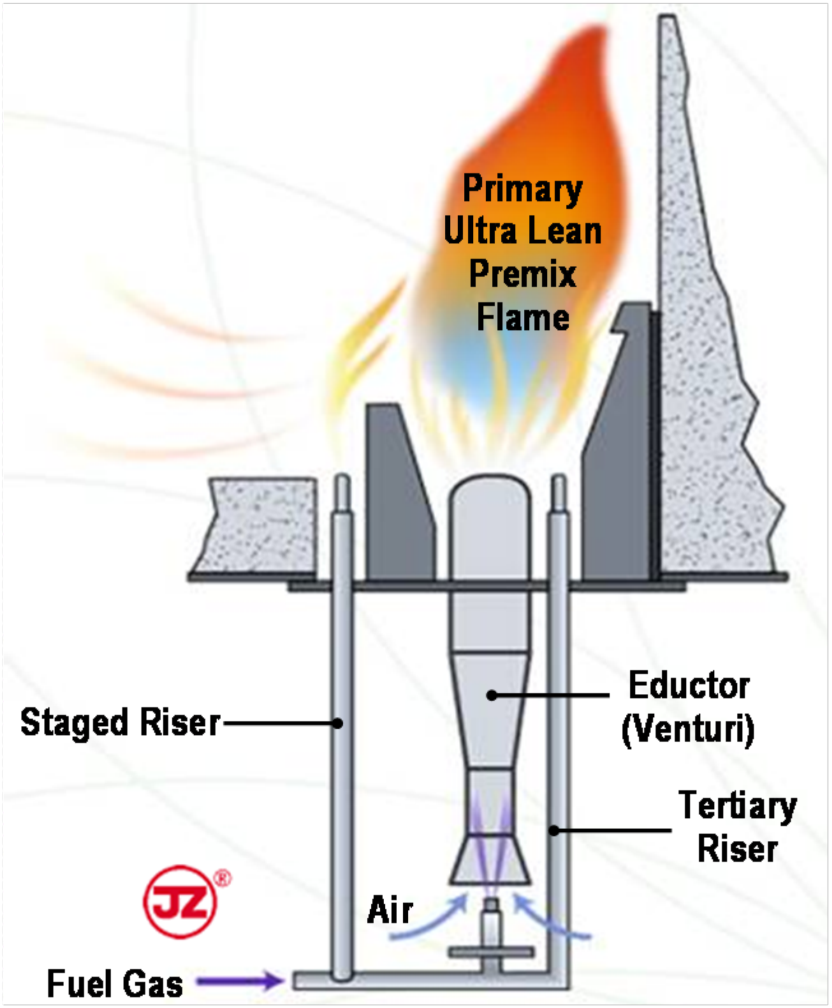


LPMF* Hearth Burner

- **Lean Premix**
- **Fuel Staging**
- **Quasi-Flameless**

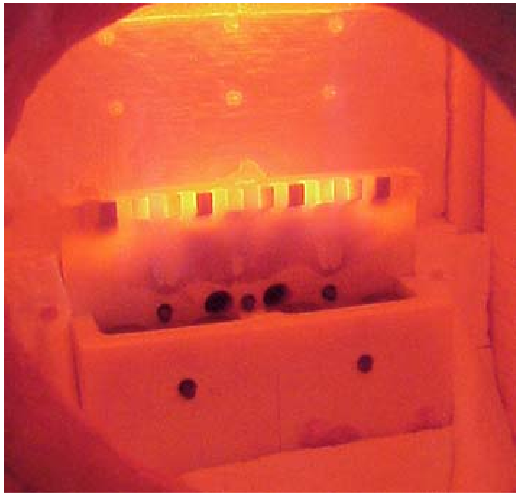
**** Lean PreMix Flat Flame (LPMF)***

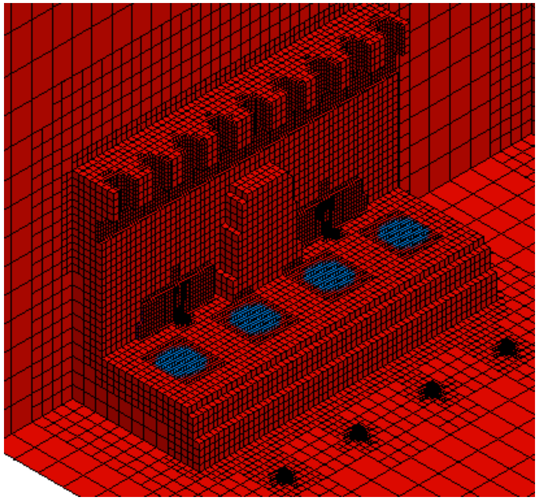




Test Furnace with LPMF Burner

- Heat Release ~ 6.5 mmBtu/h (as shown)
- Firebox Temp ~ 2,250ºF
- NO_x~ 0.02 lb/mmBtu (~17 ppmvd)

