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SCR Technology for Simple Cycle Large Frame GT Applications

Kyle Neidig

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Gas Turbines



Steam Turbines



Generators



NEXT



Conventional
Power Plants



GTCC Plants



Environmental Systems



Geothermal Plants



IGCC



SOFC-MGT Hybrid



ORIDEN
A New Generation of A MITSUBISHI POWER

Environmental Solutions Product Portfolio

- Hot Gas (SC) SCR_s
- HRSG (CC) SCR_s
- Coal SCR_s
- Industrial SCR_s
- NO_x Catalyst (Plate Type)
- Coal to Gas Conversions
- Wastewater Spray Dryer (WSD)
- Conventional & Wet ESP_s
- Pulse Jet Fabric Filters
- Dry FGD (EAD™)
- Wet FGD Systems
- Sea Water Scrubber (FGD)

Phase 1

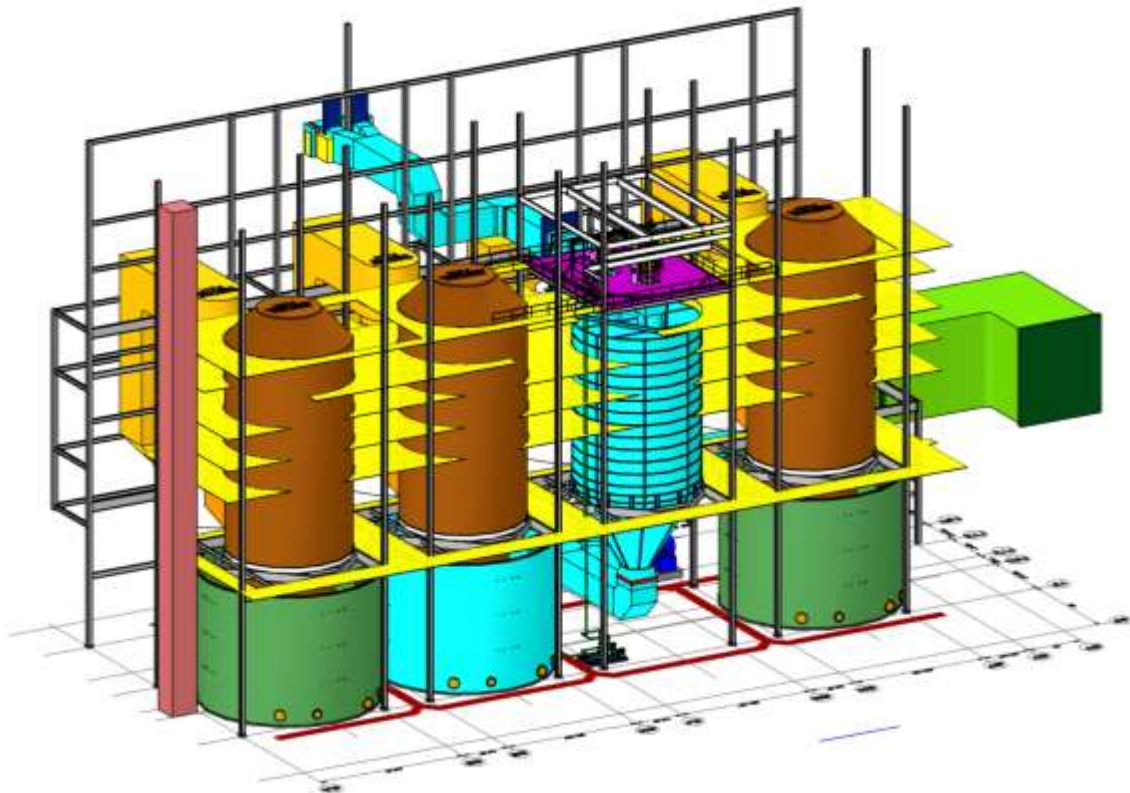
Increase existing gas firing capacity from 30% to 40%

Phase 2

Increase NG firing capability to 100%



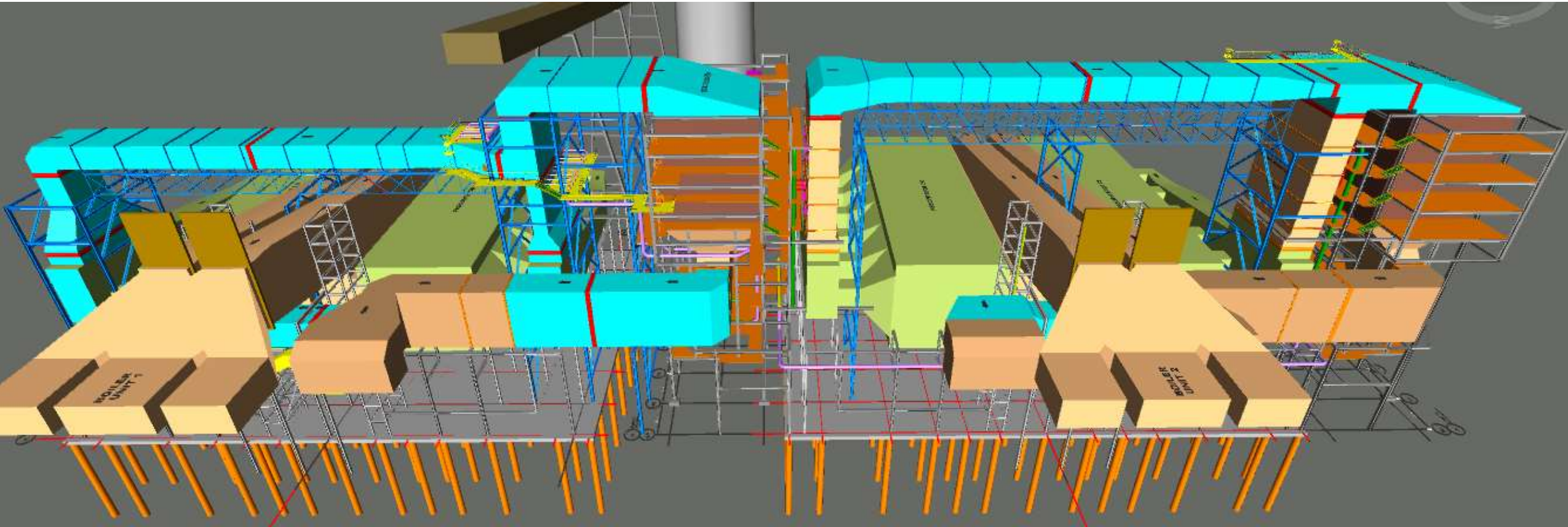
ZLD Technology for ELG Compliance
Largest WSD





First Seawater Scrubber
in United States





Unique and Low-Cost Solution to Add SCR to Unit 1 and Improve Unit 2 SCR Operations

Mitsubishi Power

SCR System Experience

Installations Worldwide – An Original Pioneer Of SCR Technology

Over 400 SCRs Installed on Gas Turbines

Mitsubishi Power		Japan, Asia, North & South America
Boiler	Coal	173
	Oil	103
	Gas	52
Gas Turbine		423
Diesel Engine		224
FCC & Refinery Heater		48
Total Units Installed		1023



Over 40 years of first hand experience

Why Simple Cycle Large Frame GT Applications?



Demand Growth

More than 6% annual growth

Historical load growth remained flat at approximately 1%, but a notable shift as electricity demand is accelerating, outpacing previous trends



Coal Retirements

Coal fired capacity continues retirements through 2030
Retirements peak in 2028

Future retirements forecast is slowing as utilities delay retirements



Renewable Growth

Solar and wind outpace coal by 90B kWh in 2024

Growth continues but challenges of transmission queues and interconnection delays remain



Grid Reliability

NOAA shows 15, >\$1B weather events in 2023

Concern on grid reliability growing due to the new energy mix – need for more dispatchable generation



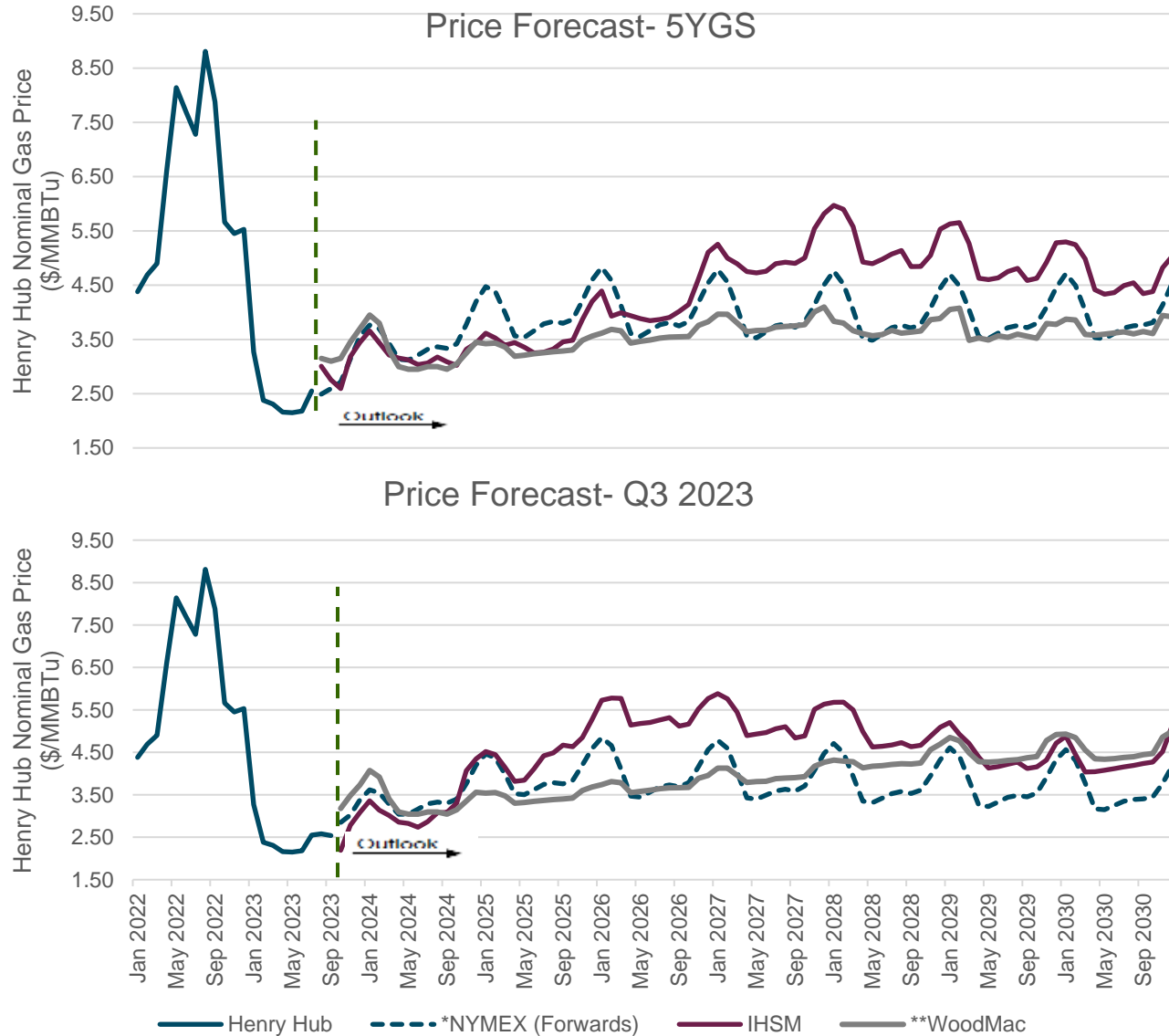
Energy Transition... Today's reality

Biden Announced 7 Hydrogen Hubs

Green H2 and H2 capable GT's, CC(U)S, NH3 leading the race of zero/low carbon tech

Dispatchable generation required for grid resiliency while energy mix evolves towards more renewable generation

Natural Gas Price Forecast 2023 to 2030



Low prices from 2023 should show a moderate increase in the long term

- **2023 Prices:** The average HH price in 2023 has been \$2.6/MMBtu, \$0.4/MMBtu lower previously forecasted
- **Long term prices:** The forecasted 2024-2030 average price of \$3.8/MMBtu is similar to previous projections.
- **LNG:** The LNG market continues to operate at a surplus, not allowing price uplift. For the rest of 2023, production is expected to outpace LNG demand.
- **LNG:** Increased exports continues to be the main driver for long term market growth, with new facilities driving in increase in price within the next 2-3 years.
- **IRA:** New renewables are expected to drive a long term decrease in NG consumption through 2030

➤ *HH Price forecast for 3rd and 4th quarter remains low, between \$2.55/MMBtu and \$2.95/MMBtu despite elevated consumption*

