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Simultaneous Waste Heat and Water Recovery from Power Plant Flue Gases for Advanced Energy System

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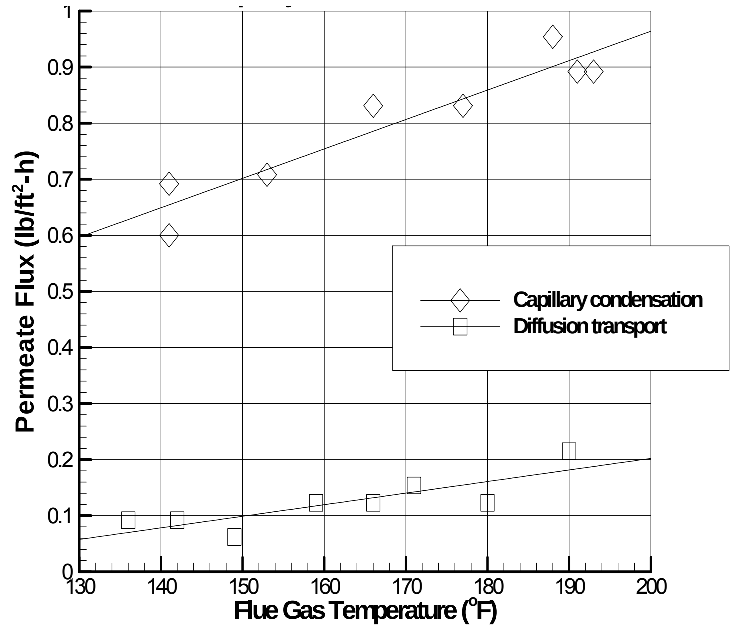
Simultaneous Waste Heat and Water Recovery from Power Plant Flue Gases for Advanced Energy System

Agenda:

- Technology Development Background
- Project Objectives, and Team Members
- Detailed Project Tasks and Progress

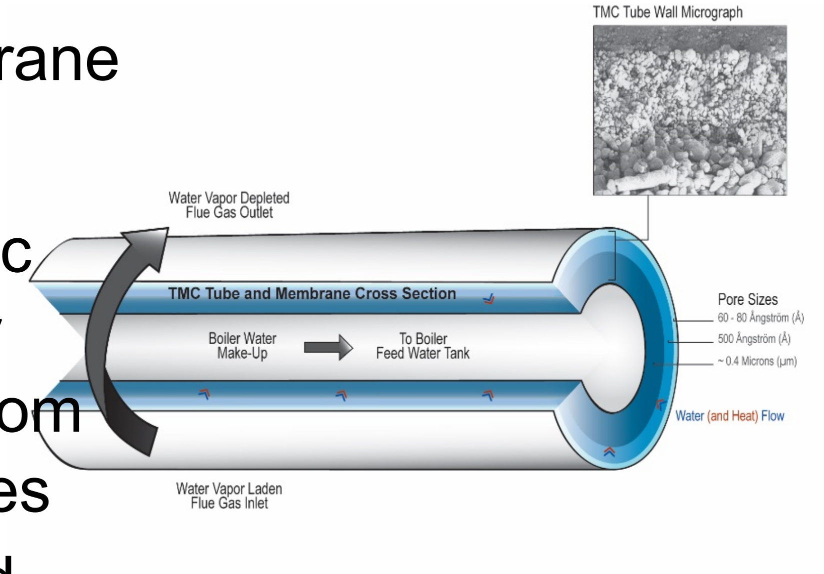
Background: Water Vapor Membrane Separation Study at GTI

- ❑Extensive study for both porous and non-porous membranes at GTI
- ❑Porous membrane was selected for its potential high water vapor transport flux for industrial uses, and its four vapor separation modes as below:
  - Molecular Sieving
  - Knudsen diffusion
  - Surface diffusion, and
  - Capillary condensation
- ❑Working mode of porous membrane is critical for water vapor transportation.
  - ✓ High permeate flux and high separation ratio could only be achieved in a capillary condensation mode for water vapor.