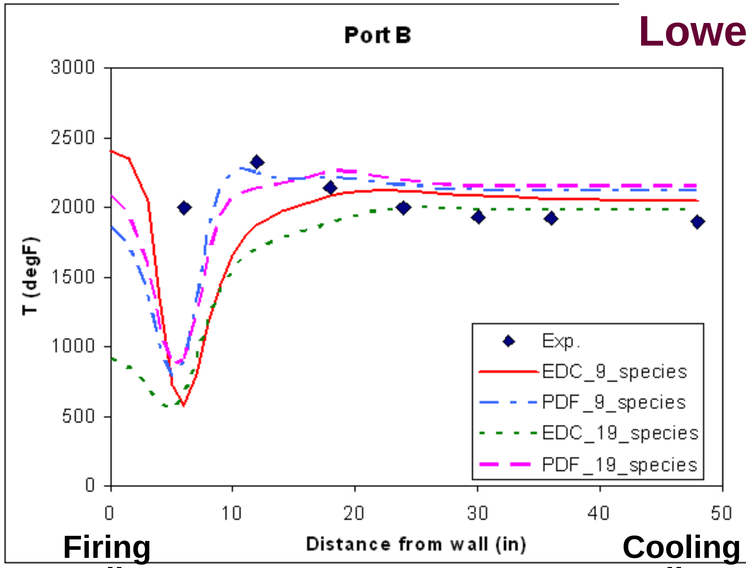




JZ® COOL*mix* Technology

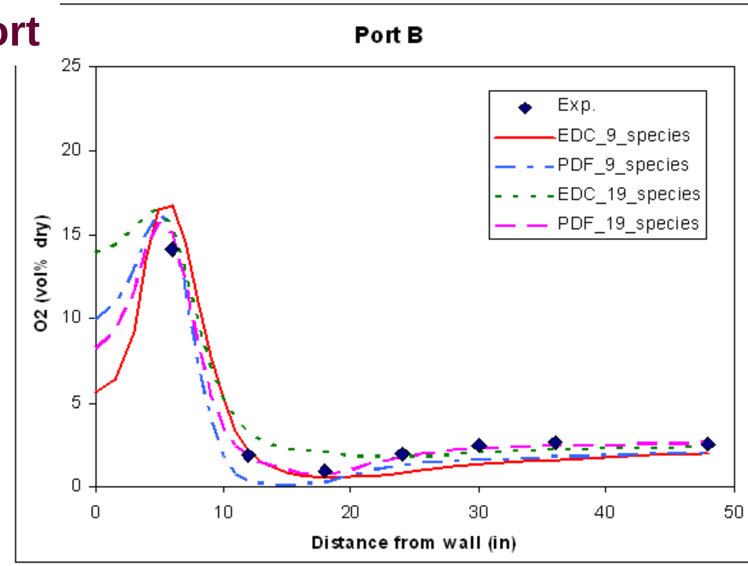
Lean Premixed Burner

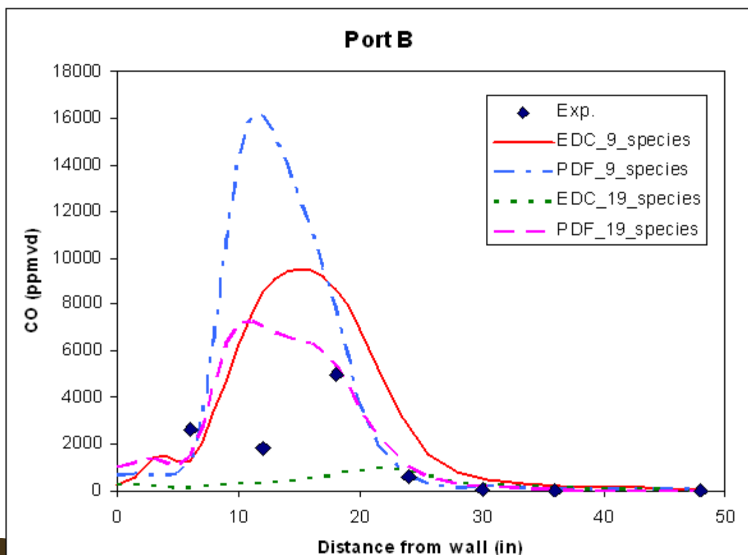
Lower Port