* NYMEX Forwards as of 19th Sep 2023

** WoodMac NG Price Forecast Aug 2023

Source: S&P Global, Wood Mackenzie, EIA

NG prices are expected to remain low, driving an increase in NG generation

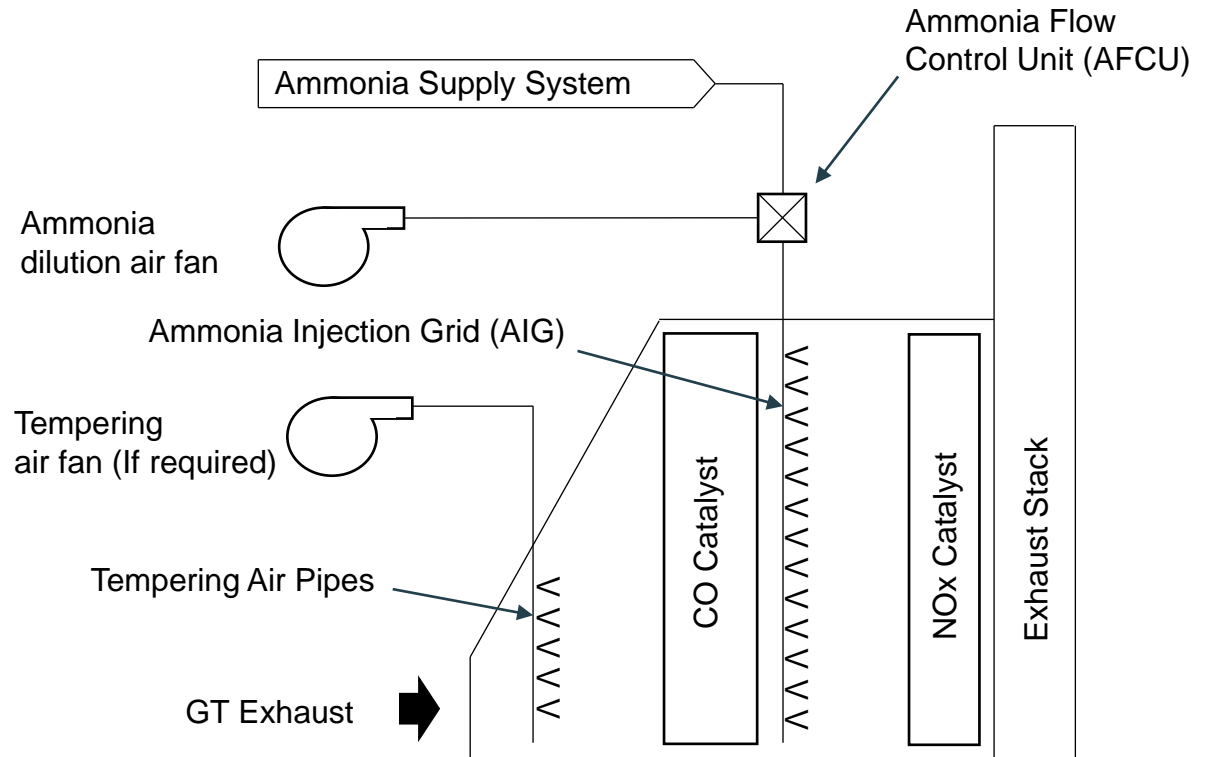
Overview of Simple Cycle SCR Application

- ❑ Ammonia Supply System Options
 - Anhydrous Ammonia
 - Aqueous Ammonia
 - On-Site Urea to Ammonia Production

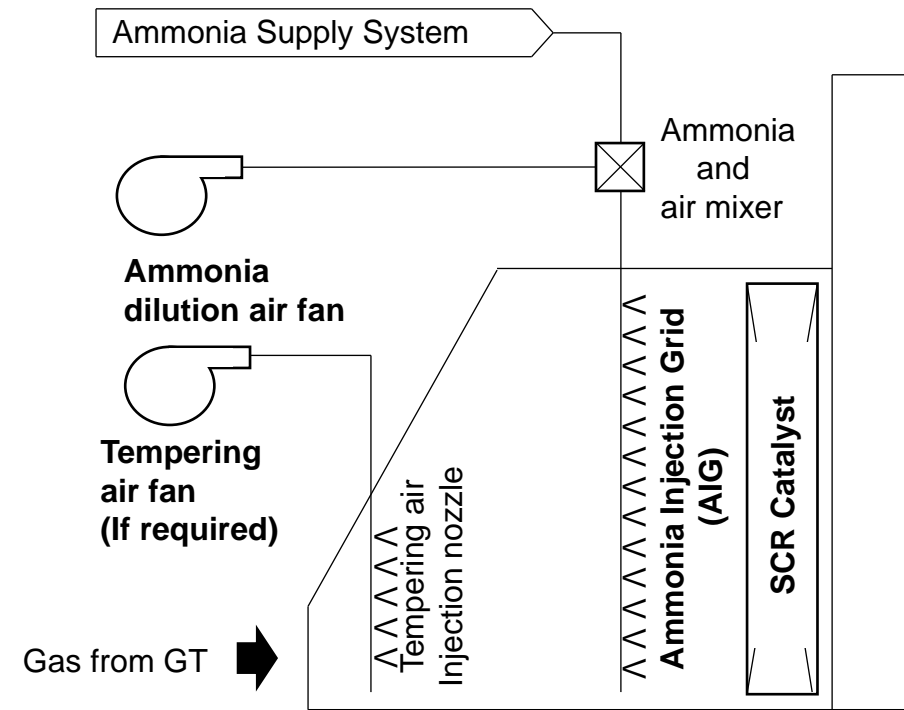
- ❑ Catalyst Options
 - CO + NOx Catalyst (as shown)
 - Dual Function Catalyst
 - One catalyst for both NOx and CO reduction

- ❑ Operating Temperature
 - Temperature is governed by NOx catalyst limitations
 - Optimize design to balance catalyst operating temperature requirements and TA system size
 - Operating bulk temperature is determined by the practical limitations for attaining homogenous temperature profile
 - Higher temperature can be tolerated by specially formulated catalyst; however, the cost of such catalyst is high, and life is limited

“Hot Gas” SCR Schematic



SCR for GTSC (Gas Turbine Simple Cycle)

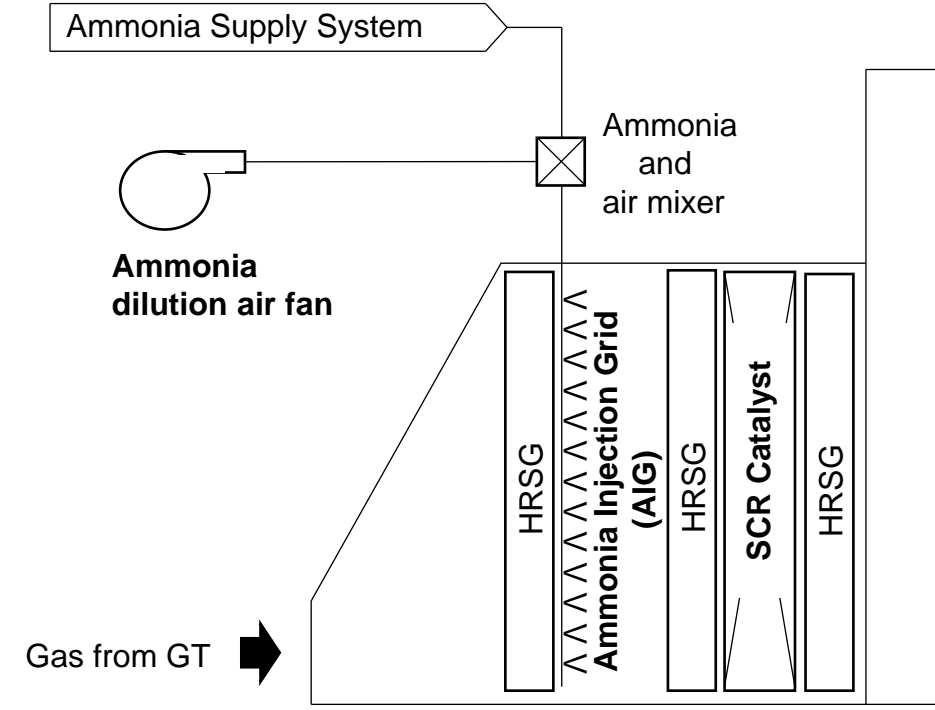


Catalyst is located in (750~980deg.F) temp. range

- Low V2O5 catalyst formulation
- Flue gas tempering air system (If required)

➔ **Most Difficult SCR Design**

SCR for GTCC (Gas Turbine Combined Cycle)



Catalyst is located at (570~750deg.F) temp. range

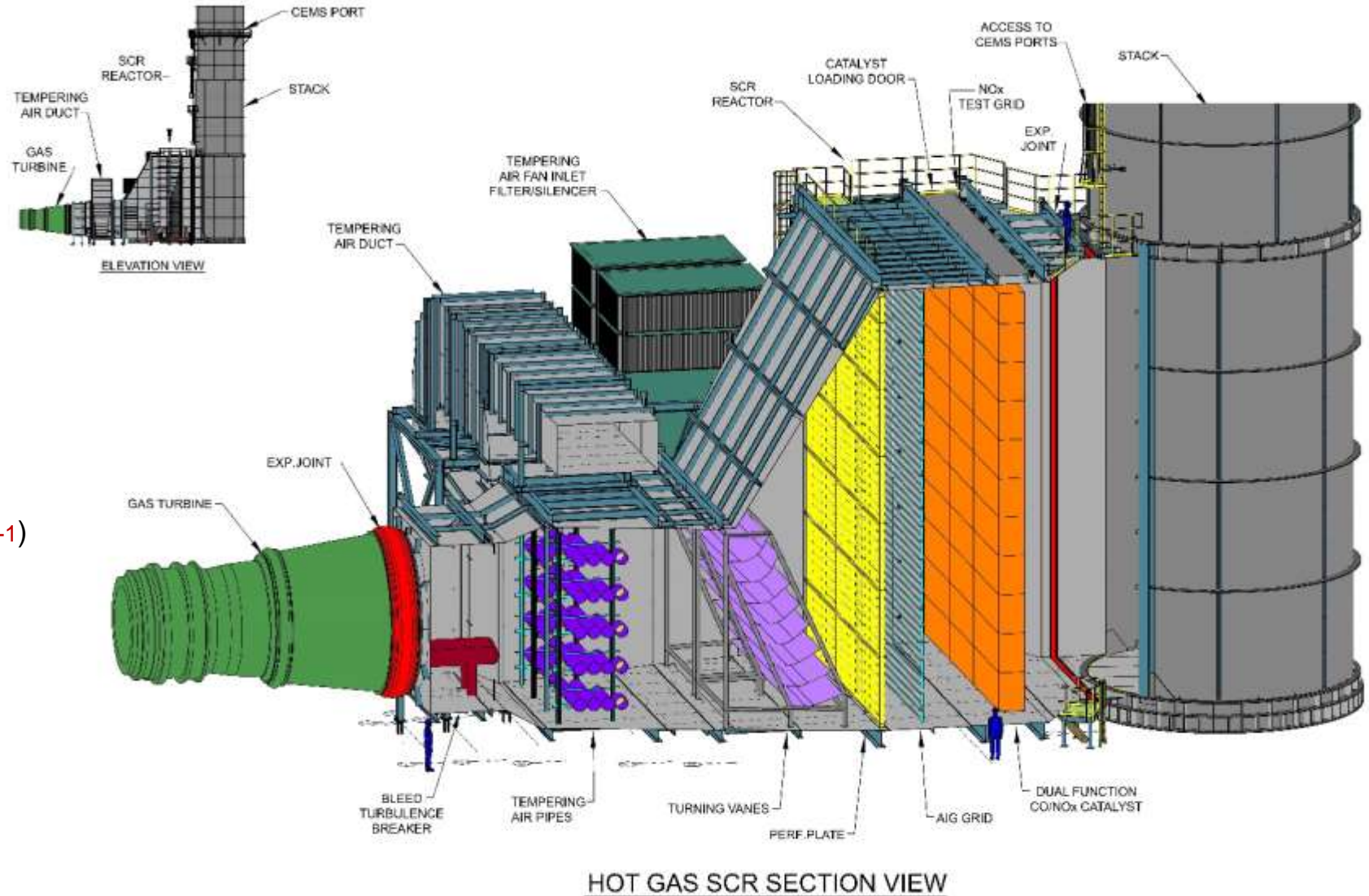
- High V2O5 catalyst formulation
- No tempering air system

➔ **Easiest SCR Design**

Simple Cycle SCR – Typical OEM Scope and Components

OEM Typical Scope

- SCR Inlet Flue
- SCR Casing
- Stack
- Expansion Joints
- Access Platforms
 - Maintenance
 - CEMS
 - Testing
- Catalyst
 - CO
 - NOx, or
 - Dual Function (CO/NOx)
- AIG
- Flow Straightening Devices (See [Note-1](#))
 - Turning Vanes
 - Perforated Plates
- Test Grid (Permanent)
- Tempering Air System
 - Temp. Air Fan/Fans
 - Ductwork & Support Steel
 - Mixing Headers/Pipes
- AFCU Skid
- Technical Advisors
 - Construction
 - Commissioning/Startup
- Training

