NOx Reduction through CFD Modeling and Design

November 15, 2018

Presented to:

Air & Waste Management Association
Ontario Section

Introductions

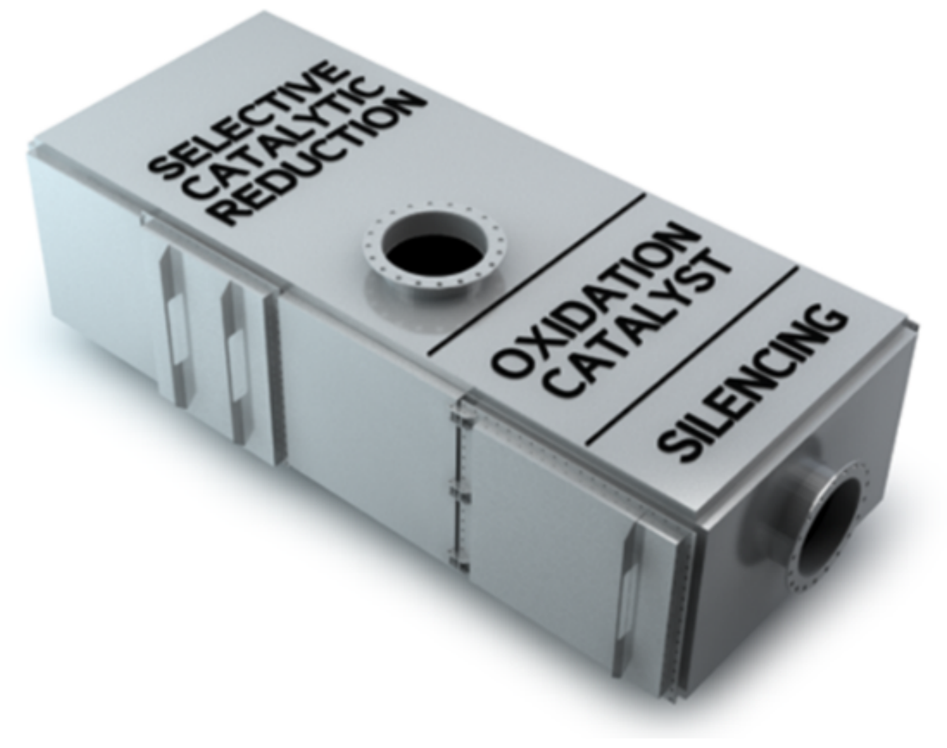
- Safety Power Inc. (SPI) is a leader in large diesel and natural gas engine emissions control
- SPI has strong regulatory knowledge and the capability to meet stringent global standards
- Major focus in Selective Catalytic Reduction technology (SCR) for exhaust NOx reduction
- SPI has completed SCR implementations for over 250 sites. Systems for ALL engine manufacturers
- In addition to SCR, many of the installations have Diesel Particulate Filters, Oxidation Catalysts and silencing combined into one compact “box” – the ecoCUBE®

