Oxy-Combustion Boiler Material Development

Cooperative Agreement DE-NT0005262

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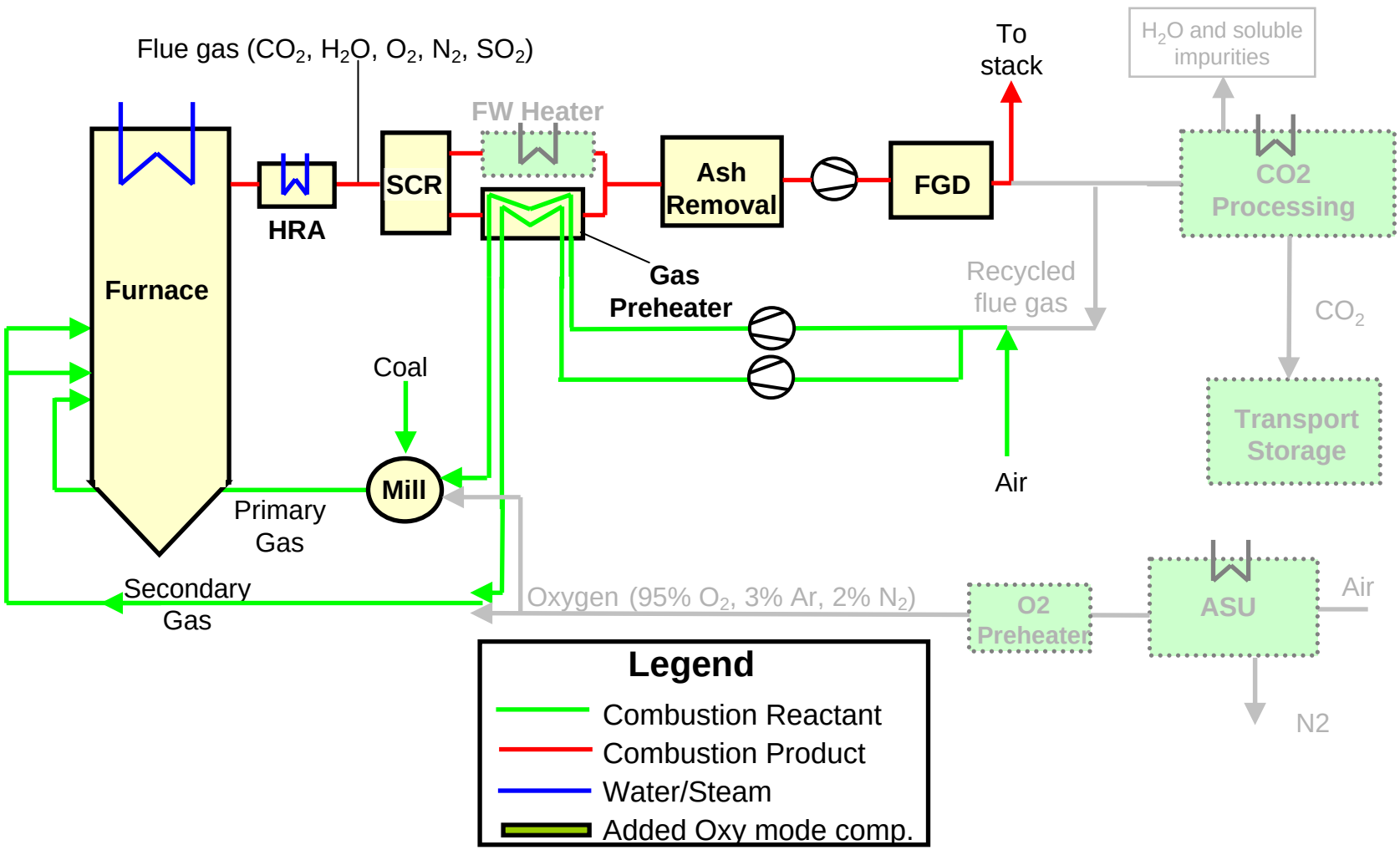
    - Aftermarket Services