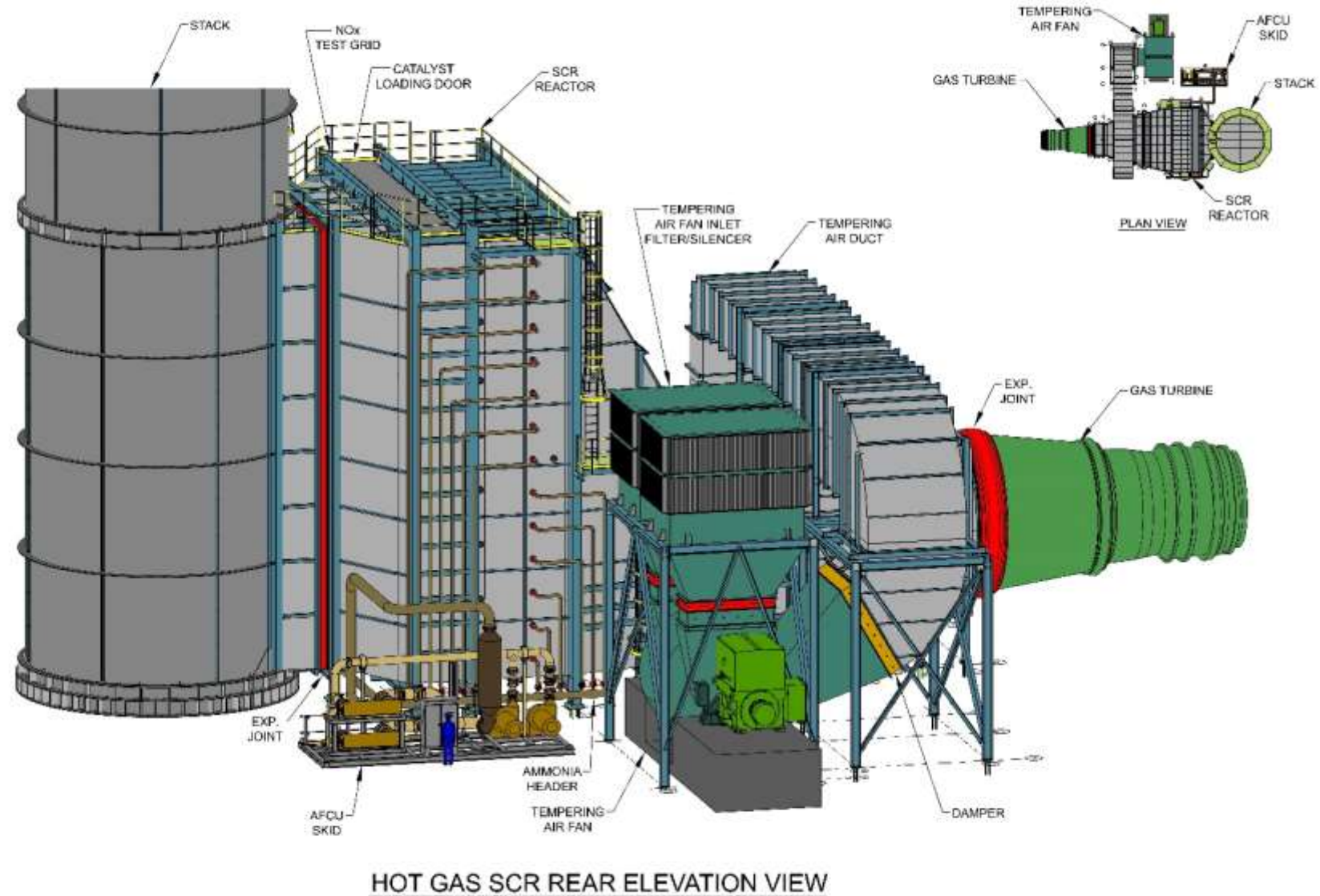


Typical Optional Scope

- PLC/Control System
- Stack Silencer (if required)
- Ammonia Tank Farm
- Ammonia Forwarding Pumps
- Performance Testing

Typical Performance Guarantees

- CO Emissions
- VOC Emissions
- Formaldehyde Emissions
- NOx Emissions
- Ammonia Slip
- Nearfield Noise
- Far-field Noise
- Catalyst Life
- Power Consumption



Catalyst design temperature	Exhaust gas temperature (w or w/o TAF)	Turbine exhaust NOx levels Required NOx removal
Ammonia slip end of life	SO2 to SO3 Conversion	Rapid cross-section change from GT outlet to SCR inlet
Pressure loss allowance	Service life year/hours (project specific)	NH3/NOX distribution
Flue gas flow/temperature distribution	Reactor duct configuration	Fast Start-up / Shutdown

- Distributions are Biggest Challenge of Simple Cycle SCR Design

Short Distance Available to Mix TA

High Velocity Requires Rapid Change in Cross Section

Mix the air into flue gas (**Turbulence**)

versus

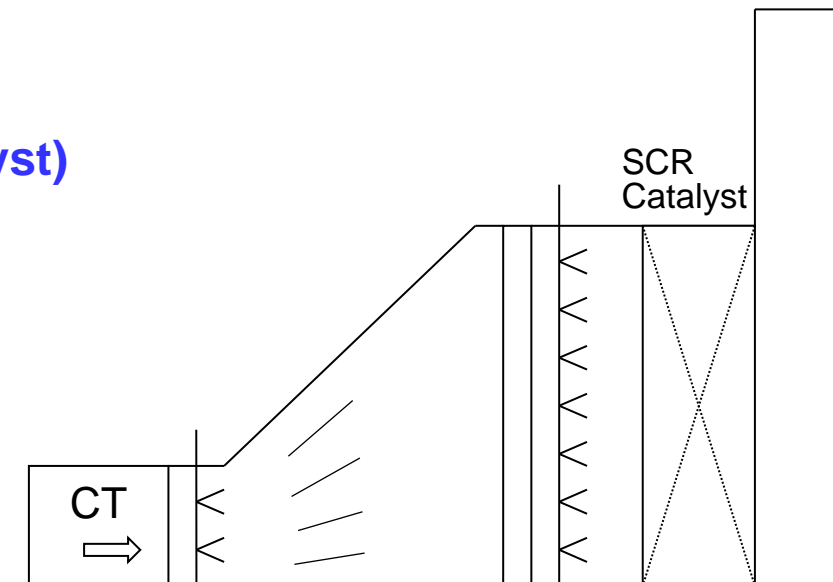
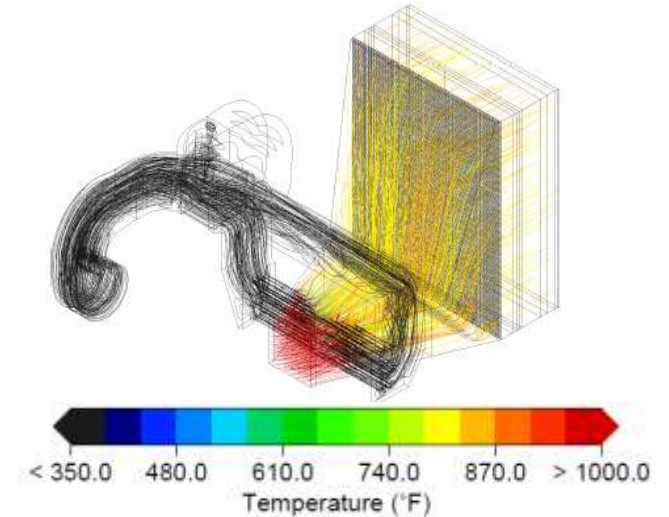
Uniform gas flow necessary at catalyst face and

Proper ammonia distribution in flue gas at SCR catalyst face

(Flow Straightening & Velocity/Temperature Normalizing at Catalyst)

Challenging design gas condition (Typical)

- Flue gas velocity at GT outlet duct ~140-200+ FPS
- Tempering air ~ 20-30+% total flue gas volume
- High exhaust gas temperature ~ 1200+ degF



Industries Lessons Learned



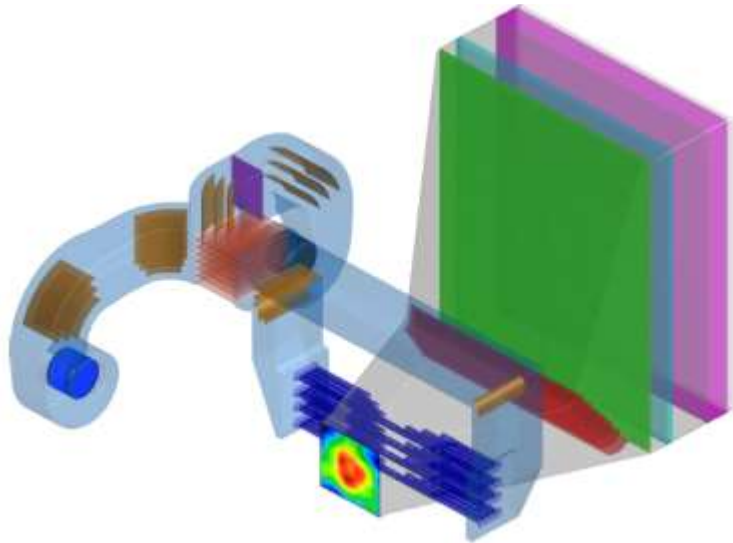
- Insufficient tempering air supply
- Poor tempering air mixing
- Improper catalyst specified
- Catalyst structure failures
- Poor AIG design/distribution
- Catalyst seal/growth failures
- Insufficient ammonia injection capability
- Internal insulation failure
- Seal failures
- Field install not in-line with design



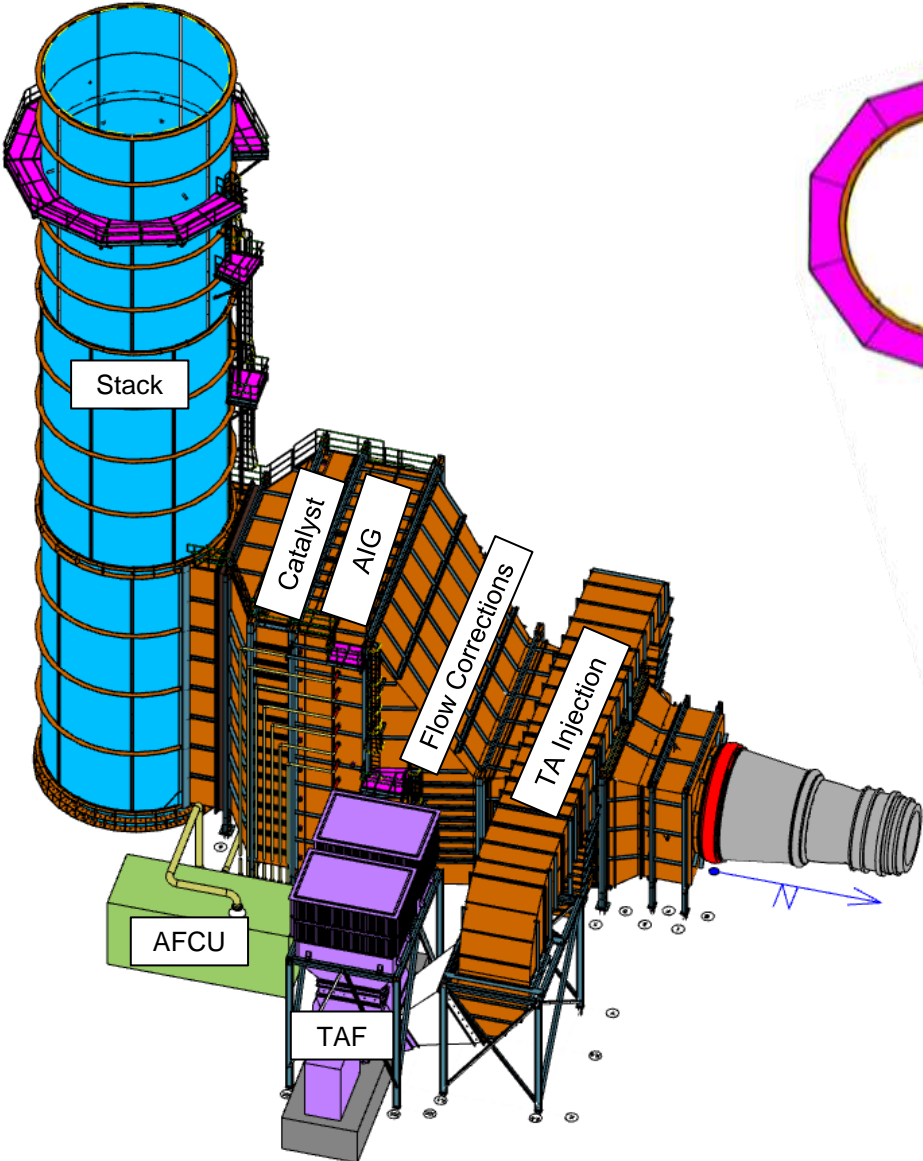
As An Experienced GTSC SCR System Provider, Mitsubishi Power Design Approach Prevents Future Operational and Maintenance Issues

Importance of Flow Modeling

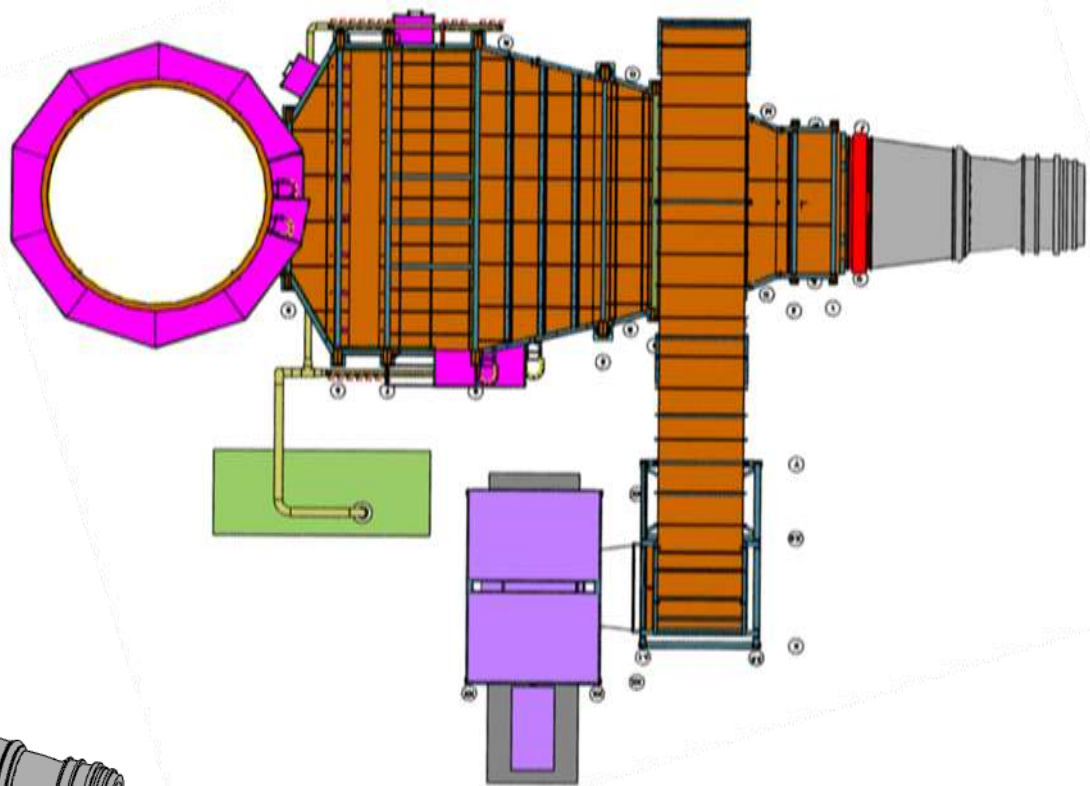
- 1) Develop flow distribution devices and injection ports to
 - a) Achieve acceptable velocity distributions through catalyst
 - b) Achieve acceptable ammonia distribution at the inlet to the SCR catalyst
 - c) Achieve acceptable temperature distributions at the catalyst inlet
- 2) Determine from model measurements the system pressure loss for the final configuration
 - Typical Boundaries: Turbine Diffuser or Process Equipment Exhaust Outlet through Stack Outlet.