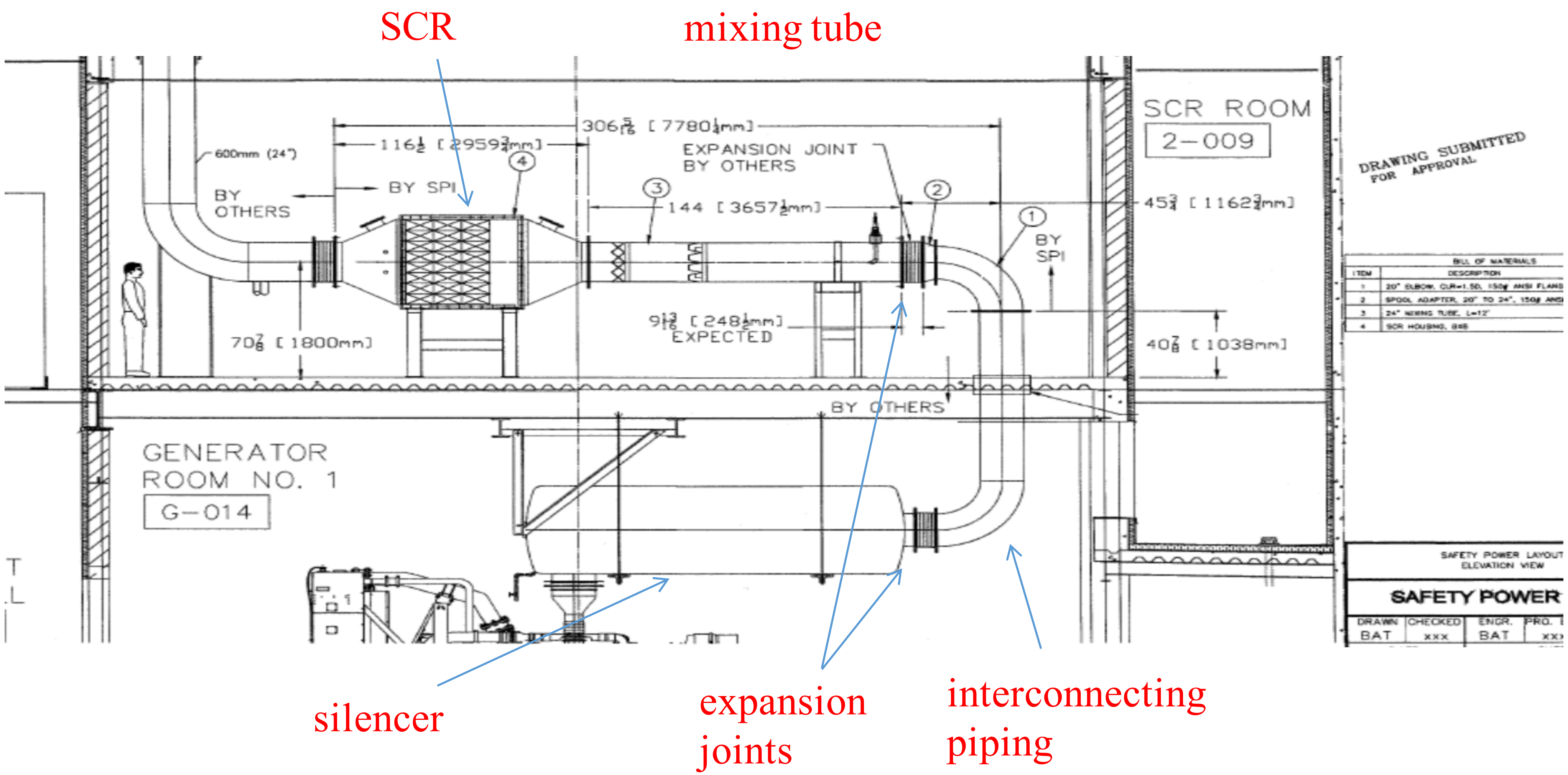
Installations

- NOx is a major pollutant from power generation
- NOx regulation (92-98% reduction)
- Safety Power Installations:
  - Classified Federal Government installation > 30 MW
  - Financial institution > 20MW.
  - Midwest Peaking Plant > 20MW
  - Major National Retailer > 20MW
  - Other sites include Datacenters, Hospitals and Universities
- **Overall 500MW of Installations in North America**