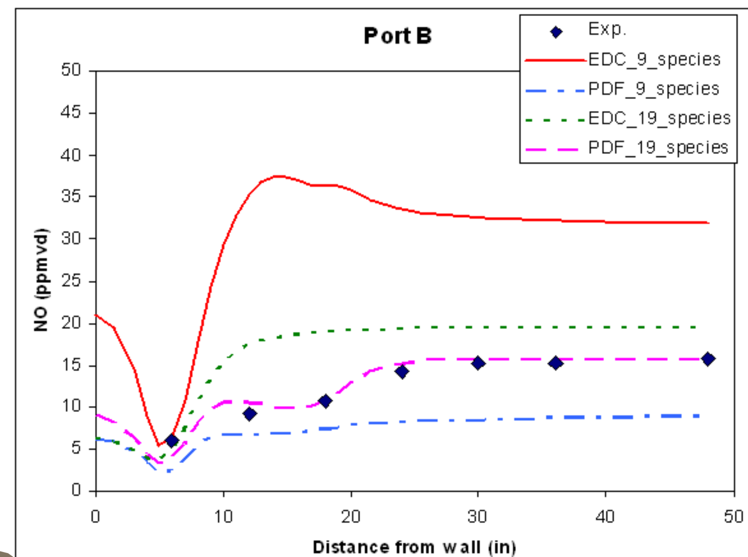


Firing wall

Cooling wall

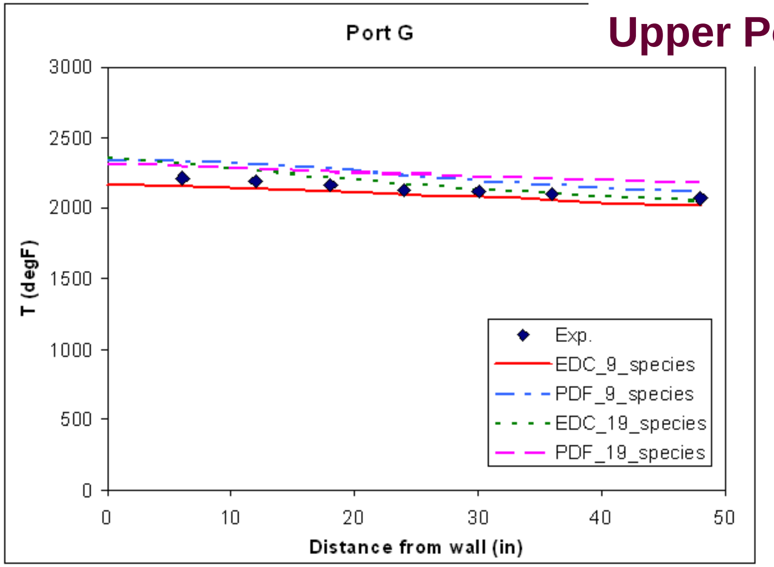


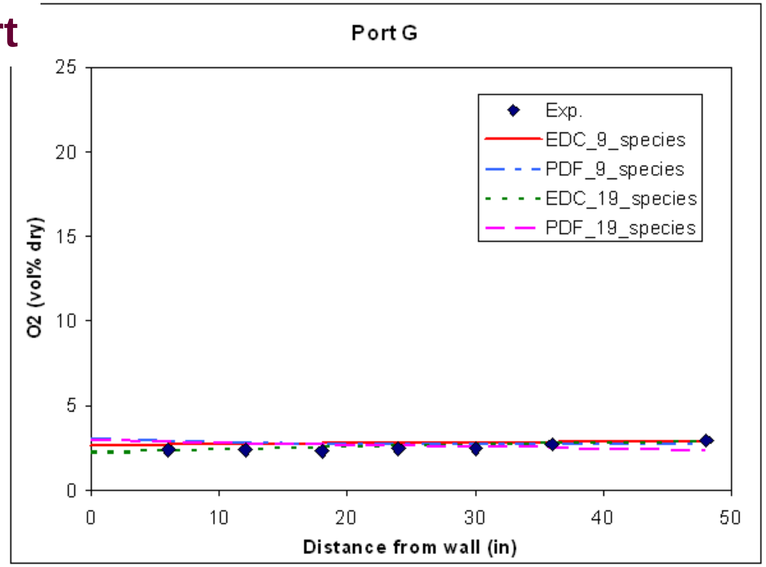


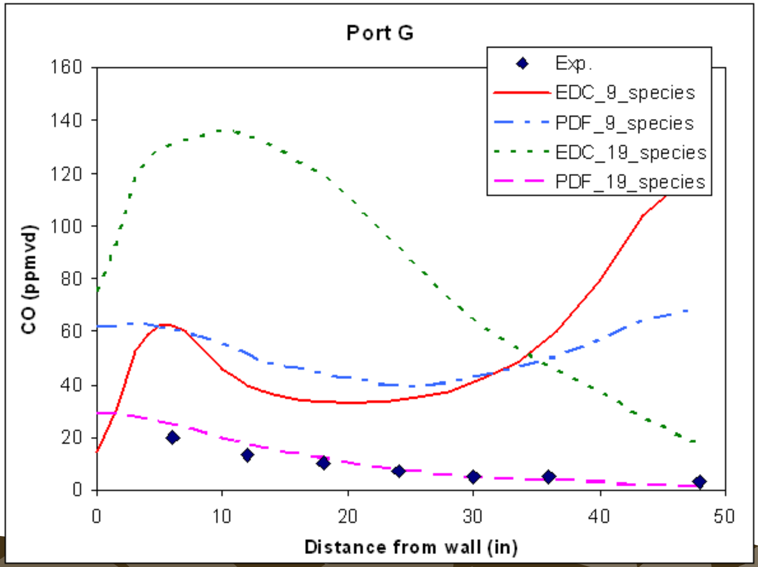