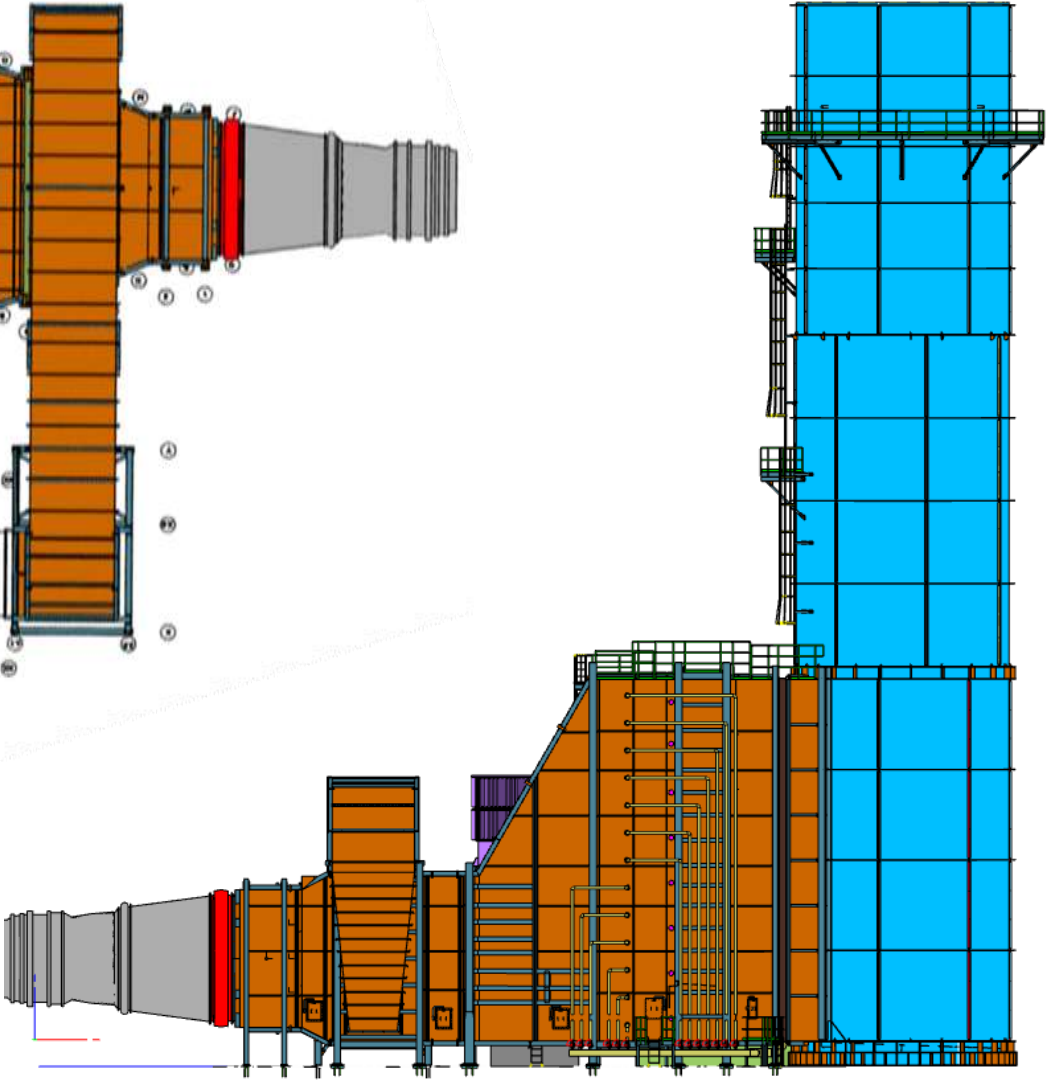
Flow Model Example



Isometric View

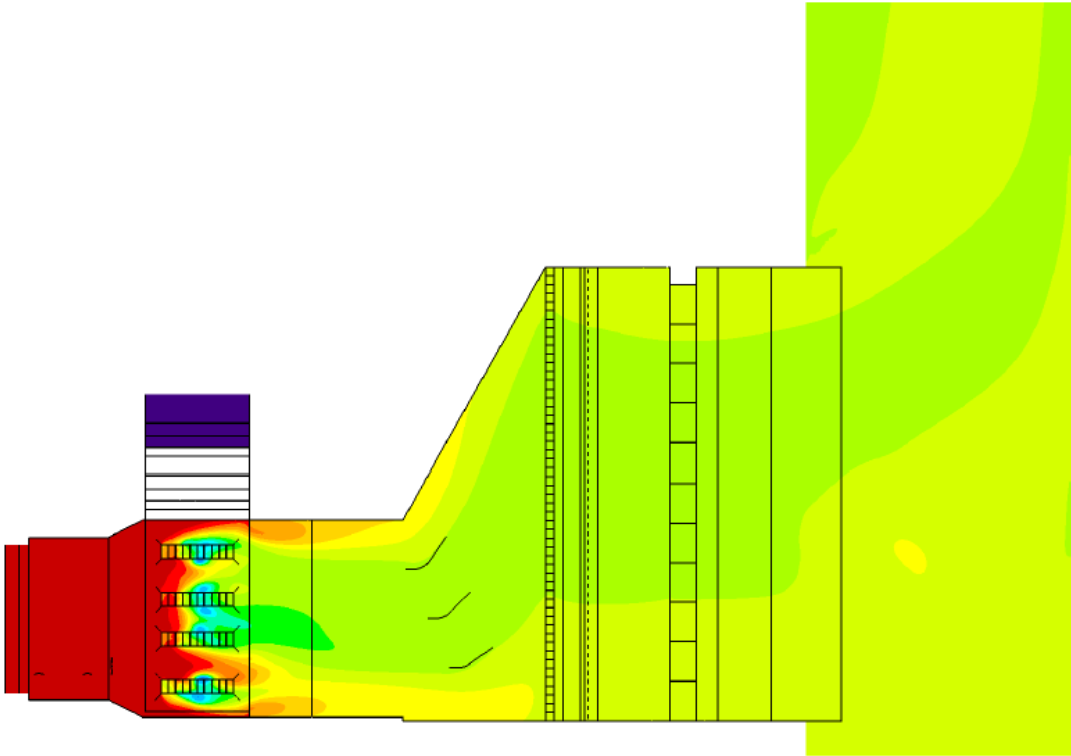


Plan View



Elevation View

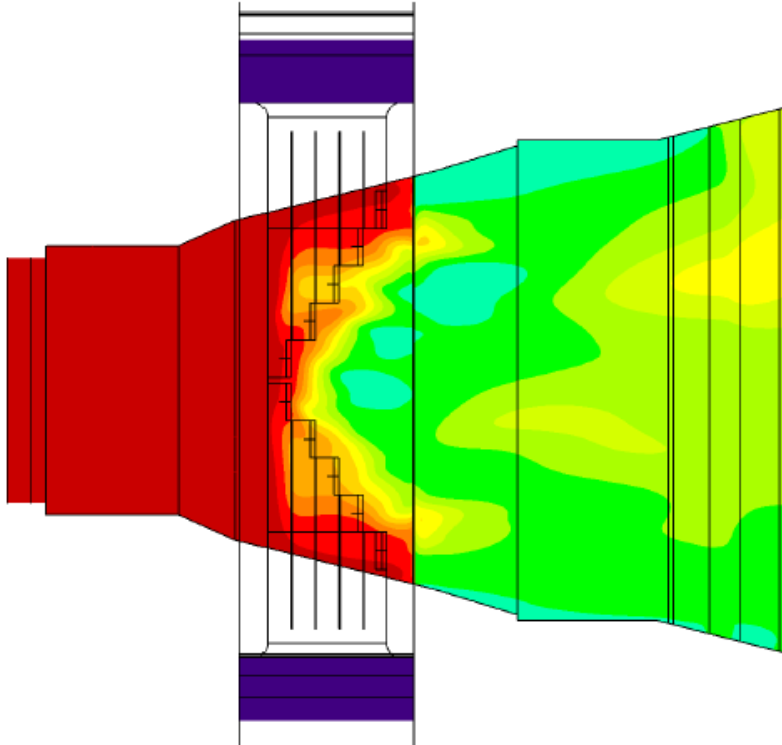
Flow Model Example – Temperature



Turbine CL



Temperature (°F)