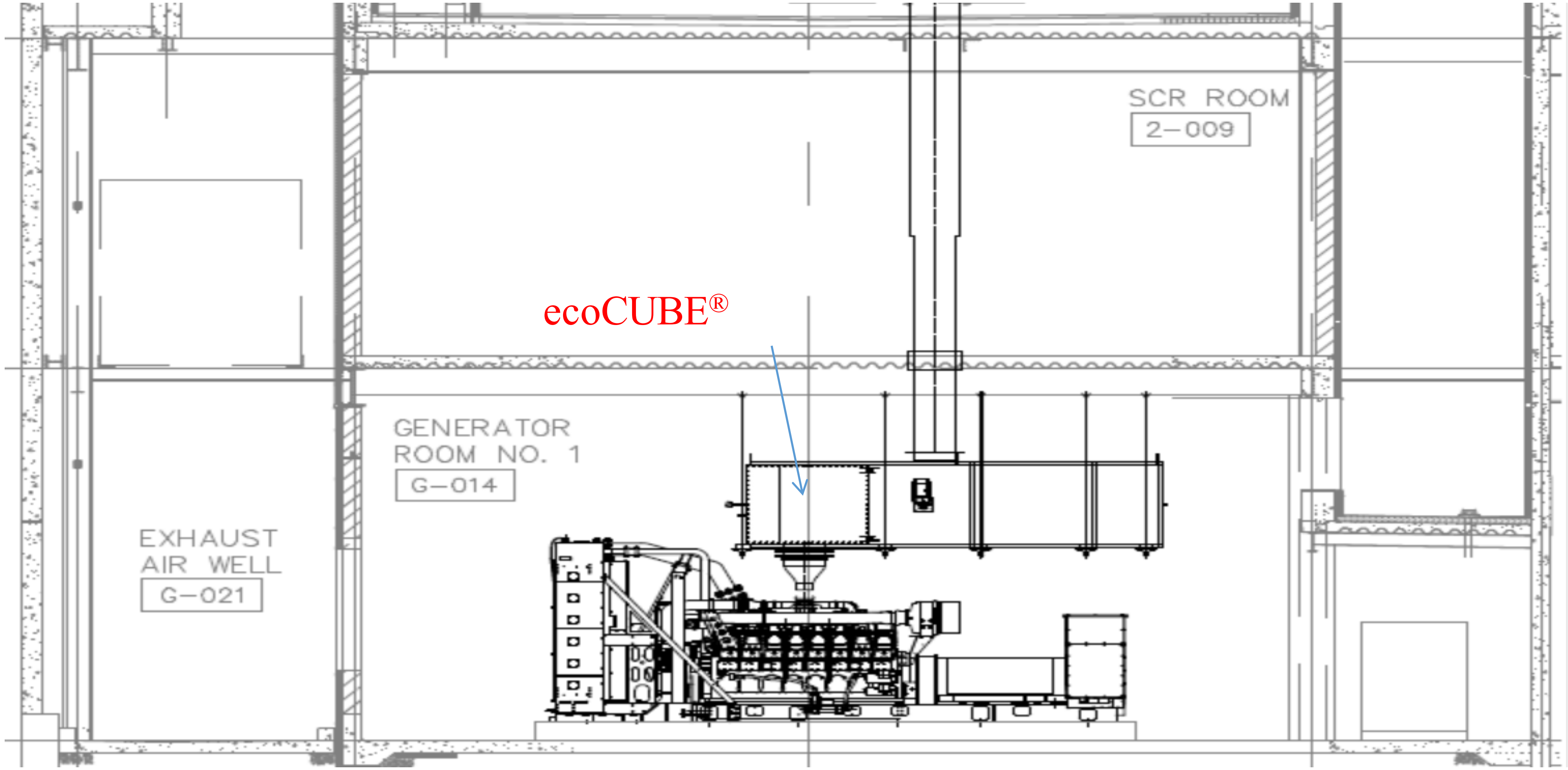
Compact "Box" Design - ecoCUBE®

- Traditional SCR Reactor requires long ductwork for adequate mixing.
- When combined with Exhaust Silencer and Diesel Particulate Filters (DPFs), significant more space is required.
- ecoCUBE® achieves emissions requirements in one single box without compromising engine performance.
- (Computational Fluid Dynamics) CFD Modeling is an integral part of our design process.