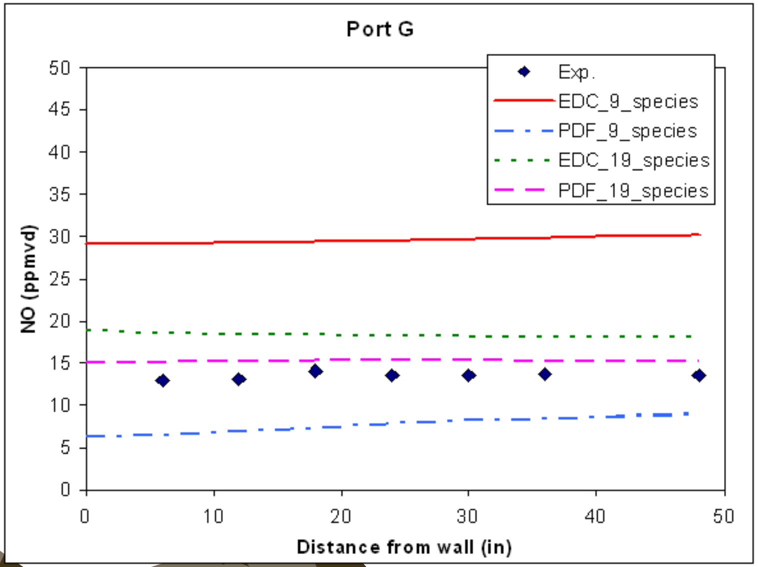
Lean Premixed Burner

Upper Port







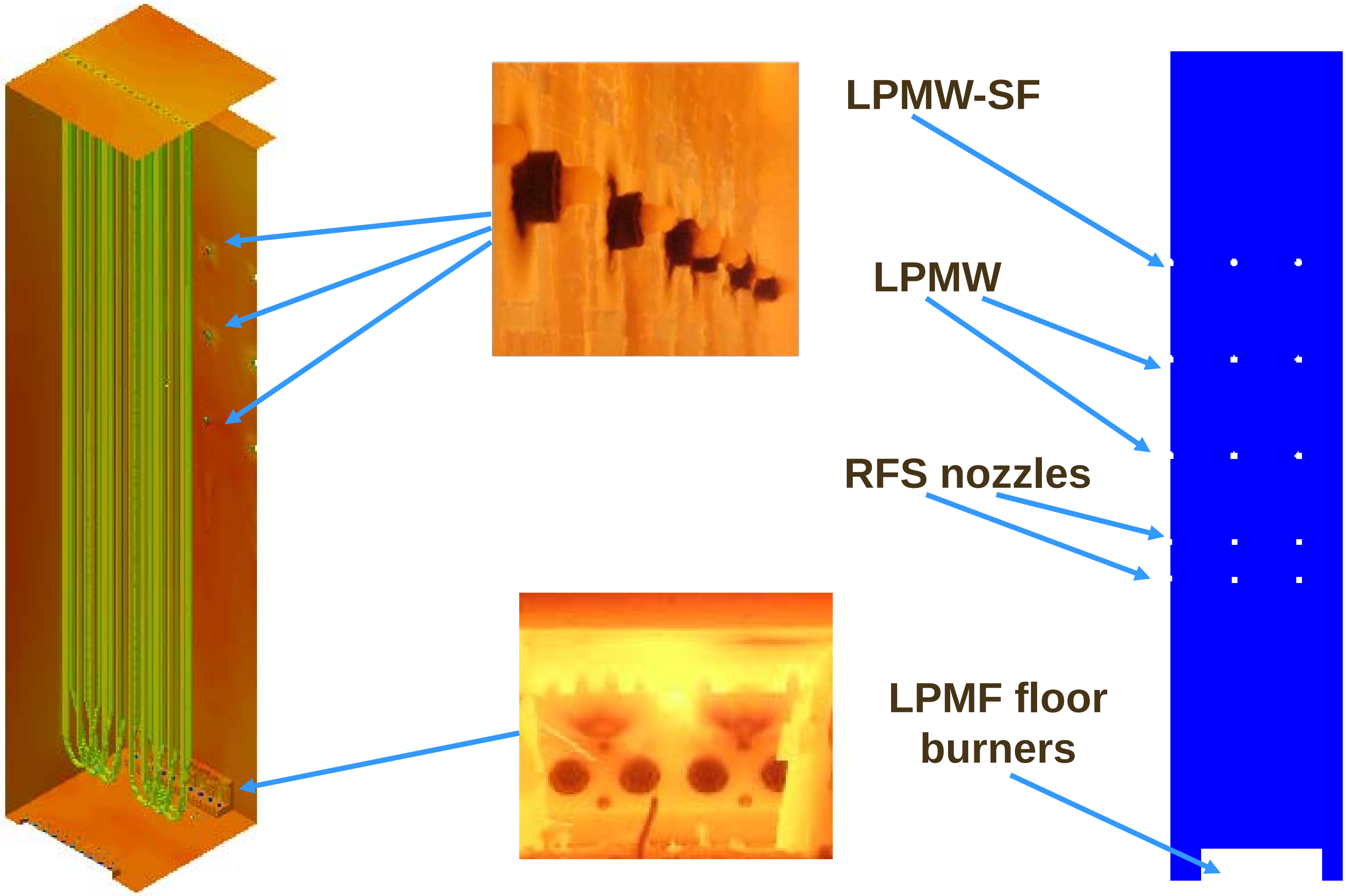


Reaction Engineering International

PTTCH Application
(Next Generation System)