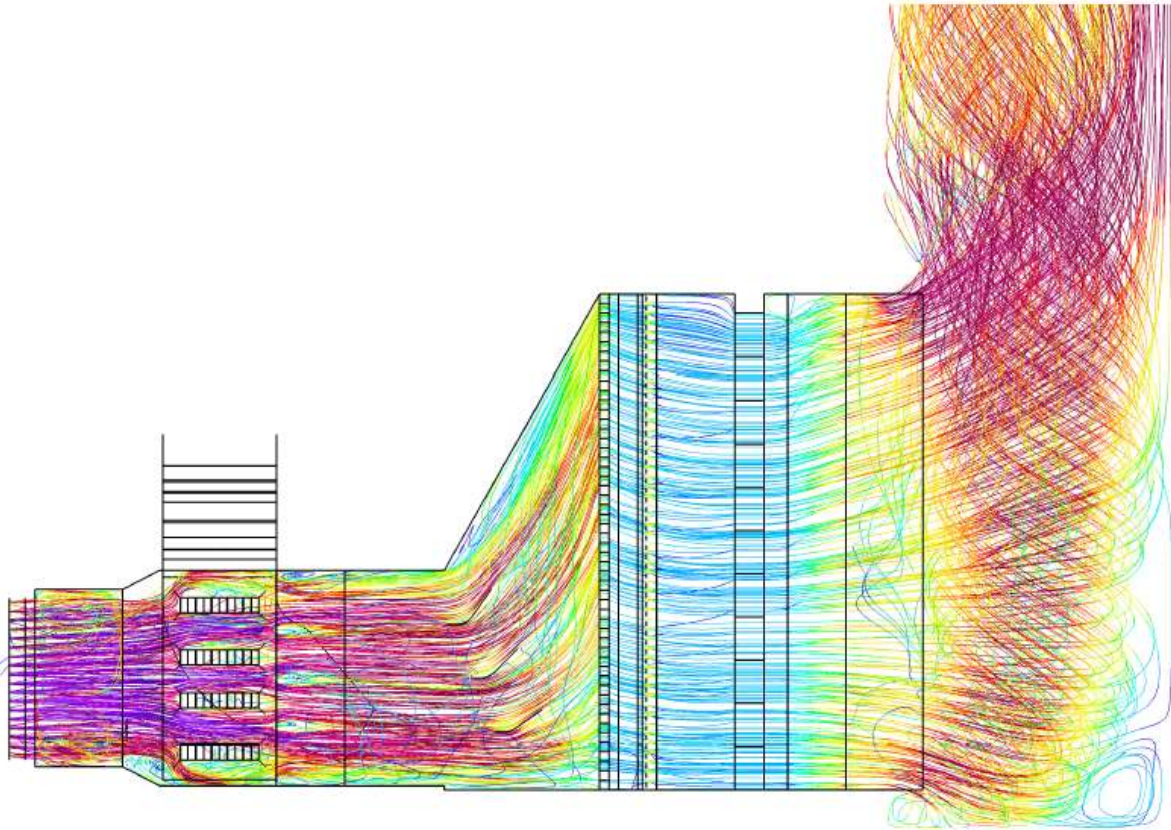


Turbine CL

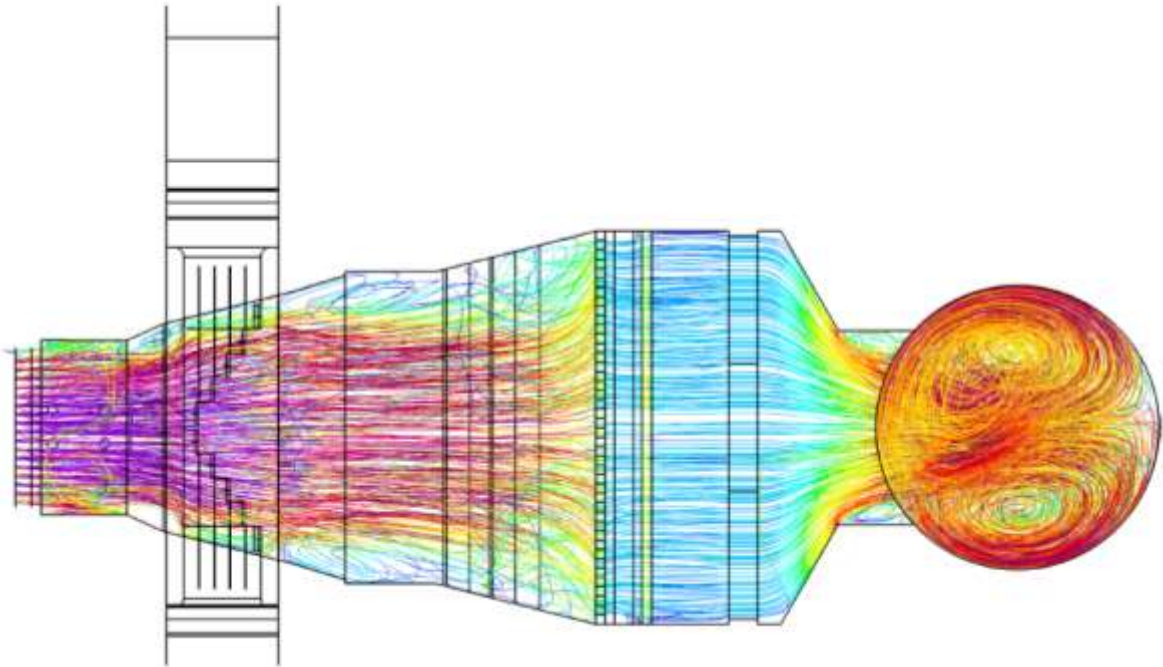


Temperature (°F)

Flow Model Example – Gas Velocity

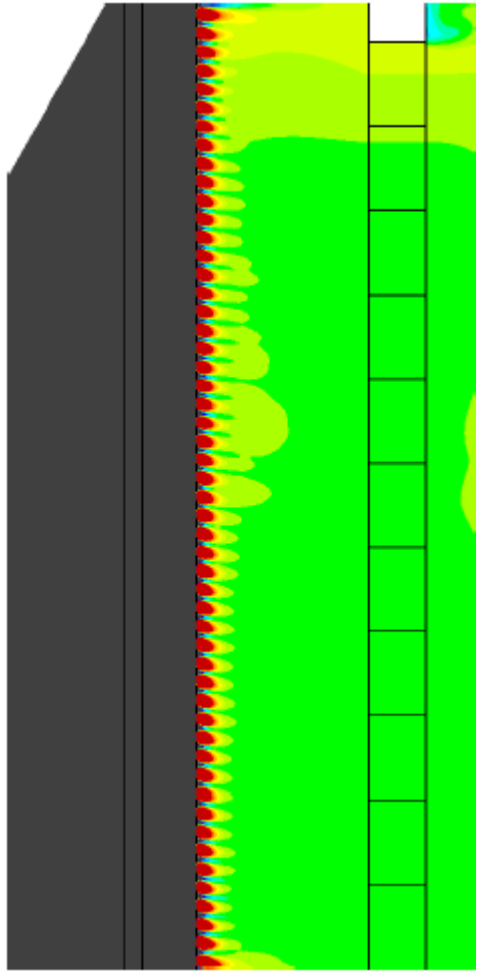


Velocity Magnitude (ft/s)



Velocity Magnitude (ft/s)