      Coal Mills, Control Systems, LNBs, Boiler Pressure Parts, etc
    - Construction and Retrofits of Boilers, SCRs, and Scrubbers

Project Objectives

- **Facilitate Retrofitting PC Boilers with Oxy-Combustion for CCS**
  - Conduct Laboratory Corrosion Studies of Boiler Materials
    - Assess Corrosiveness of Oxy vs Air-Fired Flue Gas
    - Identify Oxy-Combustion Corrosion Mechanisms
    - Determine Oxy-Combustion Effects on Boiler Materials
      Waterwall and Superheater/ReheaterTubes,
      Weld Overlays and Coatings
  - Recommend Materials for Oxy-Fired Boilers
    - Retrofit Units
    - New Units

Simplified Schematic of Oxy Retrofit

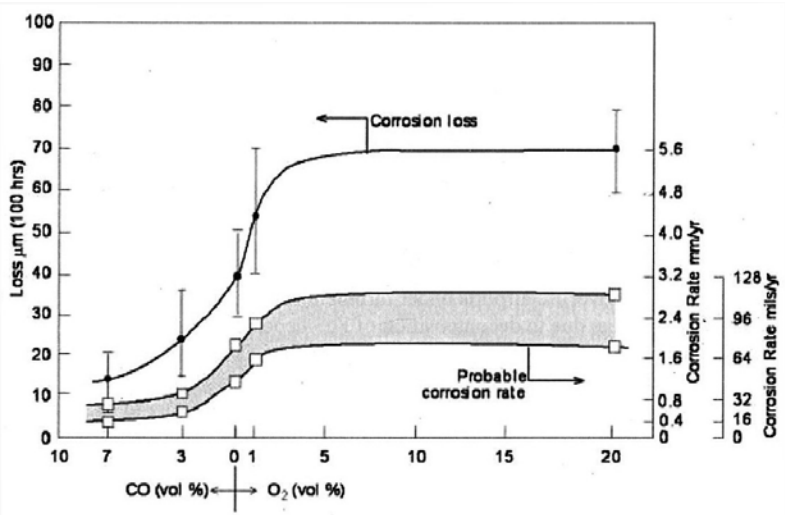


Boiler Fireside Corrosion Considerations

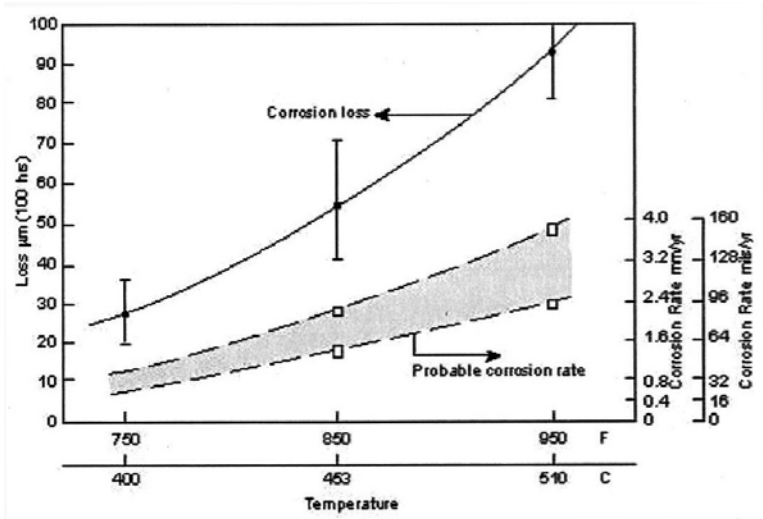
- **Oxy-Combustion Boiler Retrofits will Utilize Flue Gas Recycle**
  - Limits Combustion Temperature and Maintains Boiler Heat Absorption
  - Enables Operation without Boiler De-rating or Resurfacing
- **Flue Gas Recycle May Increase Boiler Corrosion**
  - Levels of Corrosive Gases i.e. CO, H_2S, HCl, CO_2, SO_2, etc Increased
- **Corrosion Rates Influenced by Composition and Temperature of:**
  - Flue Gas and Deposits
  - Tube Materials
- **Corrosion Mechanisms Vary with Boiler Locations**
  - Furnace Waterwalls: From Reducing Gases and Unburned Particles
  - Superheater/Reheaters: From Condensing Vapors and Deposits