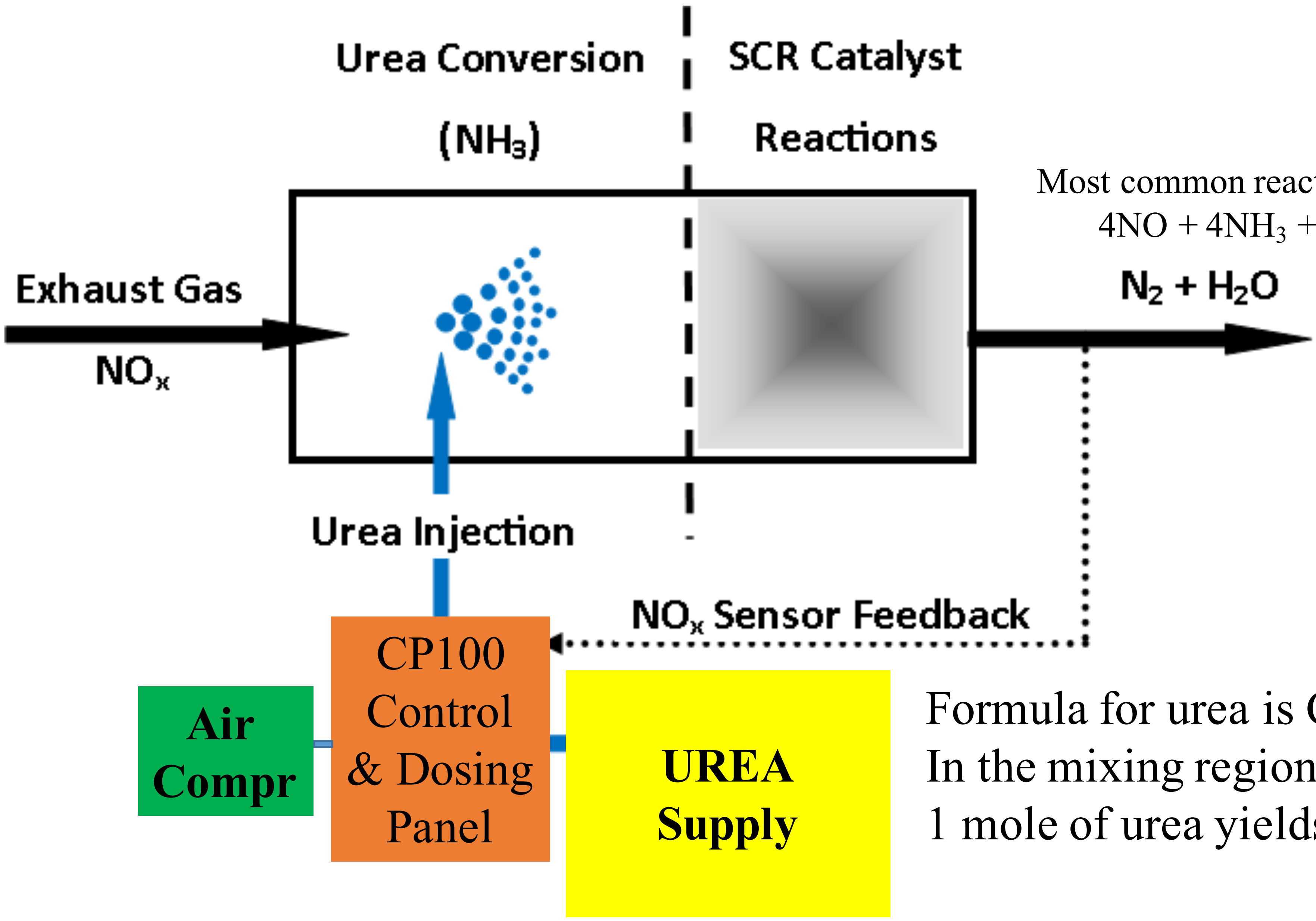




SCR
mixing tube
SCR ROOM
2–009
DRAWING SUBMITTED FOR APPROVAL
EXPANSION JOINT BY OTHERS
BY OTHERS
BY SPI
GENERATOR ROOM NO. 1
G–014
EXPECTED
BY OTHERS
SAFETY POWER
silencer
expansion joints
interconnecting piping