Simultaneous Water Vapor Latent Heat and Water Recovery from Flue Gases

- GTI developed Transport Membrane Condenser (TMC) technology
- TMC uses a nanoporous ceramic membrane to selectively recover water vapor and its latent heat from natural gas combustion flue gases
  - Increase boiler efficiency and save water, avoids corrosive condensate
- Successfully developed for industrial boilers



TMC tubes in a bundle assembly

TMC Heat/Water Recovery System for Industrial Applications

- ❑ TMC modules integrated into a housing to form a TMC unit with controls.
- ❑ Boiler feedwater is pre-heated to boost efficiency
- ❑ Fresh makeup water requirement is reduced by flue gas water vapor recovery

Cannon Boiler Works Ultramizer®

- ❑ Advanced TMC-based heat recovery systems for industrial, large commercial, and institutional boilers commercially available from <u>Cannon Boiler Works</u>
  - ➢ Current sizes around 10-20 MMBtu/hr
  - ➢ 92-95% efficiency
- ❑ Ongoing development to scale-up to larger sizes
  - ➢ Over 20 MMBtu/hr

Industrial boiler heat recovery with Ultramizer product at a brewery

TMC System Field Demo for a Laundry Steam Tunnel

TMC unit installed on top of the Steam Tunnel stack

The Steam Tunnel stack gas before and after TMC installation

- ✓ Recovered water and heat are used for washing machine hot water, saves energy and water from a steam boiler.

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Transport Membrane Condenser for Water and Energy Recovery from Power Plant Flue Gas

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TMC Applications for Water Vapor Recovery from Coal Flue Gases

Benefits for the energy industry:

- ✓Recover mineral-free water for boiler makeup and other plant uses, and reduce waste water disposal.
- ✓Recover waste heat from flue gases to greatly enhance the energy system efficiency. Will be more significant for high moisture content flue gases from future advanced power generation system, which has much more latent heat available and easy to capture.
- ✓Reduce water vapor emission to the environment to meet power plant regulations, and improve plant heat rate.

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Pilot scale TMC Field Slip Stream Testing at a Power Plant

Pilot unit test in the field: left shows in installation, right shows in testing with a tent

Current Project Objectives and Team

❑ Project Objectives:

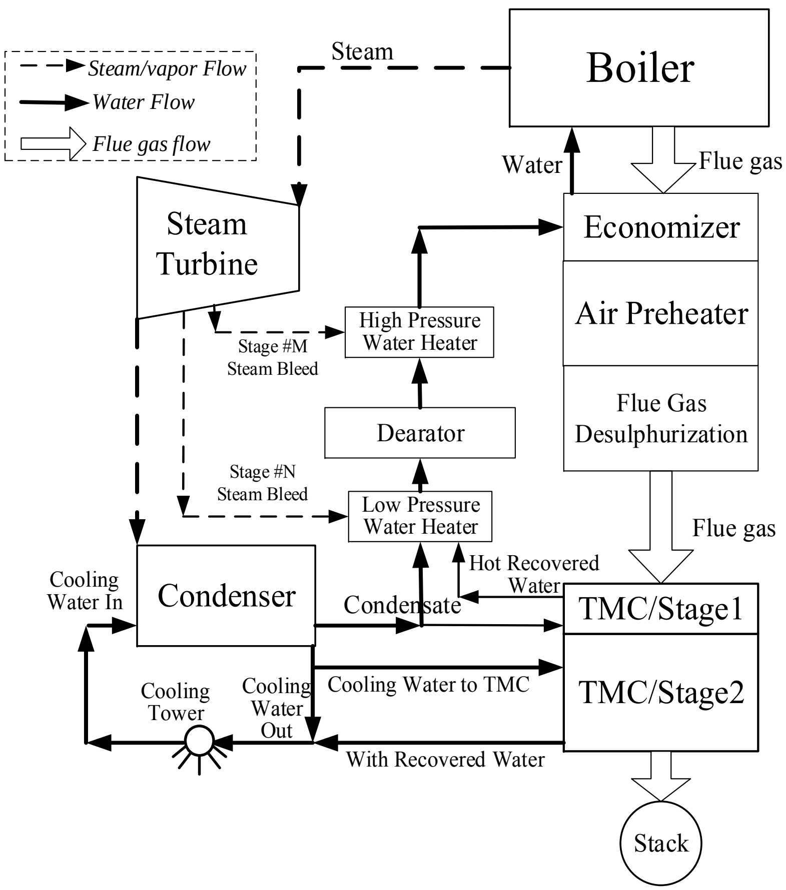
- Further improve TMC water vapor transport flux and system efficiency, ready for high moisture content flue gases from future advanced power generation system, and evaluate membranes for low PH value flue gas applications,
- Explore low cost TMC unit fabrication and control methods to reduce capital and installation costs.