Waterwall Corrosion (EPRI)

- **T2 Corrosion Loss Under FeS Deposits**



O_2 & CO Effects at 850ºF



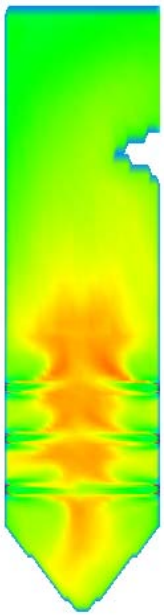
Temperature Effect at 1% O_2

Project Plan / Approach

- **Conduct Fire-Side CFD Analyses of Oxy and Air-Fired Boilers**
  - 500 MWe Wall and Tangential-Fired Boilers with High & Low Sulfur Coals
- **Identify Gas Compositions along Boiler Gas Flow Path**
  - Superheater/Reheater (Shrt/Rhtr) and Furnace Wall Micro Climates
- **Select Oxy and Air-Fired Gas Compositions for Corrosion Testing**
- **Expose Boiler Matls to Selected Gases in Electric Furnaces**
  - Matls Coated with Deposits Representative of High to Low Sulfur Coals
  - Test Gases Synthesized from Pressurized Cylinders
  - Tests Conducted for 1000 Hrs at Waterwall & Shtr/Rhtr Temperatures
- **Conduct Post Test Analyses to Assess Corrosiveness**
- **Recommend Matls for Oxy Retrofits & New Oxy-Fired Boilers**

Ill #6 Furnace Flue Gas Temperature and Wall Heat Fluxes via FW-FIRE

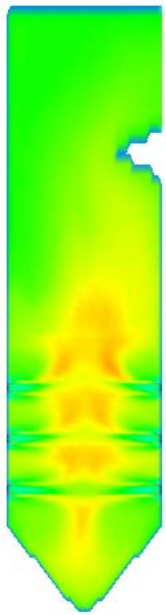
Air-Fired



O2 = 21%

Gas Temperature (F)

O2-Fired

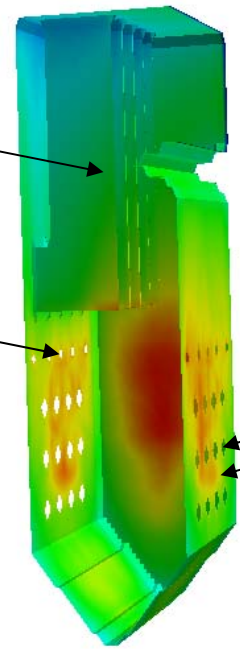


O2 = 26%

(recycle = 70%)

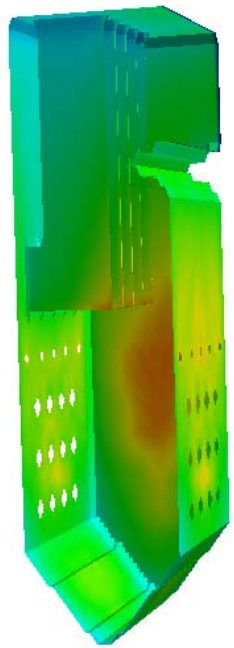
Same boiler heat absorption as air

Air-Fired



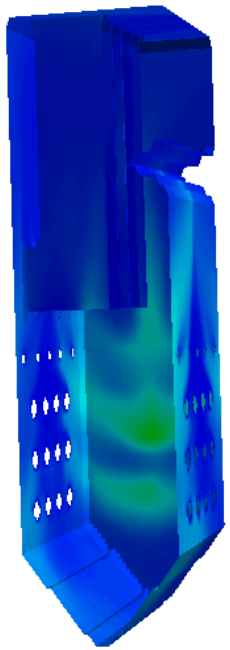
Heat Flux (Btu/hr-ft^2)