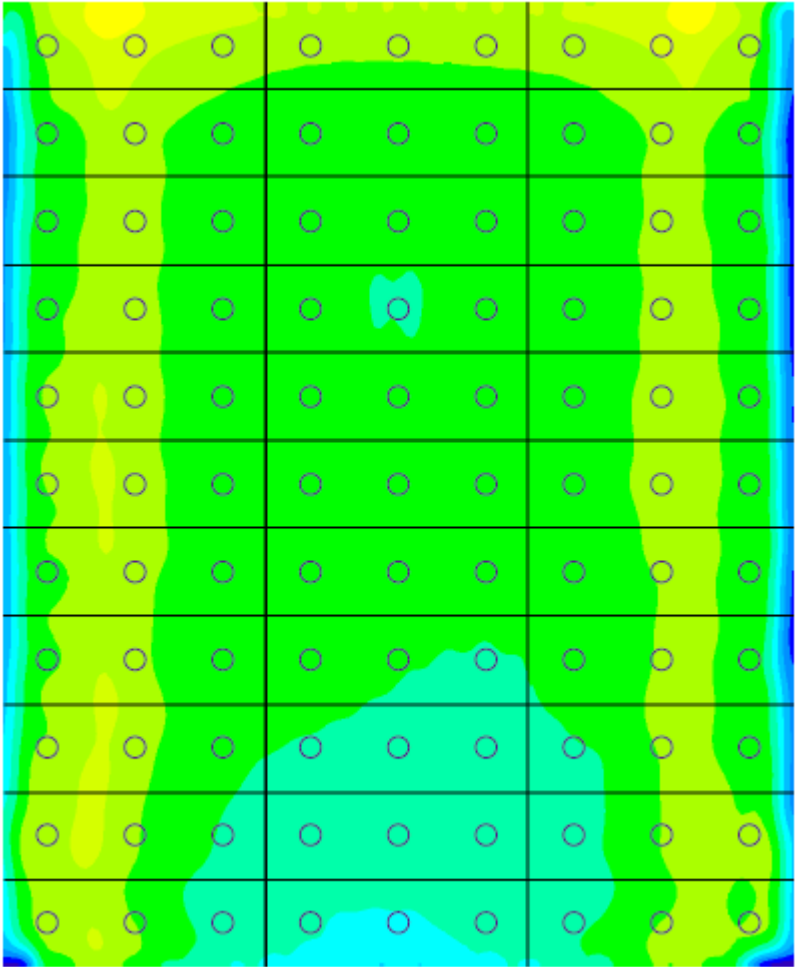
Flow Model Example – NH3 Distribution



Side View



Normalized Ammonia Concentration

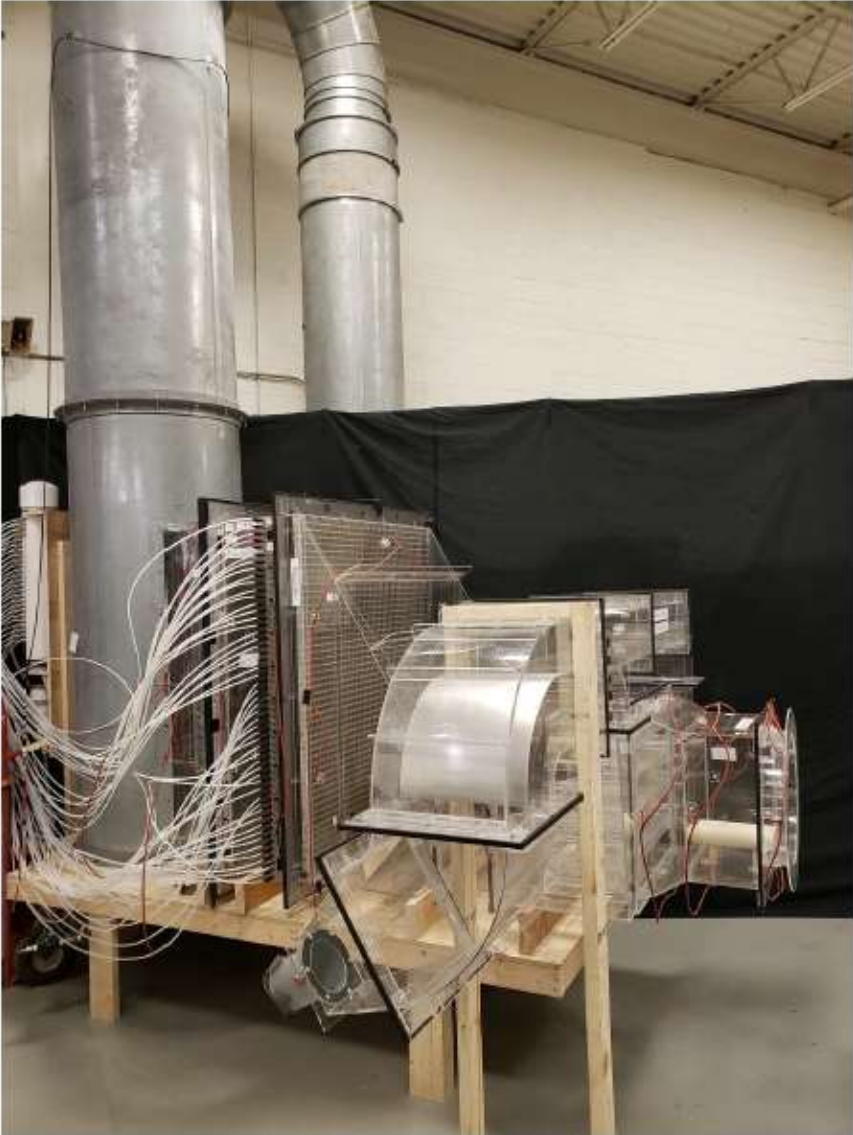


Catalyst Inlet

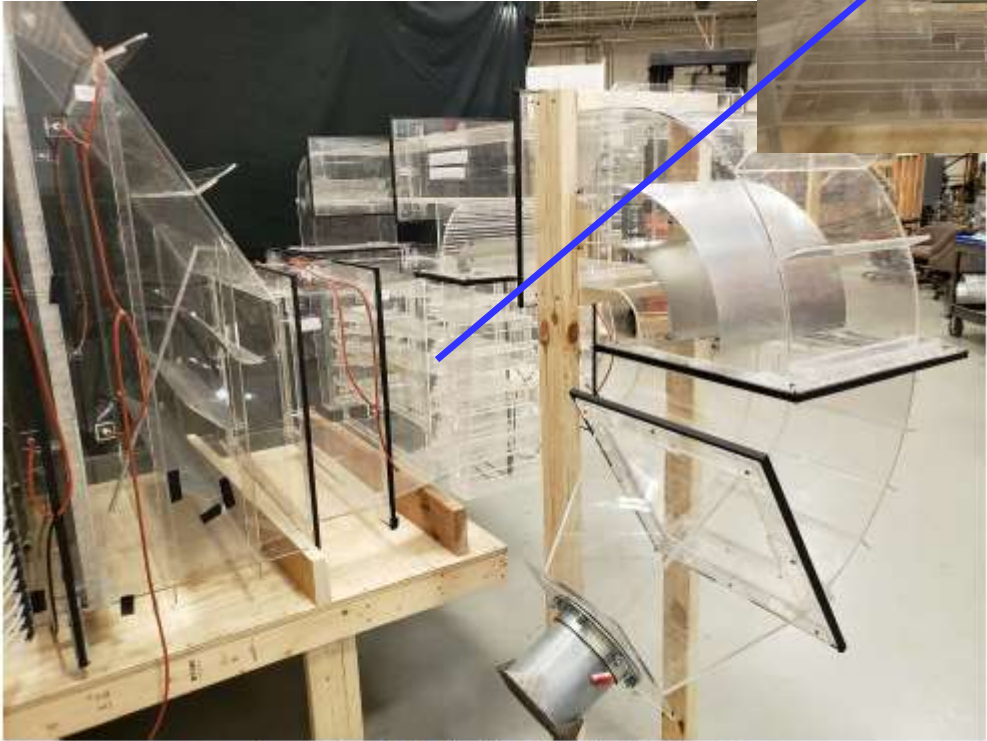


Normalized Ammonia Concentration

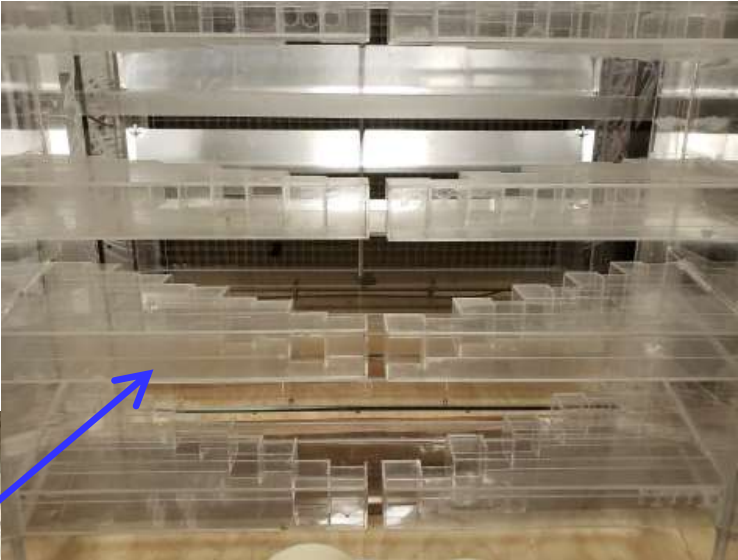
Flow Model Example – Physical Model



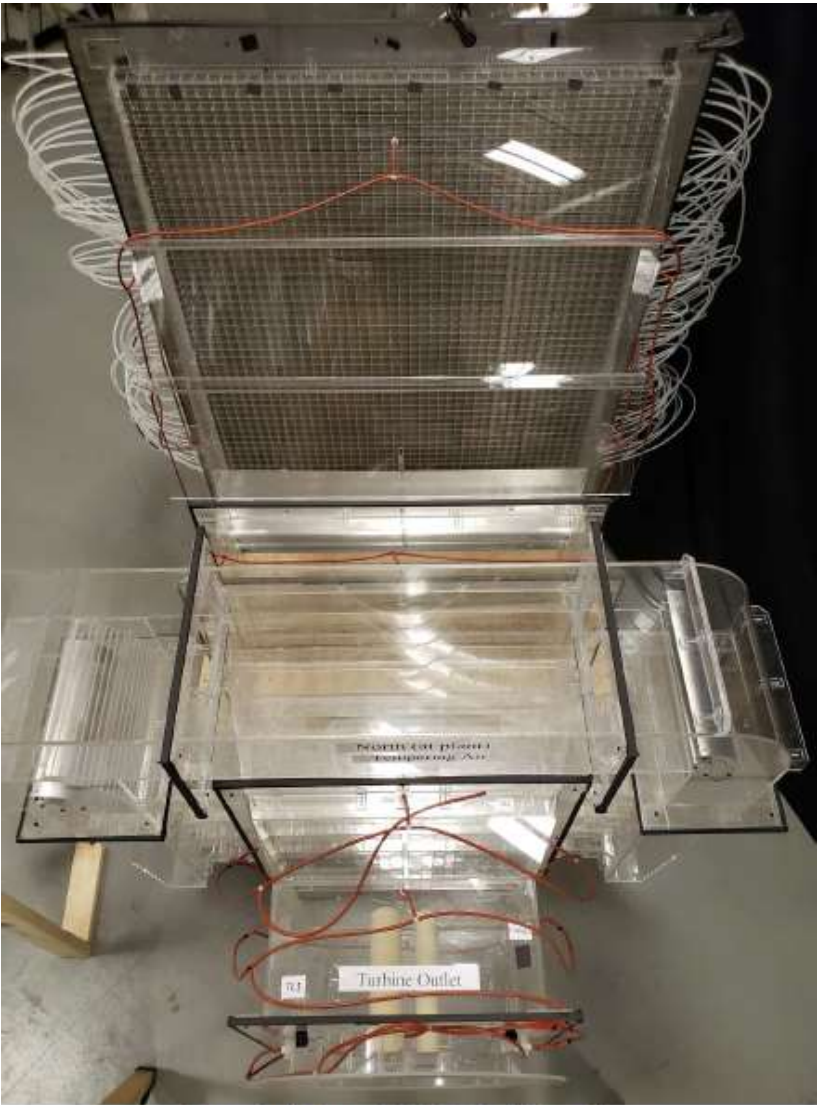
Full Model - View Looking WSW



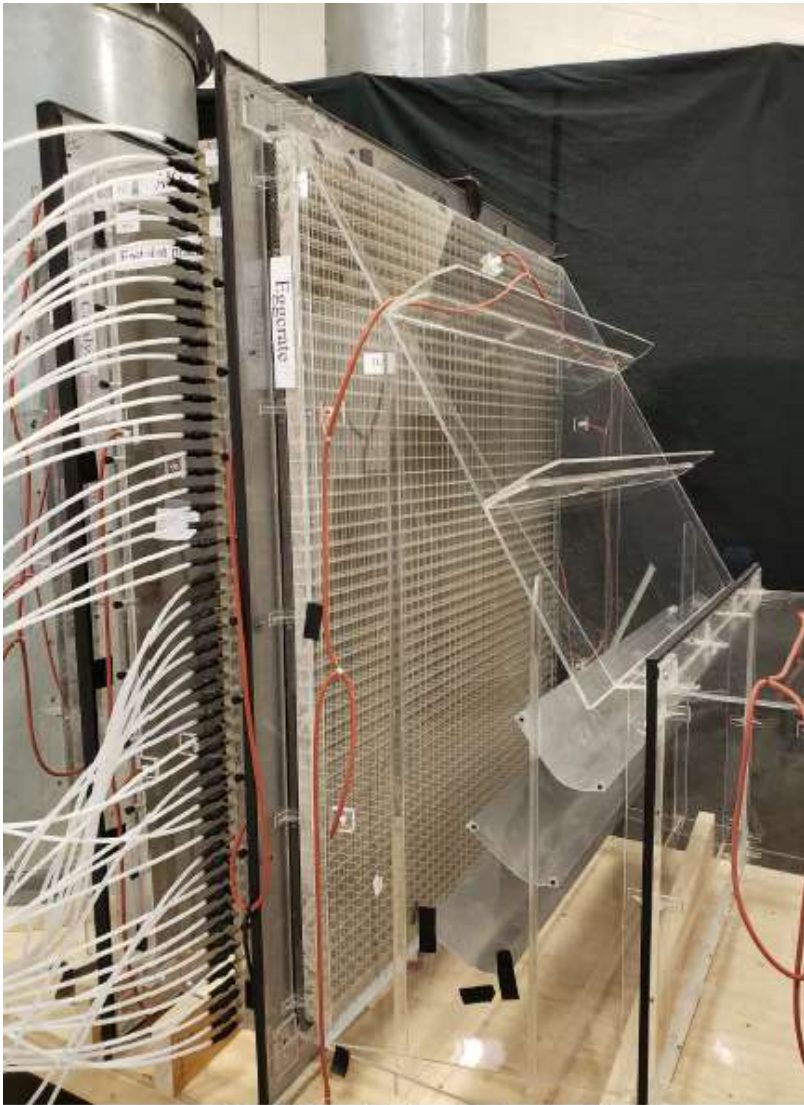
Tempering Air Duct - View Looking Northwest



Flow Model Example – Physical Model



Expansion / Eggcrate / Perf - South Plan View



SCR Catalyst - View Looking Southwest



SCR Catalyst - View Looking Northwest

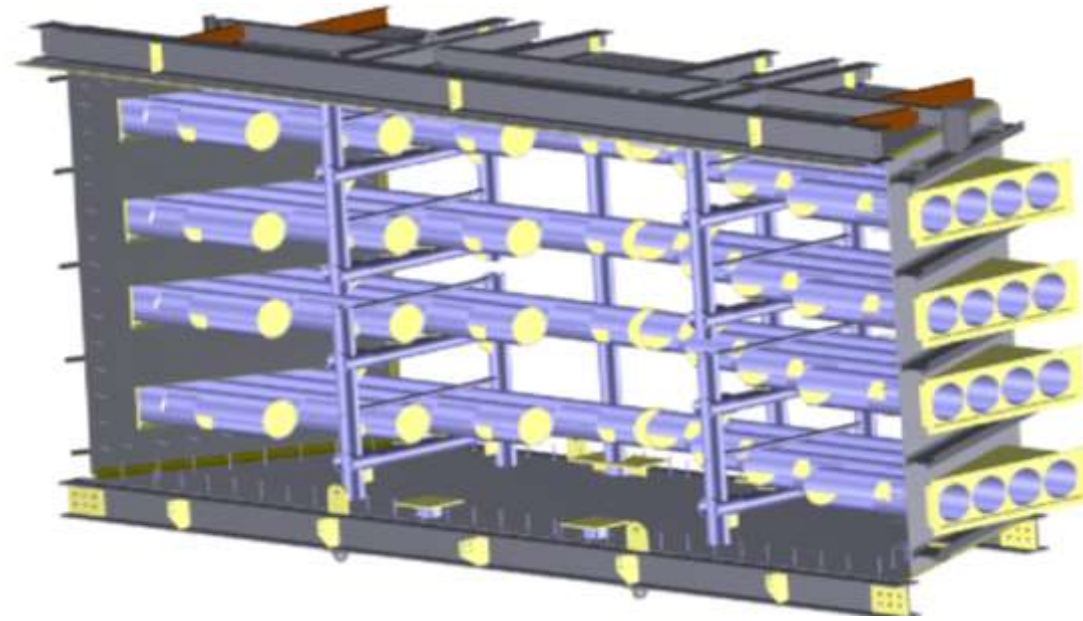
Key Simple Cycle SCR Design Features



TA Injection

- Dual Side Penetration
- Multi Stage Injection Lances
- Flow Penetration for Mixing

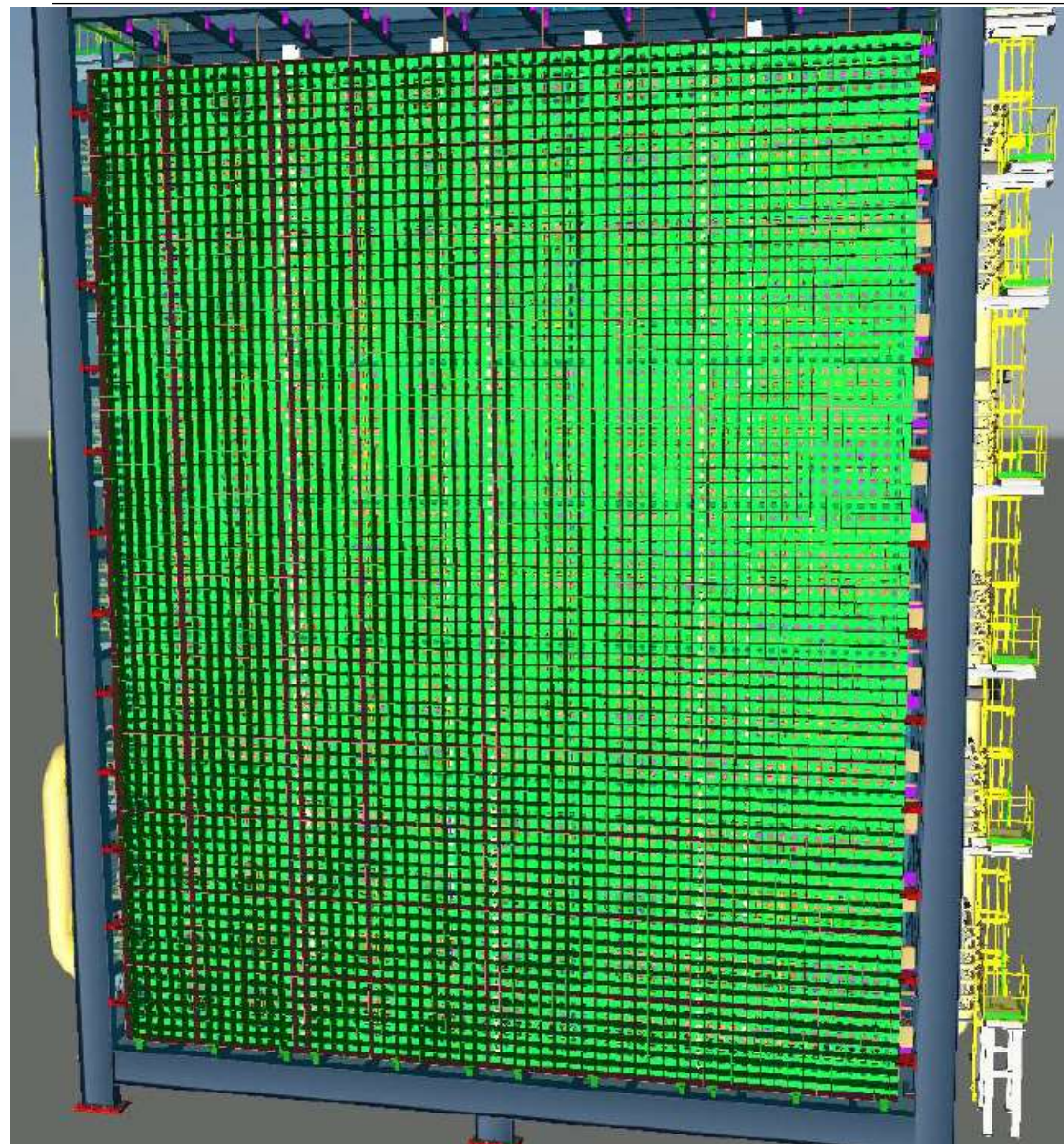
*MPW Proprietary Design



- Double entry tempering air ensures uniform air injection into duct
- Equally staged nozzles discharge across turbine exhaust cross section
- Tempering air penetration in high velocity zones
- High strength retaining structure construction ensures reliable performance

FLUE GAS TEMPERATURE CONTROLS

The required SCR temperature is achieved by modulating the Tempering Air Fan Inlet Control Damper to ensure SCR temperature set point range is satisfied using the average measure SCR temperature as feedback.