❑ Project Team:

Gas Technology Institute(GTI), Media and Process Technology(M&P), SmartBurn and Florida International University (FIU).

Task 2: Process Modeling

TMC Power Plant Integration Concept Update



Flue Gas Water/Heat Recovery with a Two-stage TMC

- The TMC power plant integration concept has been improved and updated, especially for TMC/stage2. It will use the outlet cooling water from the condenser for TMC/stage2, instead of using the inlet cooling water. In this way, the steam condenser performance will not be affected at all, which will ensure the original plant cycle efficiency not negatively affected by the cooling water use for TMC/stage2.

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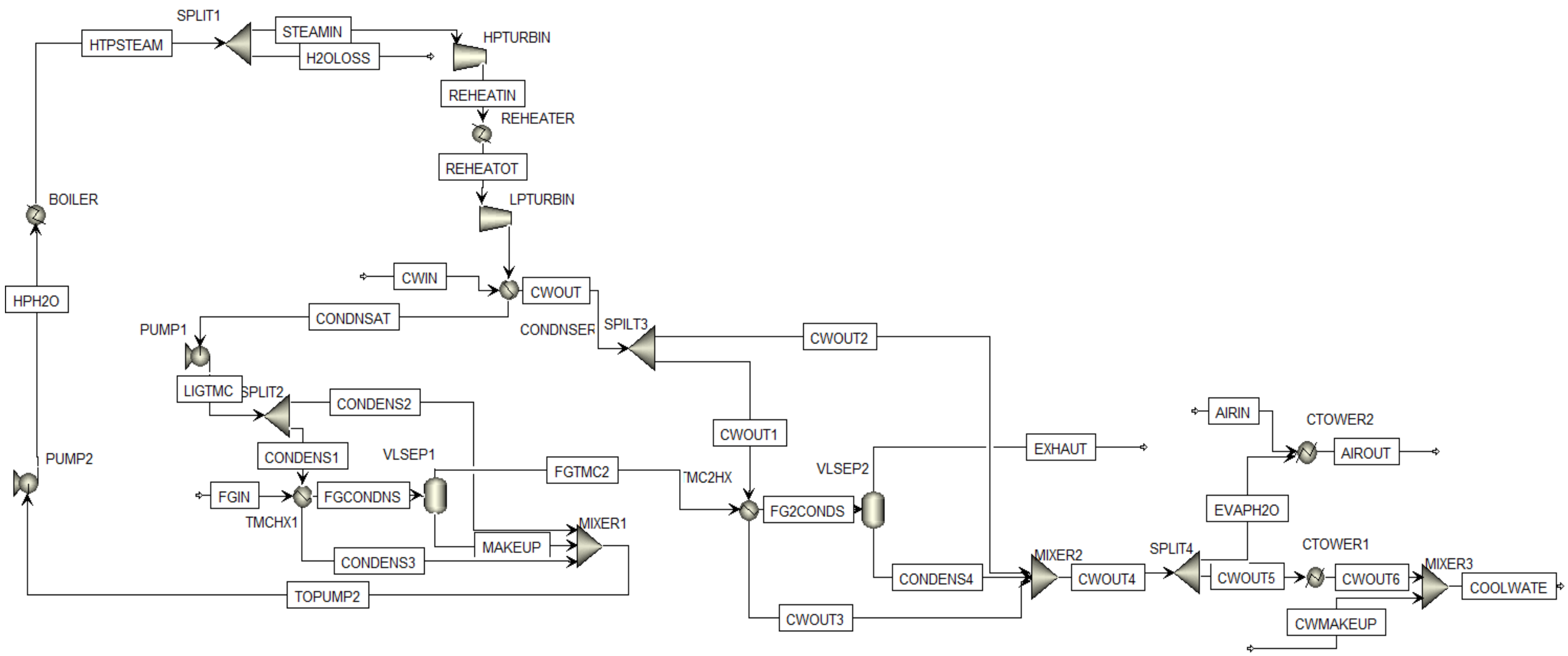
Task 2: Process Modeling