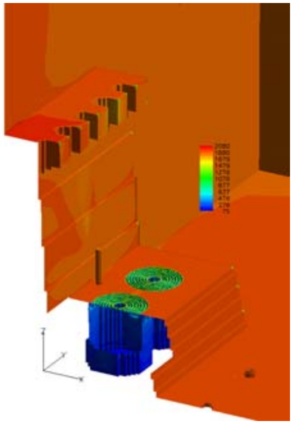
- **JZ Solar Technology™**
- **Combustion System**
  - **CFD crucial**
  - **<u>Not</u> just burner technology**
- **First Application Outside US Gulf Coast**
- **0.035 lb/mmBtu guaranteed**
  - **HHV basis**
  - **Corresponds to 32 ppmvd**

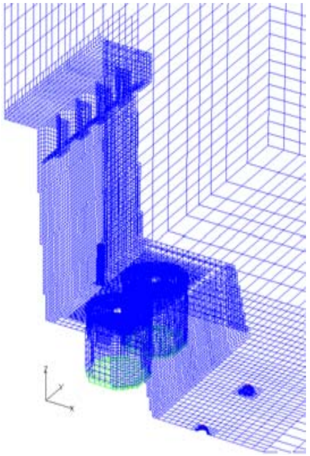
PTTCH Furnace Model



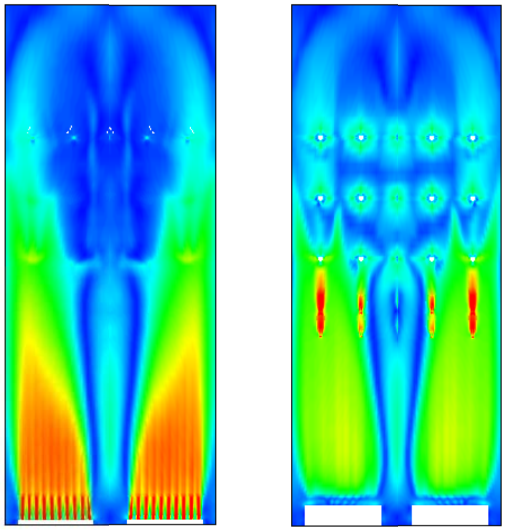
Purpose of CFD at PTTCH

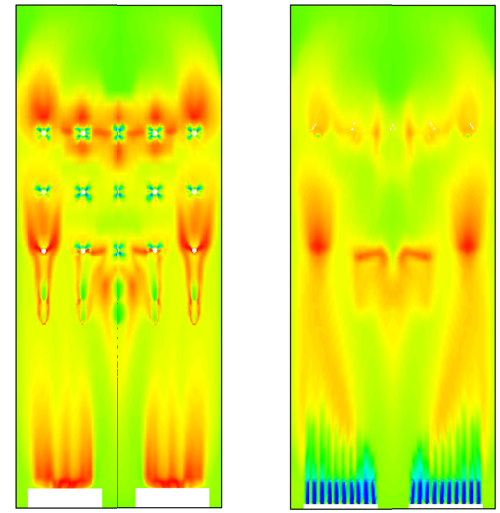
- **To determine optimal furnace performance**
  - For different burner layouts
  - For different burner configurations
- **Based on predictions of**
  - Flame shape
    - from velocity, CO concentrations and gas temperatures
  - Furnace CO and NO_x emissions
  - Furnace exit temperature
  - Heat transfer to process coils
  - Heat flux profiles to process coils