SCR ROOM
2–009
ecoCUBE®
GENERATOR
ROOM NO. 1
G–014
EXHAUST
AIR WELL
G–021

SCR Technology Overview, NOx Removal

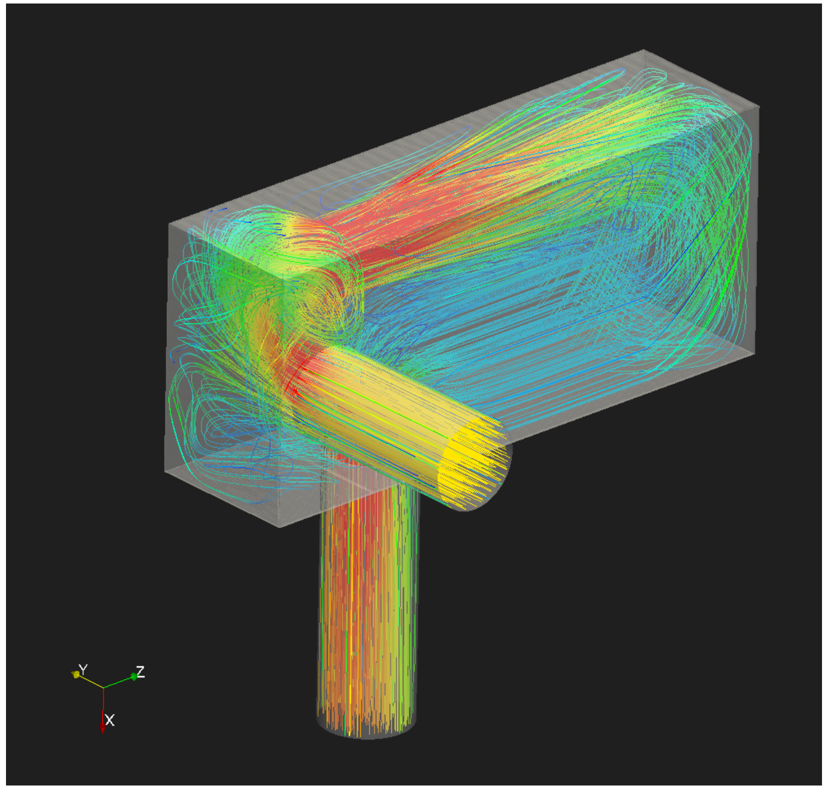


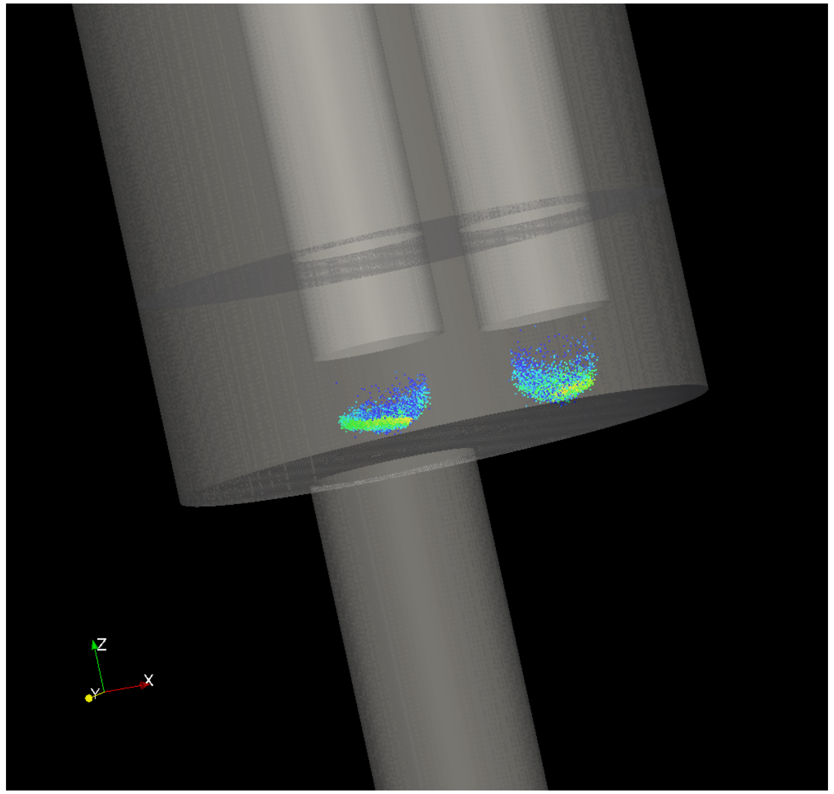
Most common reaction of several variants:
$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

Formula for urea is CH_4N_2O or $CO(NH_2)$2
In the mixing region the urea hydrolyzes –
1 mole of urea yields 2 moles of ammonia

Why CFD?