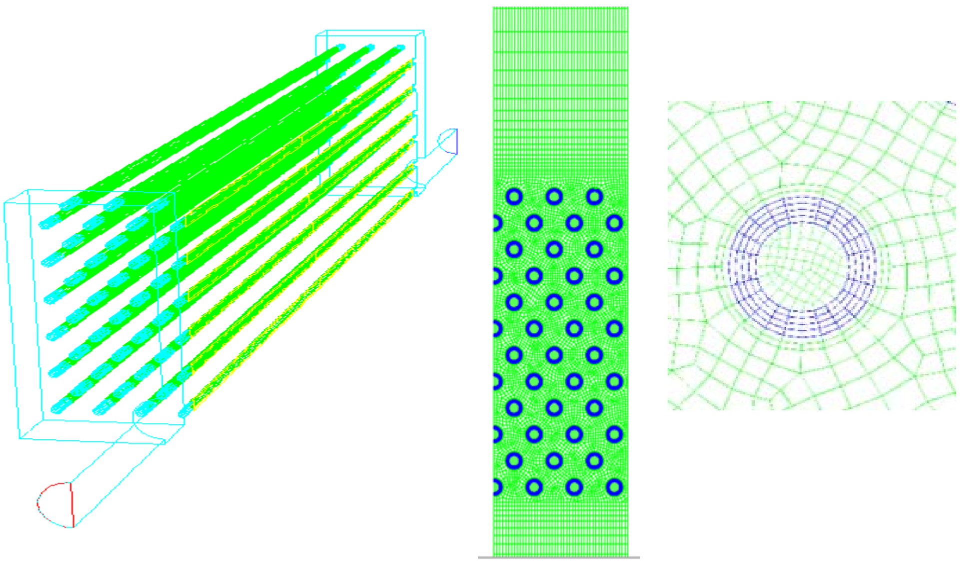
Aspen Simulation with TMC integrated into a Power Plant



Aspen study shows, if the TMC/stage1 is integrated into the steam cycle, it can increase the cycle efficiency by 0.72% from a baseline 36.3%, save 2% makeup water which is 500kg/min for a 550MW unit. TMC/stage2 can recover about 3,506 kg/min water for cooling water makeup.

Task 2: CFD Simulation for Design

Use CFD simulation tools we developed in previous projects, optimize the two stage TMC unit design to achieve maximum water/heat recovery