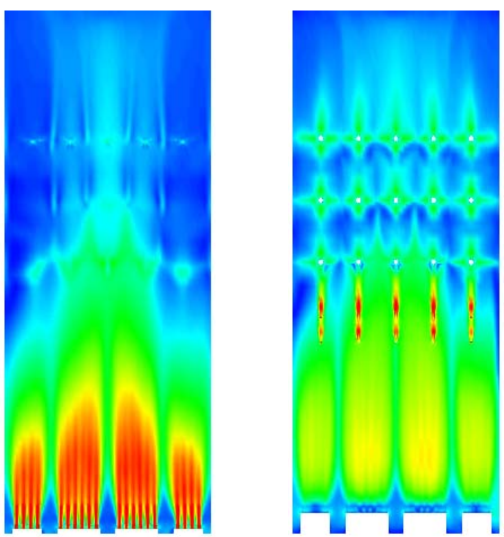
Study 1: Burner Layout

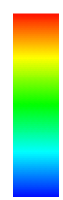


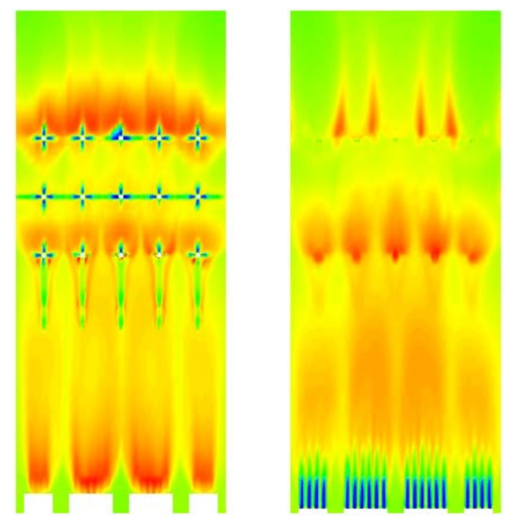


Initial design had poor heat release patterns

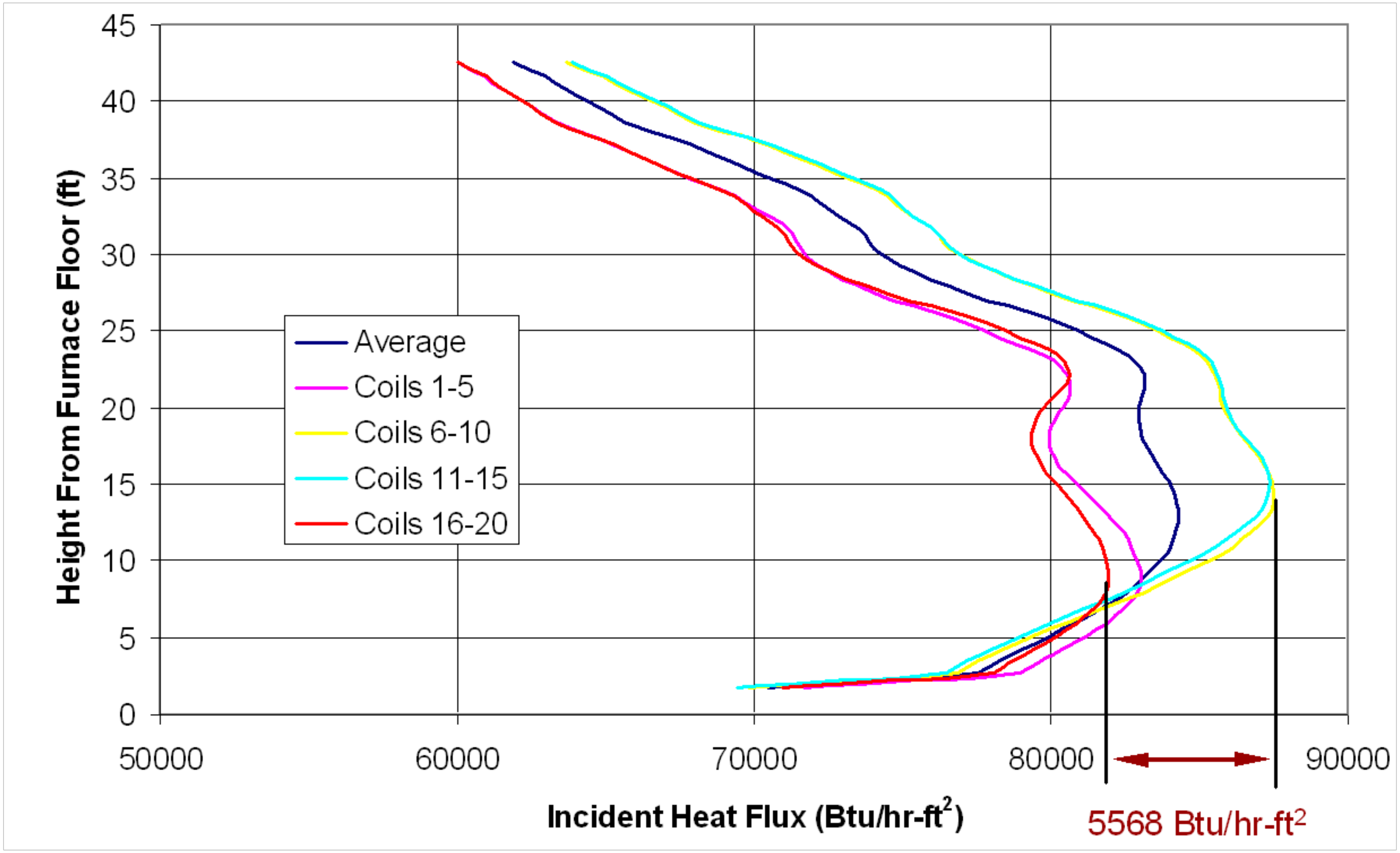
Revised design improved heat release patterns