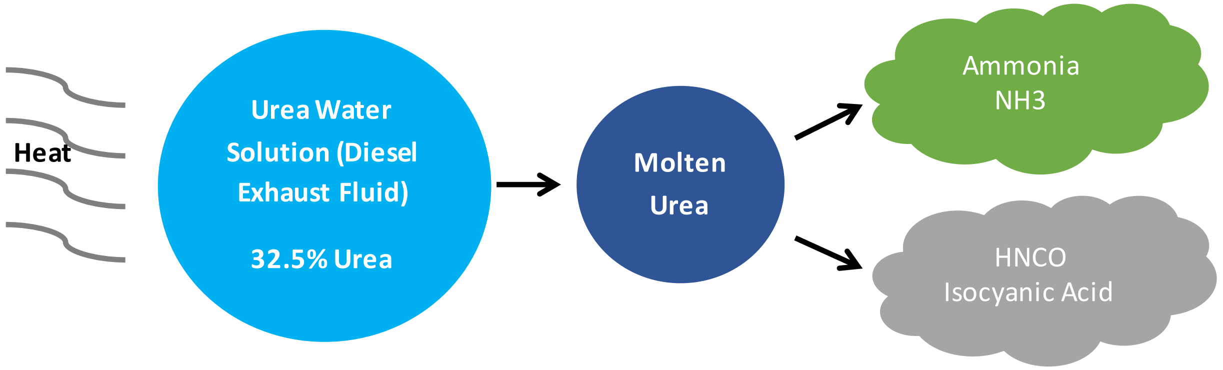
1. Experiment is prohibitively expensive.
2. Estimate NOx reduction performance very early in the project cycle.
3. Identify "red flags" (ie. flow bias, wall-wetting, separations, etc.)
4. Especially crucial when dimensions deviate significantly due to customer requirement.

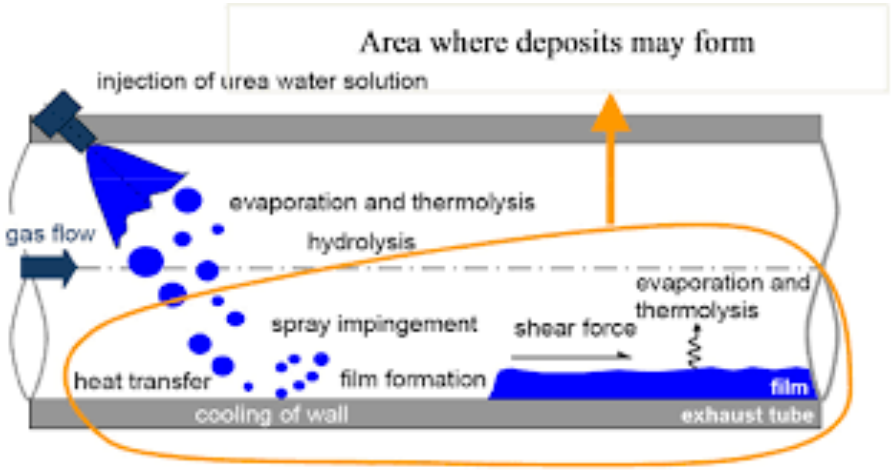




Design Considerations

1. Identify worst engine operating scenarios.
2. Two extremes:
   1. Maximum load and exhaust temperature.
   2. Very low temperature during start-up
3. Adequate residence time for DEF droplets to evaporate.
4. Flow entrainment near the injector can cause wall wetting and must be avoided.
5. Site specific flow disturbances (ie. An elbow or sudden expansion upstream of the SCR reactor)





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Methodology

OpenFOAM

Stage 1

Pre-processing

Prepare 3D Geometry

Include piping upstream and downstream of SCR if flow disturbances are expected

Set up boundary conditions and exhaust flow parameters

Stage 2

Meshing

Divides flow domain into small cells called control volumes. Typically 10+ million cells