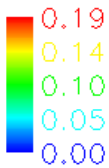
O2-Fired



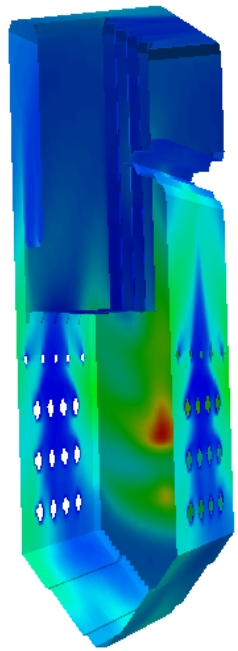
Ill #6 Wall-Fired Furnace CO and H_2S Concentrations via FW-FIRE

Air-Fired



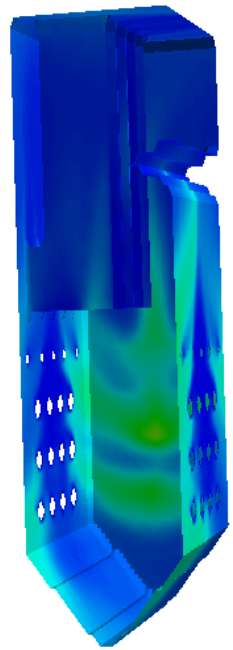


O2-Fired

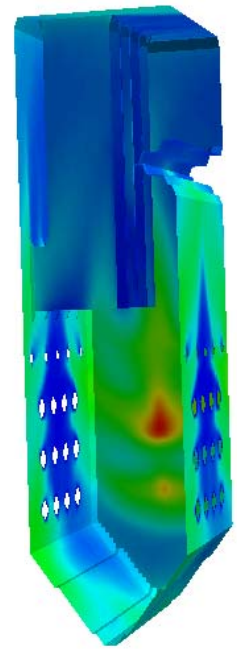


CO Mole Fraction

Air-Fired



O2-Fired



H_2S Concentration (ppm)

Air vs Oxy-Fired Boiler Gas Compositions

500 MWe Wall - Fired Boiler										
Coal	Location	Condition	CO	H2S	CO2	H2O	SO2	N2	O2	Misc
Air - High S Bit. (Illinois 6)	Lower Furnace	Max CO H2S	9%	0.15%	11%	8%	0.15%	65%	0.5%	5.9%
	Lower Furnace	Medium CO, H2S	5%	0.08%	13%	9%	0.19%	69%	0.8%	3.3%
	Lower Furnace	Low CO, H2S	2%	0.03%	14%	9%	0.20%	72%	2.0%	1.3%
	Furnace Outlet	Average	0.2%	0.00%	14%	9%	0.20%	74%	3.3%	0.1%
O2 - High S Bit. (Illinois 6)	Lower Furnace	Max CO H2S	19%	0.24%	49%	17%	0.17%	7%	0.5%	6.6%
	Lower Furnace	Medium CO, H2S	10%	0.14%	58%	19%	0.23%	8%	0.9%	4.3%
	Lower Furnace	Low CO, H2S	5%	0.06%	63%	20%	0.27%	8%	1.6%	1.7%
	Lower Furnace	Low CO, H2S	2%	0.02%	66%	20%	0.28%	8%	2.5%	0.7%
	Furnace Outlet	Average	0.7%	0.01%	68%	20%	0.30%	8%	2.1%	0.4%

Proposed Material Corrosion Tests

- **10 Waterwall & 10 Superheater/Reheater Matls to be Tested**
  - Waterwall Matls at: 750ºF, 875ºF and 1000ºF
  - Superheater/Reheater Matls at: 1000ºF, 1100ºF, & 1200ºF
- **Each Matl to be Coated with 3 Different Deposits**
  - Deposits Representative of High, Medium, & Low Sulfur Coals
    - 3 Furnace Deposits and 3 Superheater/Reheater Deposits
- **Tests Involve:**
  - 4 Oxy- Fired and 3 Air- Fired Furnace Gas Micro Climates
  - 1 Oxy- Fired and 1 Air- Fired Superheater/Reheater Gas Climate
- **Test Summary: 27 Furnace Tests with Total of 810 Coupons**