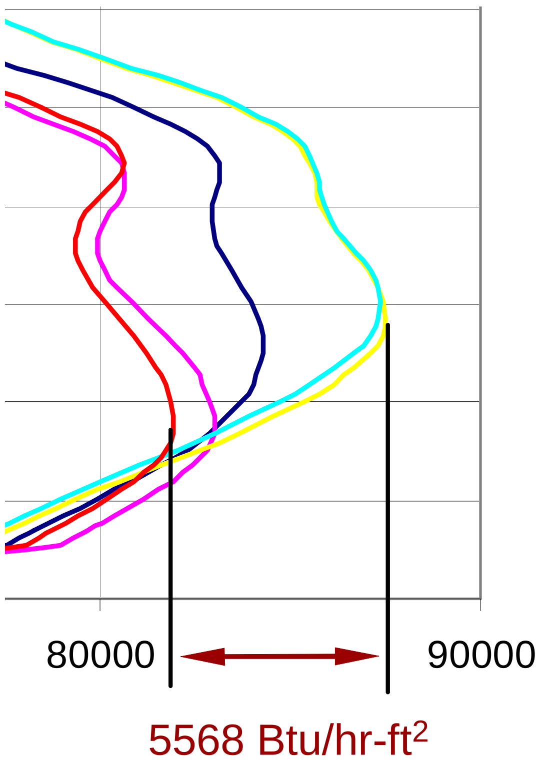


Study 2: Process Coil Heating Uniformity

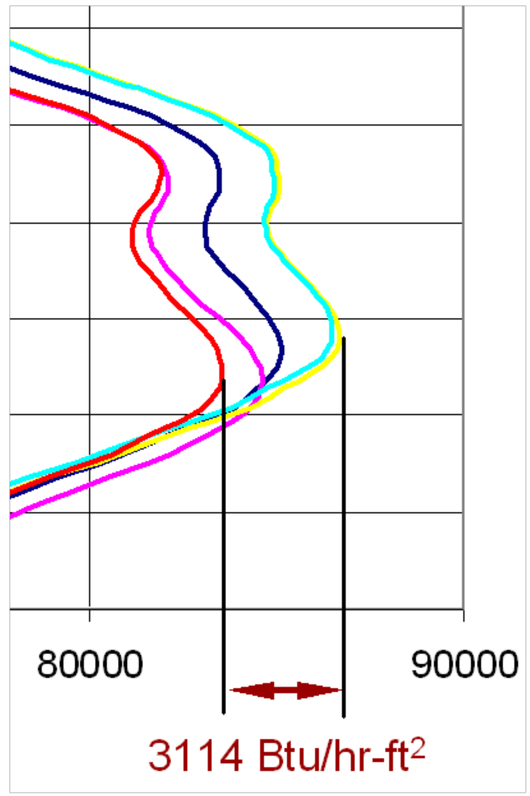


Study 2: Improve Heating Uniformity

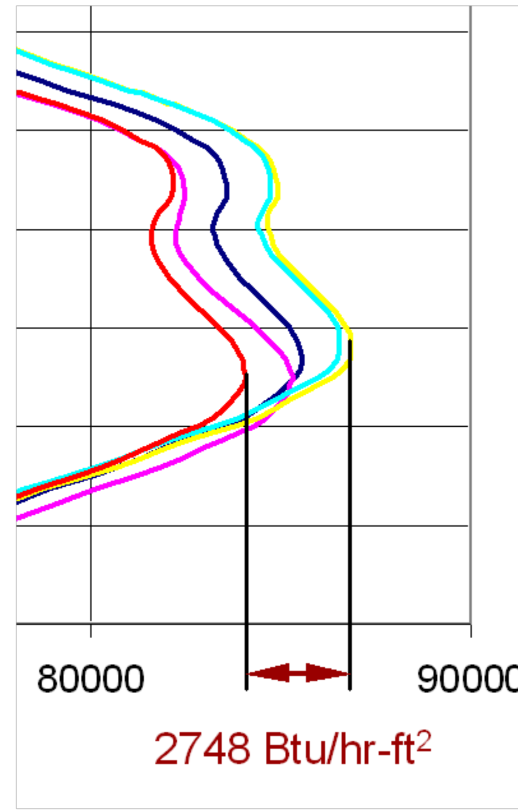
Improve uniformity by optimizing burner configuration (fuel distribution)