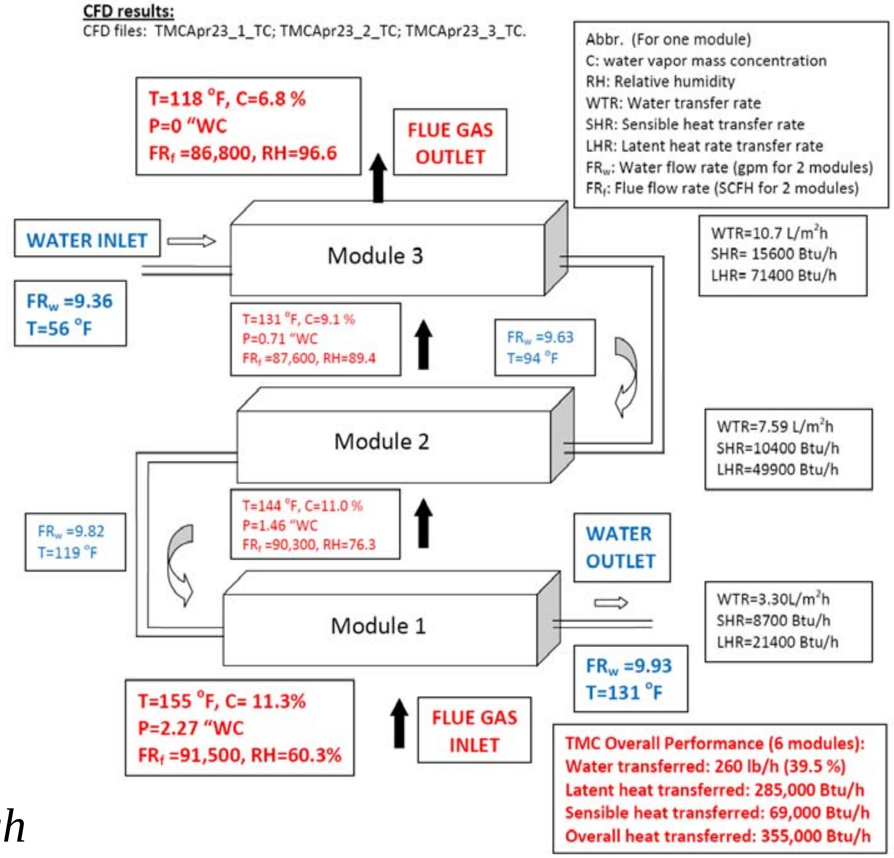


TMC module CFD simulation geometry and mesh

Case 4: New 3-pass TMC design
(Same inlet conditions as Case 1)

Flue FR	Flue T_{in}	Flue C_{in}	Water FR	Water T_{in}
SCFH	°F		gpm	°F
95902.7	155	11.3%	9.32	56

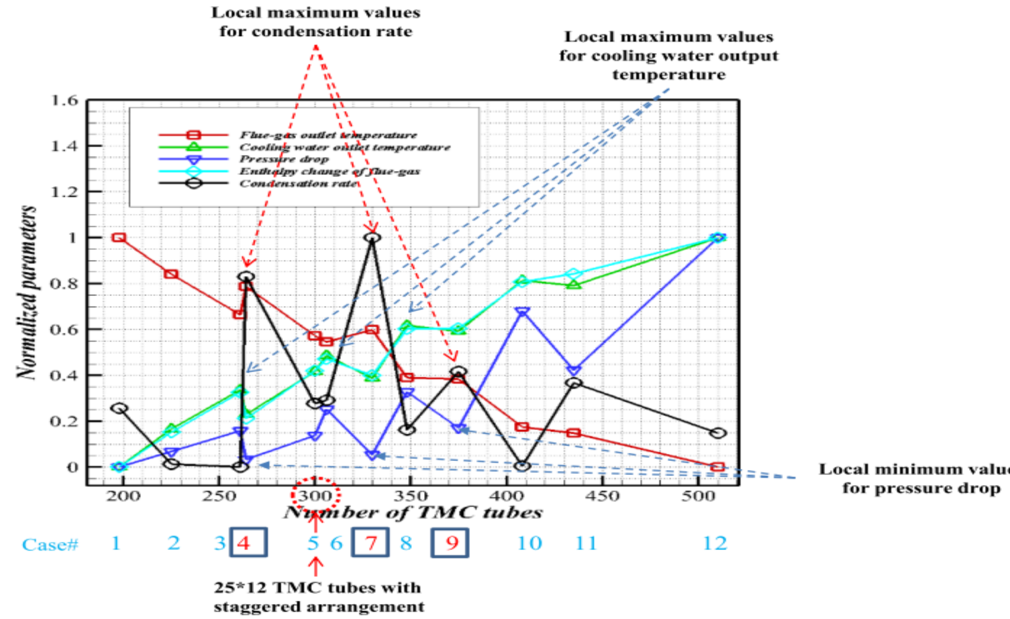
CFD results:
CFD files: TMCApr23_1_TC; TMCApr23_2_TC; TMCApr23_3_TC.