Reactor Flow Distributer and Rectifier

- Located upstream of CO catalyst
- Further mixes cool tempering air with hot exhaust gas
- Critical for meeting flow distribution requirements at catalyst
 - Temperature
 - NO_x
 - Velocity

*MPW Proprietary Design



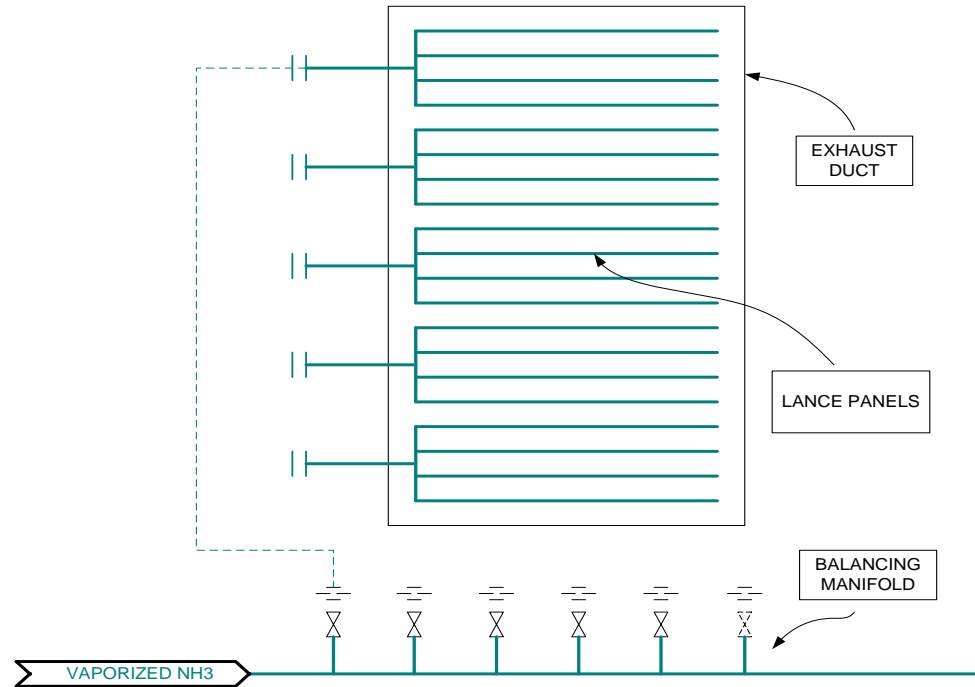
AIG

- Located downstream of CO catalyst
- Injects and disperses NH₃
- Includes static mixer
- High density injection nozzle pattern
- Tunable side-to-side and top-to-bottom
- Individual zones and NH₃ piping are flow modeled to ensure balanced injection rates within each zone
- Critical for meeting NH₃ to NO_x distribution requirement at catalyst

*MPW Proprietary Design



High Density Ammonia Injection Grid



HIGH DENSITY AIG

The AIG design is important for maintaining proper NH₃/NO_x distribution. Must be tunable and contain proper injection nozzle sizing, pattern, and density.

NH₃ CONTROLS

The required NH₃ flow is determined using a feedforward algorithm and the NH₃ flow is trimmed by a feedback signal comparing NO_x set point to actual NO_x measurement.



Typical Steady State Emissions Requirements

Pollutant	Units	Natural Gas	ULSD
NOx	ppmvd@15%O2	2.5	5.0
CO	ppmvd@15%O2	3.5	5.0
NH3 Slip	ppmvd@15%O2	10.0	10.0



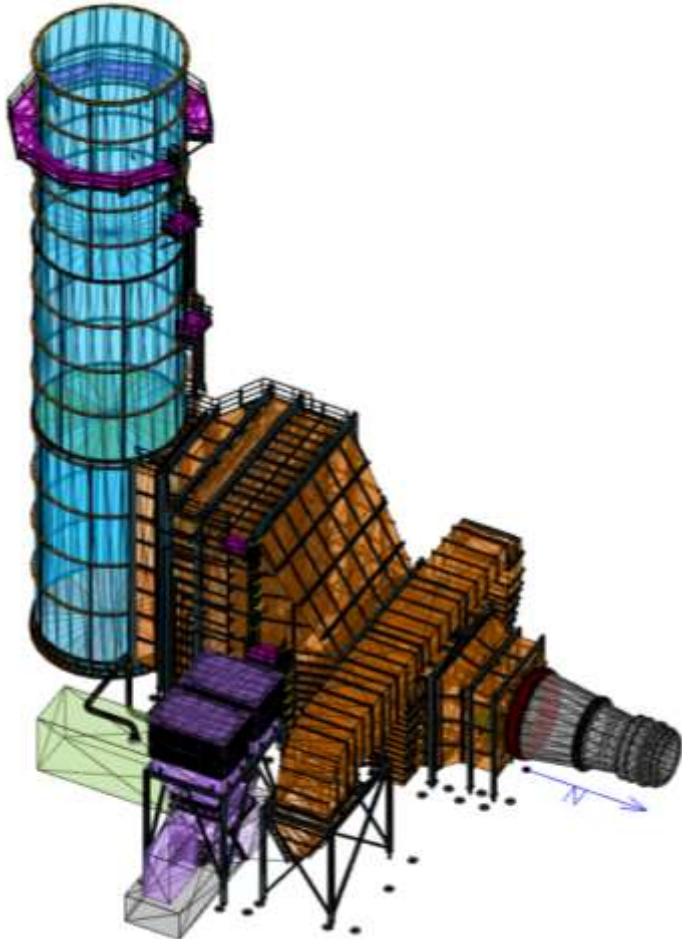


Tempering Air
Fans

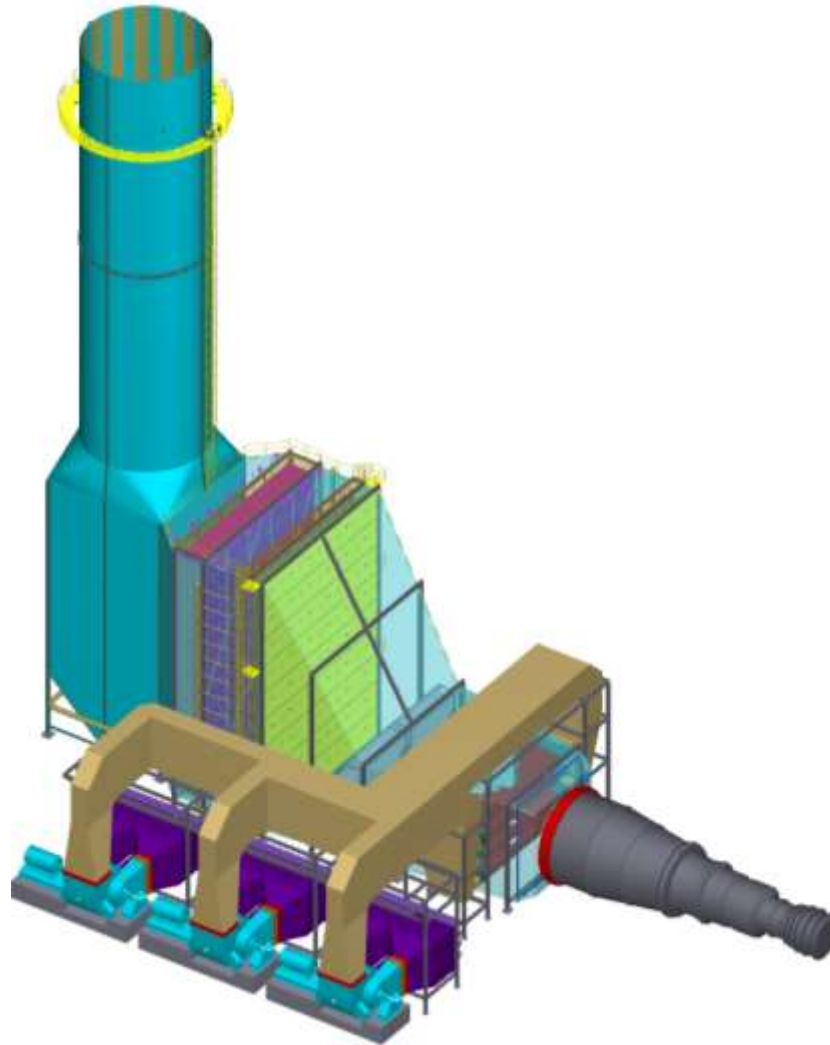
TA Fans

- Various Fan Arrangement
- Inlet housing with screens
- Inlet vane damper controlled
- Redundancy Options

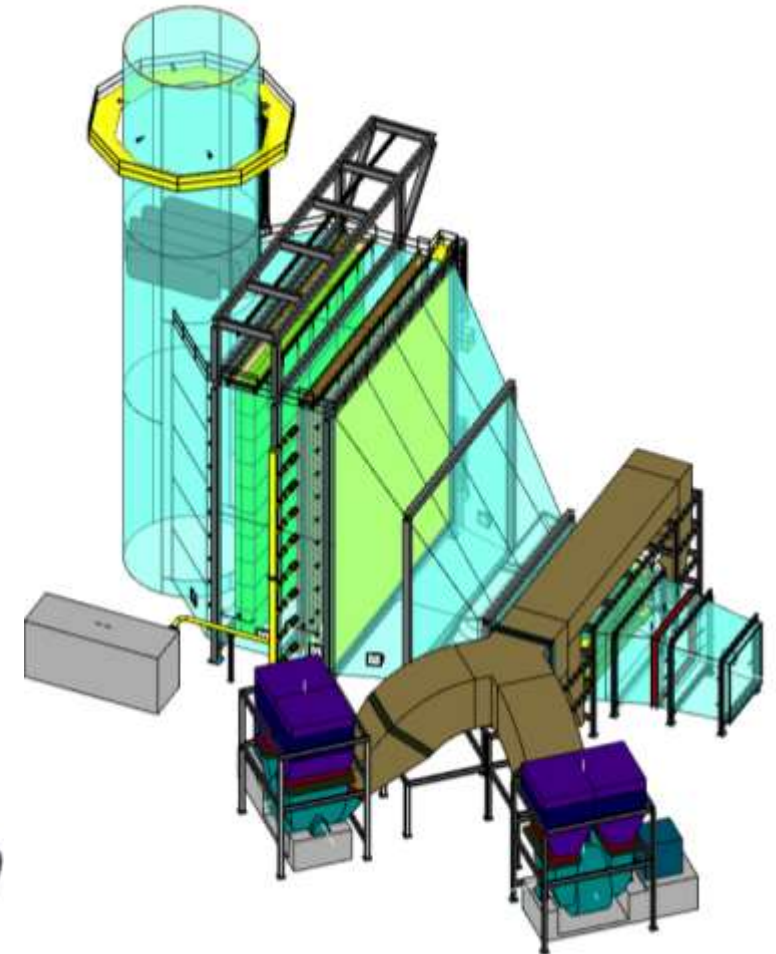
Tempering Air Fan – Redundancy Options



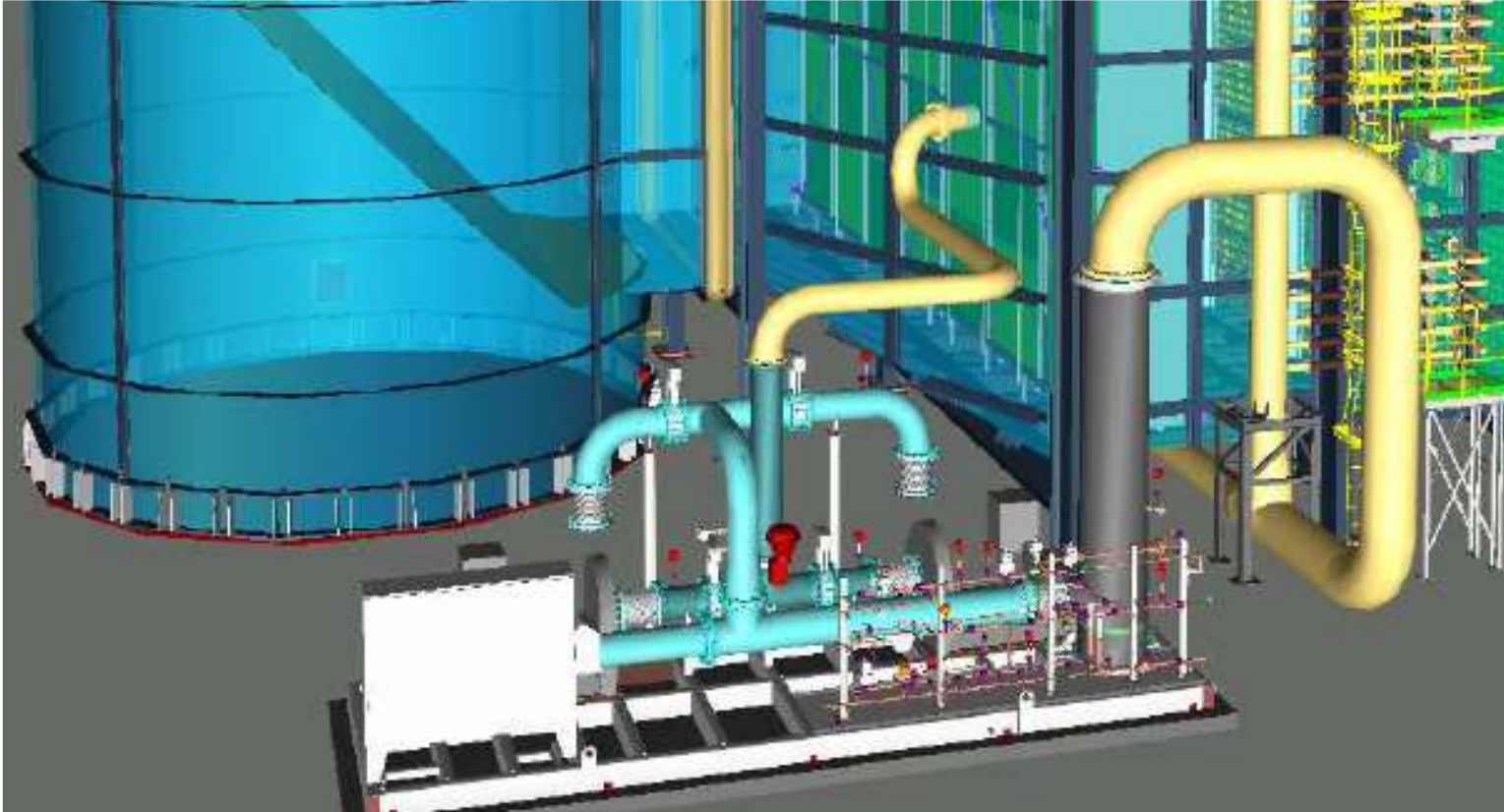
1 x 100%
(No Redundancy)