Case 2

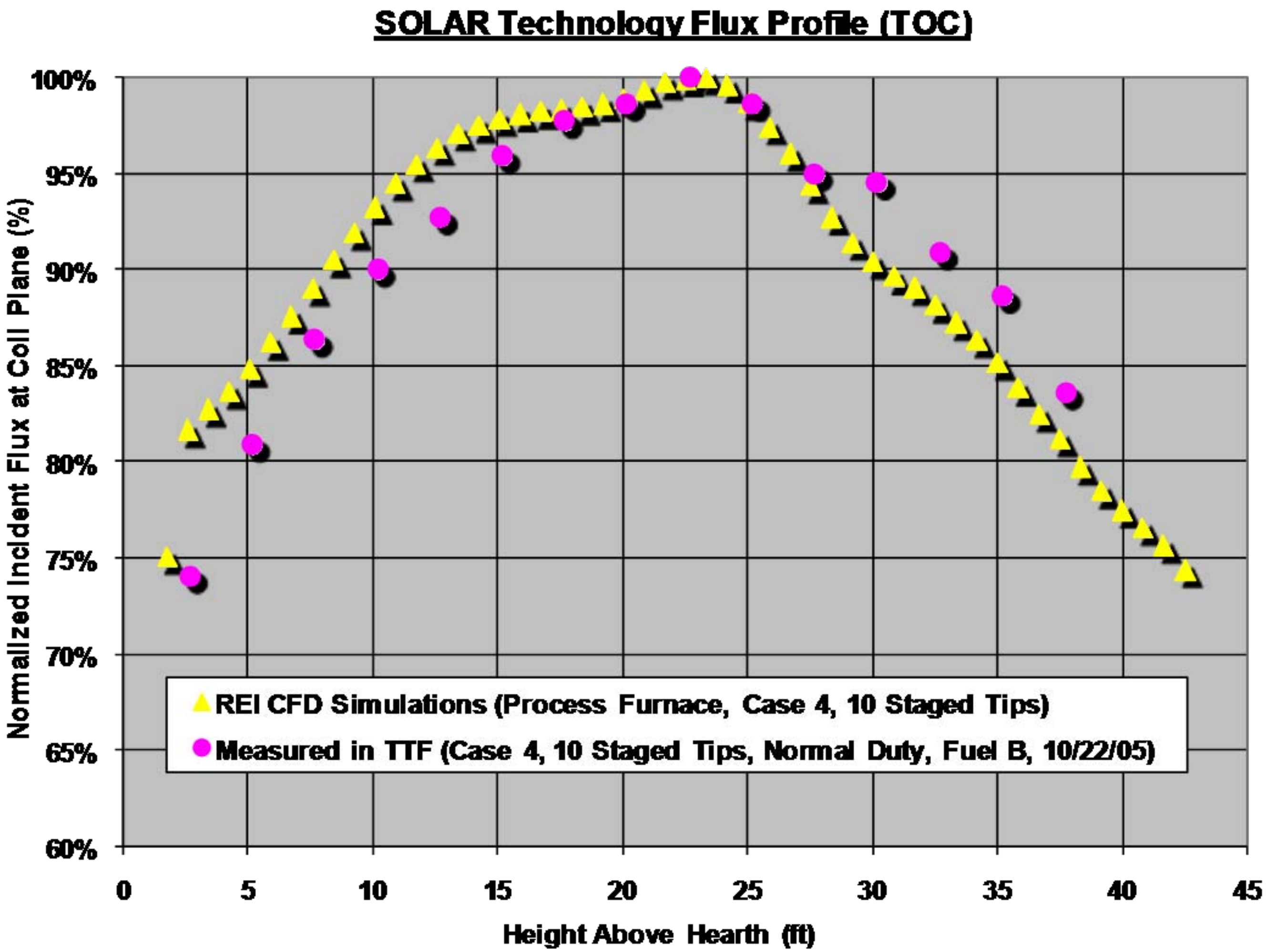


Case 3



Case 4

Model-Furnace Data Comparison



NOx Emissions

- CFD predicts 21 ppm @ 3% O_2
- Tests measured 17-21 ppm @ 3%
- CO <1 ppm in both cases

Furnace passed warranty and regulatory testing

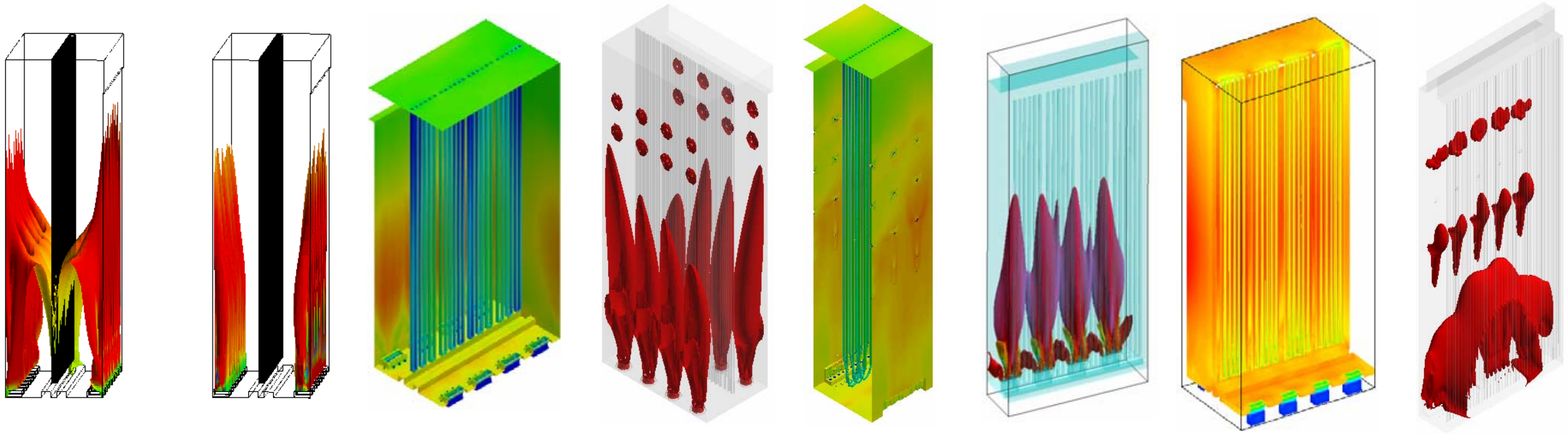
Why Use CFD Modeling?

- **CFD is a vital design tool**
  - Improves understanding
  - Compared to testing
    - Better for flux profile
    - Better for 'flame quality'
    - Almost the same for NO_x
    - Cheaper
    - More data
  - Validates designs
  - Avoids operational problems

Conclusions
(industry perspective)

- New *ADAPT* CFD software is a powerful tool for modeling next generation low NOx firing systems
  - Not a sledgehammer
  - Requires capable modeling engineers
- Successful application requires full collaboration and commitment from
  - CFD specialist
  - Licensor/ furnace designer
  - Burner manufacturer
  - Producer/End User
- Still challenges ahead
  - Validity of results limited by
    - Computational power
    - Budget and schedule constraints

Thank You



adams@reaction-eng.com