Stage 3

Processing

Select numerical solver

Select discretisation scheme

Set up Multi-core simulation

Stage 4

Post-processing

Plot results

Visualize flow via streamline and contour plots

Re-iterate design until mixing & pressure drop performances are satisfactory

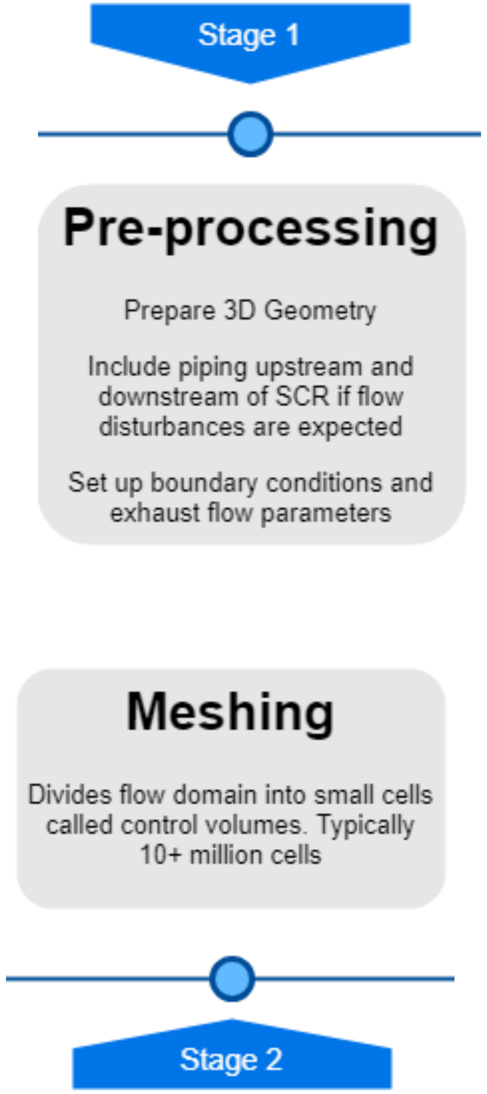
Methodology

Pre-processing

1. Convert detailed fabrication drawing to 3D surface files
2. Remove internal features with negligible impact on flow profile
3. SCR catalysts modeled as Porous Media

Meshing

1. Divides flow domain into small cells
2. Mesh refinement on complex regions
3. Typically 10+ million cells for a 2MW class SCR Reactor



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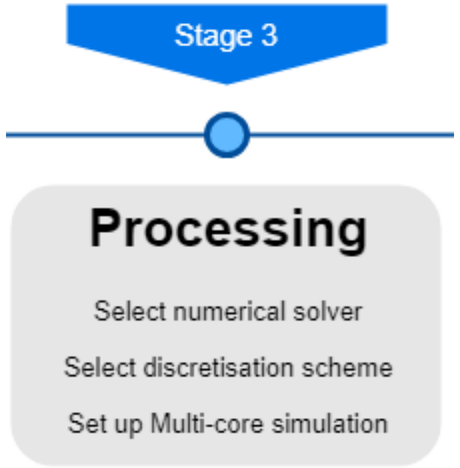
Methodology

Processing

1. Steady flow simulation with RANS Turbulence Model
2. Use converged solution to initialize unsteady flow simulation
3. Enable Two-way coupling between droplet (liquid) and exhaust flow (gas)

Spray Modeling

1. Euler-Lagrangian Method
2. Turbulent dispersion of droplet parcels included in the model
3. Rosin-Rammler size distribution
4. Forces impacting droplet motion (ie. Drag force)
5. Mass transfer occurs at droplet surface



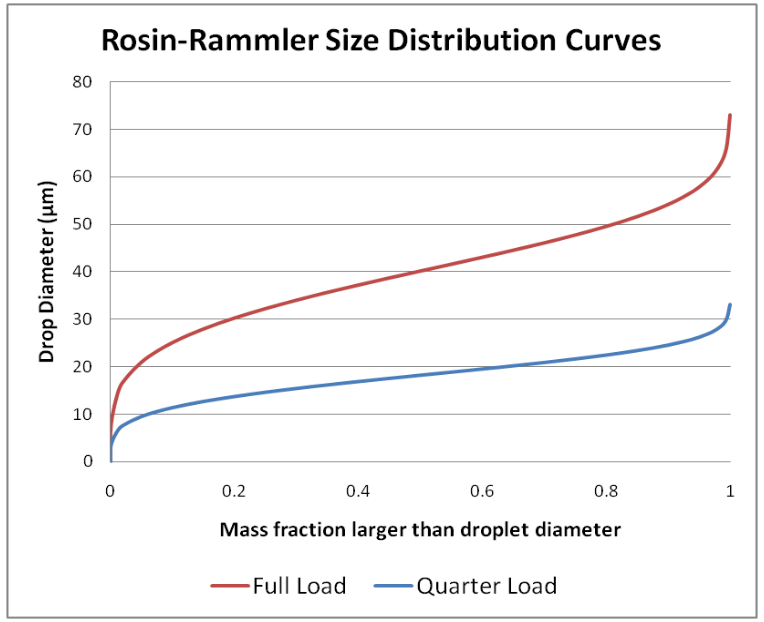


Figure 4: Rosin Rammler Size Distribution Curve for Quarter Load and Full Load
(From SAE 2012-01-1300)