3 x 50%

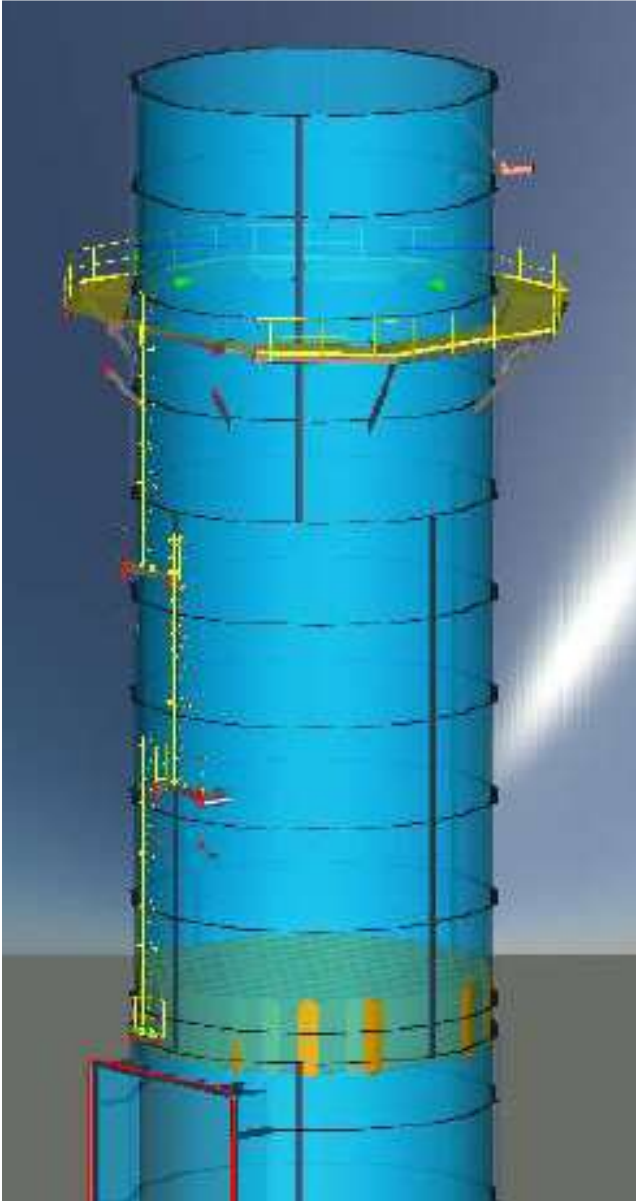


2 x 100%
2 x 50% (No Redundancy)



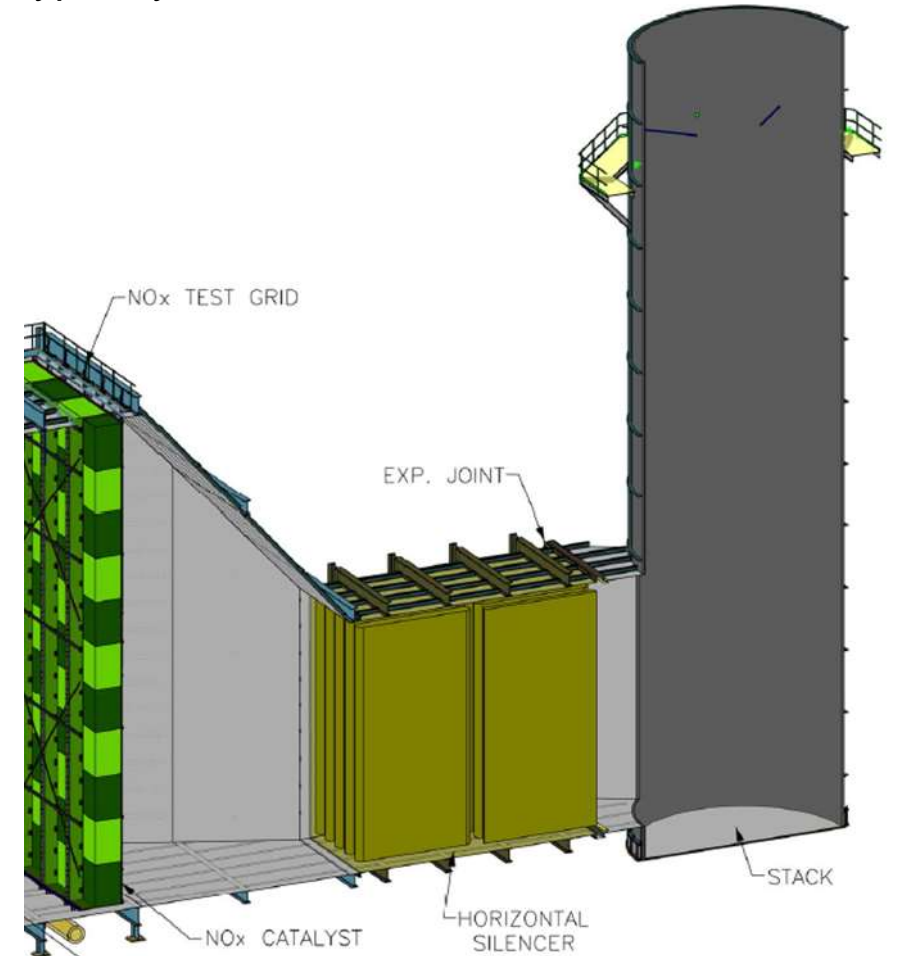
NH3 System

- Aqueous and anhydrous ammonia are most common
- Options for electric heaters or hot gas recirculation as heat source for vaporization
- 2 x 100% fans



Stack and Silencer

- Project specific sizing
- Ports located to meet EPA Requirements
- Silencer typically located in stack



Relevant Simple Cycle SCR Experience

SCR for Simple Cycle GT (Carson Ice Gen)



	Project features
GT	GTG(LM6000)
Output	38MW
Max. operating temp.	876 deg.F / 469 deg.C
NOx removal ratio	90%
COD	1995
Features	No tempering air
	<u>Over 2500 starts</u>
	Low V2O5 catalyst formulation

Site Arrangement

4 x STG6-5000F

Simple Cycle Gas Turbines
with MPW Tempering Air

SCR Systems



SCR for Large Frame Simple Cycle Gas Turbine – NRG Marsh Landing



	Project features
GT	Four(4) SG4T6-5000F CTG's
Output	750MW
Max. operating temp.	1146deg.F / 619 deg.C
NOx removal ratio	87%
COD	May 1, 2013
Features	Innovate tempering air injection
	Fast start vaporization skids
	High density ammonia injection
	NOx control over ramp conditions
	Low V2O5 catalyst formulation

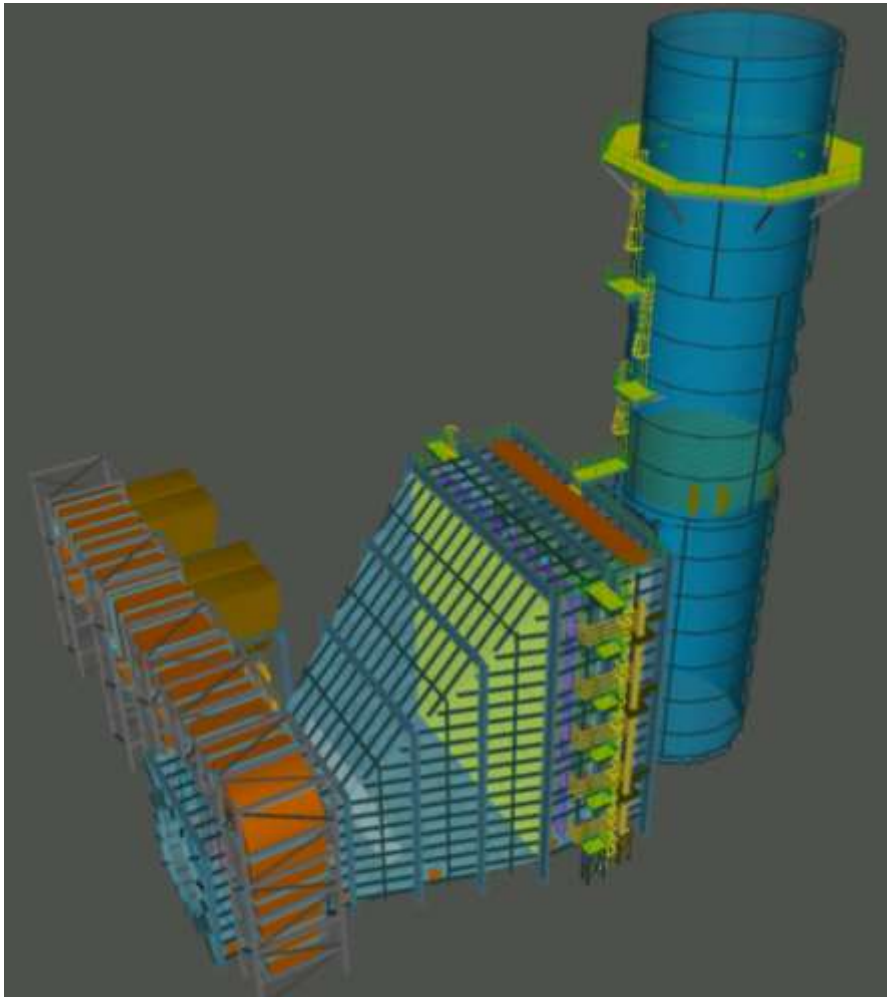
El Paso Electric



	Project features
GT	M501GAC
Output	228MW
Max. operating temp.	Over 1200 deg. F
NOx removal ratio CO removal ratio	88% 70%
COD	2023
Features	Dual Function Catalyst
	Innovate tempering air injection
	Fast start vaporization skids
	High density ammonia injection
	NOx control over ramp conditions

MP Typical GTSC SCR Design Approach for Advanced Class Gas Turbines

GRDA & Southern Company (4 Units)



	Project features
GT	M501JAC
Output	450+MW
Max. operating temp.	Over 1200 deg. F
NOx removal ratio	94%
COD	2026-2027
Features	MPW Proprietary Technologies
	Innovate tempering air injection
	High density ammonia injection
	Low V2O5 catalyst formulation

MP Typical GTSC SCR Design Approach for Advanced Class Gas Turbines

Reference Units: GT Simple Cycle SCR Systems

#	Plant	CT Model	GT Outlet Gas Temp (°F)	Temp. Air Fan	CT Output (MW)	Fuel	DeNOx Eff. (%)	COD	Country
1	Moon Light	No Data	No Data	No Data	100	GAS	84	1984	JAPAN
2	Kanazawa Factory	Frame: M701F	1112	Yes	150	GAS	86	1992	JAPAN
3	TEPCO, Yokosuka Power Station U2	Frame: M701DA	986	Yes	144	GAS	60	1992	JAPAN
4	Toyosu Power Station U1 - U2	2 x Frame: F6	993	No	42	GAS	60	1992	JAPAN
5	Sodegaura Power Station U1	Frame: F9	1024	No	127	GAS	60	1993	JAPAN
6	Ice-Gen, Carson U1 - U2	2 x Aero: LM 6000	875	Yes	38	GAS	90	1995	USA
7	SMUD, McClellan	Frame: GE 7EA	1020	Yes	75	GAS	90	2004	USA
8	Himeji No. 1 Power Station, U1 - U2	2 x Frame: H-25	1092	Yes	32.7	GAS	60	2012	JAPAN
9	NRG Marsh Landing Gen. Station U1 - U4	4 x Frame: SGT6-500F	1146	Yes	200	GAS	87	2013	USA
10	Mickleton Energy Center	Frame:W501AC	900	No	45	GAS	75	2015	USA
11	Carll's Corner Energy Center U1 - U2	2 x Aero: FT4	900	No	33	GAS	76	2015	USA
12	Wellhead Laluz	Aero: LM 6000	<900	Yes	50	GAS	95	2016	USA
13	SERC, Stanton U1 - U2	2 x Aero: LM 6000	855	Yes	Total 98	GAS	95	2020	USA
14	MM15 Waters River Station/Peabody	Aero: FT4000	922	Yes	70	GAS/OIL	90	2023	USA
15	El Paso Electric	1 x M501GAC	1265	Yes	228	GAS	88	2023	USA
16	GRDA – GREC U4	1 x M501JAC	1230	Yes	450+	GAS	94	2026	USA
17	Southern Company (GPC) – Yates U8-U10	3 x M501JAC	1230	Yes	450+	GAS/OIL	94	2027	USA
18	Confidential Client (Technical Selection)	2 x M501JAC	1230	Yes	450+	GAS	94	2028	USA

29 Units Total



**MITSUBISHI
POWER**