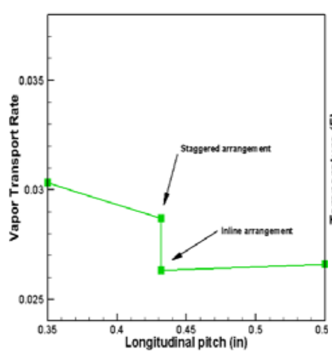
Task 2: CFD Simulation for Design

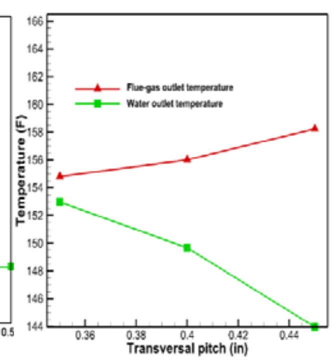
- Four objectives for TMC design:

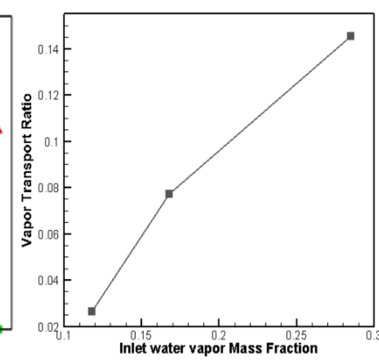
1- Maximizing the heat transfer from the flue-gas to the cooling water.
2- Maximizing the condensation rate of TMC heat exchangers.
3- Minimizing the membrane tube use.
4- Minimizing the amount of pressure drop.



- Effect of longitudinal and transversal pitches of the bundle tubes on the heat transfer, water recovery and pressure drop of TMC. Multiple cases with various inlet boundary conditions have been carried out.

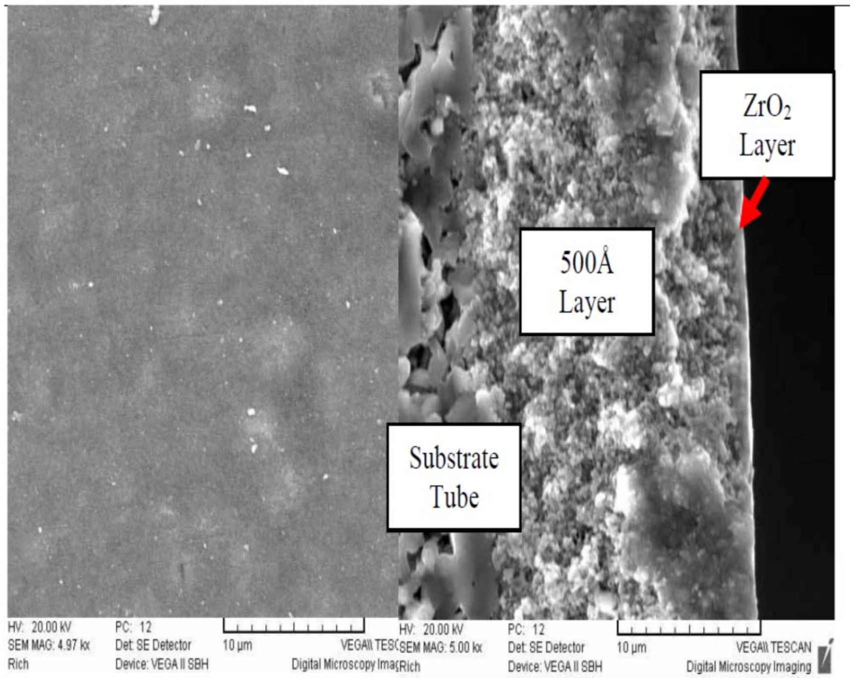






Task 3: TMC Membrane Development for High Performance

- Advantages of zirconia and titania: superior **acid resistance** and potentially **higher water flux** at comparable pore sizes in the 40Å to 200Å range over the standard γ-alumina material used in our current commercial version of the TMC tubes



SEM the surface and cross section of a ZrO2 modified TMC membranes prepared as part of the production batch. The ZrO2 layer is ultrathin at <2micron thick.

Membrane ID	H_2O [liter/m2/hr/bar]
4Q 2015 Membranes (36"). Production Membranes	
ZrO2(50/14)-01P	228
ZrO2(50/14)-02P	235
ZrO2(50/14)-03P	211
Standard MPT Alumina Membranes	
MPT 40Å Gamma Alumina	8 to 15
MPT 100Å Gamma Alumina	80 to 110
MPT 500Å Alpha Alumina	220 to 280

Water permeance of 3 production ZrO_2 membranes pulled for QC testing, compared with various MPT alumina based substrates. This value is consistent with the 500Å alumina support membrane. Hence, the ZrO_2 layer deposited must be very thin and of high quality since the water permeance is very close to the underlying support membrane.