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Methodology

Post-processing

1. Determine mixing performance using Uniformity Index (UI)
2. For very high NOx reduction, profile data extracted from CFD result is fed to a 2-D CSTR (Continuously Stirred Tank Reactor) model for detailed NOx and ammonia slip estimation

Post-processing

Plot results

Visualize flow via streamline and contour plots

Stage 4

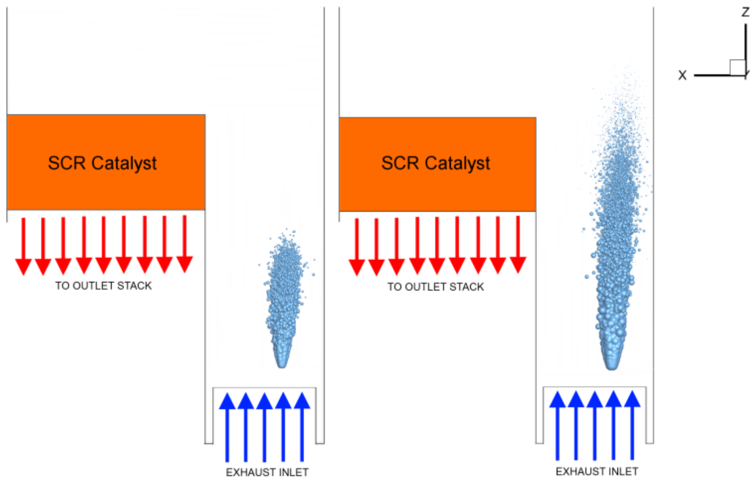

Figure 8 Top view showing spray plume at quarter engine load (left) and full engine load (right). Droplet parcels arbitrary scaled by droplet diameter to show evolution of droplets as they move downstream (SAE 2012-01-1300)

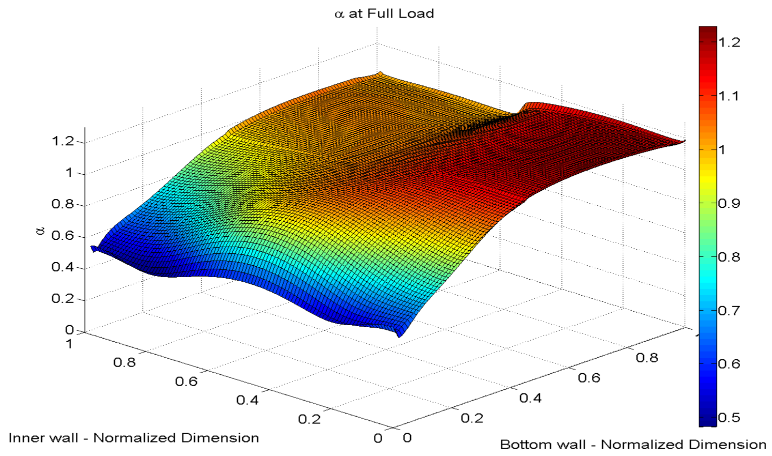

Figure 10 Geometry 1: α profile at full load (SAE 2012-01-1300)

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CFD Designed Systems

- ecoCUBE® reactor on top of generator enclosure

- ecoCUBE® Reactor vertically mounted between Engine and Heat Recovery System

- Limited indoor space requirement. ecoCUBE® reactor mounted on its side

Summary

- CFD continues to play a key role in finding out NOx reduction performance early in the project cycle.
- This helps our engineers to evaluate multiple designs and come up with a solution quickly.
- CFD is used extensively to continuously optimize our products to meet increasingly stringent emissions targets

Questions?

SPI – A Strong Environmental Partner

- Sales/service to support site
- ecoCUBE® ideally suited for new builds and retrofits
- Significant installed base
- Proven management & implementation experience
- Experienced engineering and technical support
- Inspection & maintenance expertise to ensure on-going performance
- Knowledge of complex regulatory issues within industry agencies
- Excellent reputation in served market
- Continuing focus on new technology