Task 4: Low Cost for Commercialization

- Evaluate TMC parts fabrication cost reduction approaches, which includes strategies to reduce the membrane cost, injection/compression molding methods to fabricate TMC module end caps and tube sheets, as well as potential design optimization to reduce system cost.

Table x: TMC Membrane Module Cost Estimation

Item	Supplier	Unit Cost	Number required	Present cost	Improvement	Future Cost
Tubes	M&PT	$ 1.69	389	$ 657		$ 657
Tubesheets		**$ 330**	**2**	**$ 660**	**Assume compression molding @ $60/each**	**$ 120**
End Caps		$ 190	2	$ 380	Injection molded parts at $10/each	$ 20
Side plates		**$ 25**	**2**	**$ 50**	**Assume injection molding at $10 each**	**$ 20**
Miscellaneous parts - 'O' ring, screws, etc.		$ 50	1	$ 50		$ 50
Epoxy	**Grainer**	**$ 47**	1	**$ 47**	**None**	**$ 47**
Assembly labor - 1 hour for tube installation + 20 minutes for epoxy+ 1 hour for assembly of end caps/O ring/screws = 2.4 hours	$55/hr assembly facility	$ 55	2.4	$ 132	20% due to higher production rates	$ 106
Pressure test labor	**$55/hr assembly facility**	**$ 55**	**0.5**	**$ 28**	**None**	**$ 28**
				$ 2,004		**$ 1,048**

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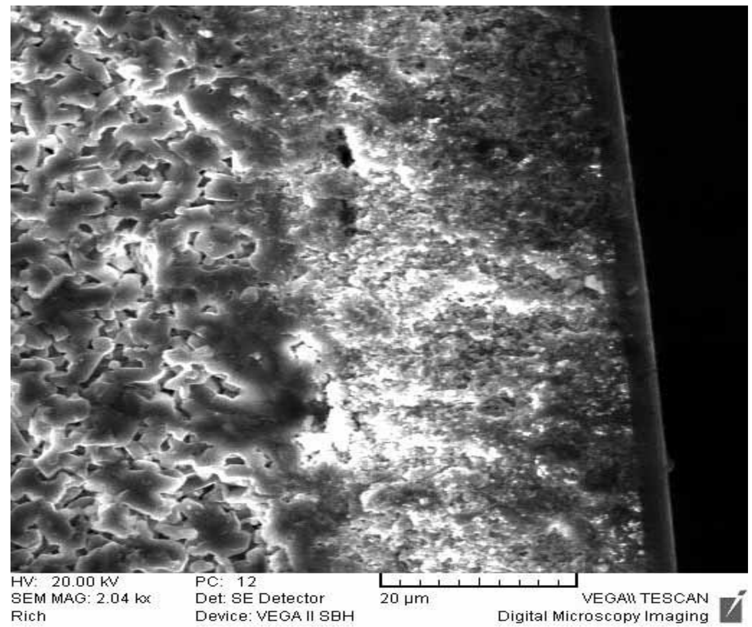
Task 4: Low Cost for Commercialization

Table 5. Performance of the low purity alumina substrate with the MPT standard substrate tube.

Part ID	**Water Permeance(lmhb)**	**N_2 [$m^3/m^2/hr/bar$]**	**Bend Strength [psi]**
SubAL-P807.02	142	27	48
SubAL-P807.06	155	33	46
MPT Standard Substrate	220 to 250	75 to 90	40 to 45

- Use <u>low purity (LP) </u>alumina substrate.
- Simplify control and system design, including ductwork connections.



SEM cross section of the standard intermediate layer and top surface γ-alumina layer on the <u>low purity (LP) </u>alumina substrate.

Task 5: TMC Unit Design, Fabrication and Assembly

TMC Unit

TMC Membrane Module

TMC Unit Controls and Data Acquisition

Task 5: TMC Design and System Setup

TMC lab test system with a boiler, heat exchanger, flue gas conditioner, etc.

Task 6: TMC Test System Installation and Shakedown

- ✓ Boiler: successful startup of the boiler and ramp up to full fire rate.
- ✓ TMC unit: Installed and pre-tested at cold flow conditions
- ✓ System control: checked control system for TMC startup and parameter changes, including water inlet flow rates and temperature, vacuum and water level control, etc.
- ✓ Data Acquisition: A data acquisition box and computer have been setup and tested to read and record the required data.
- ✓ System shakedown: the whole test system has been run and checked, everything looks ok for next step parameter testing.

Task 7: Scale-Up and Integration Evaluation for Commercial Scale Power Plant

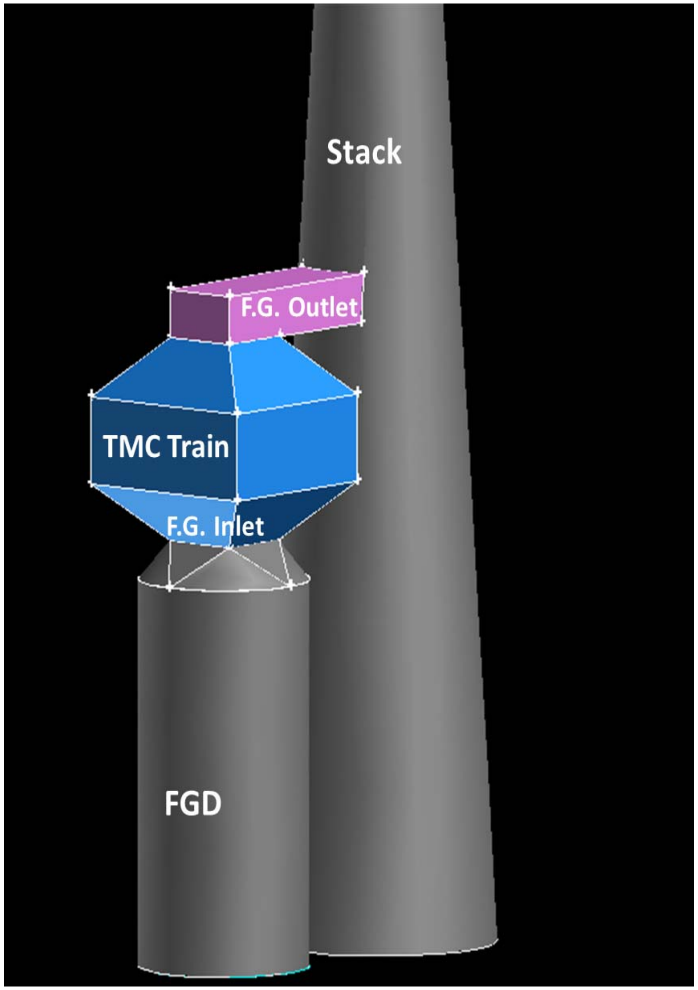


Table 1: 550MW TMC preliminary design modeling results

Inlet	Case1	Case2	**Case3**	Case4
Flue Gas Temperature (° F)	135*	135*	135*	135*
Flue Gas Flowrate (lb/hr)	5,043,920 *	5,043,920*	5,043,920*	5,043,920*
Flue Gas H2O Mole Fraction	0.1517*	0.1517*	0.1517*	0.1517*
Steam Condensate Temp (° F)	100*	100*	100*	95
Steam Condensate Flowrate (lb/hr)	1,965,934	3,087,536*	3,087,536*	3,087,536*
Outlet				
Flue Gas Temperature (° F)	130.0	128.3	127.3	126.0
Flue Gas Flowrate (lb/hr)	4,988,926	4,978,136	4,966,146	4,951,282
Flue Gas H2O Mole Fraction	0.1377	0.1316	0.1281	0.1236
Steam Condensate Temp (° F)	119	119	125	125
Steam Condensate Flowrate (lb/hr)	2,011,034	3,153,462	3,165,454	3,180,320
Net Water Recovered (lb/hr)	45,099	65,898	77,891	92,756
Heat Added to Steam Condensate (MW)	12.08	18.85	24.71	29.64

* From DOE Case 9 study

Thanks!

Questions?