Waterwall Materials

	Material	Description	Boiler Use	Nominal Composition
1	Tube	A1	Conventional	0.27%Carbon
2	Tube	T2	Conventional	1/2 Cr-1/2Mo
3	Tube	T11	Conventional	1-1/4Cr-1/2Mo
4	Weld Overlay	309L StnStl	Conventional	24Cr
5	Weld Overlay	Inconel 622	Conventional	21Cr-55Ni
6	Weld Overlay	VDM Alloy 33	Conventional	33Cr-31Ni
7	Thermal Spray	Amstar Inconel 888	Relatively new	50Cr-50Ni
8	Thermal Spray	IGS UTEx 5-450	Relatively new	58Ni-30Cr
9	Welded Coupon	T11 to T11	Conventional	1-1/4 Cr to 1-1/4 Cr
10	Nano	Coating	In development	TBD*

* To be selected by July 1, 2009 from an EPRI electric furnace corrosion test

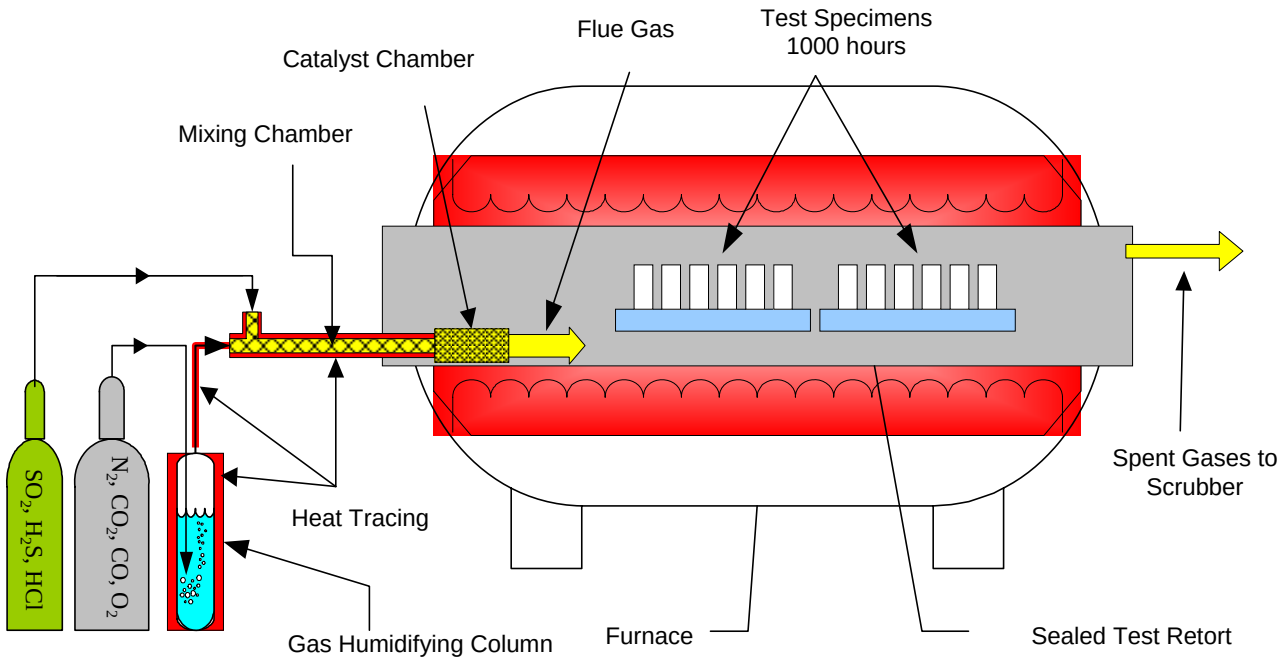
Superheater/Reheater Materials

	Material	Description	Boiler Use	Nominal Composition
1	Tube	T22	Conventional	2-1/4Cr-1Mo
2	Tube	304H StnStl	Conventional	18Cr-8Ni
3	Tube	347H StnStl	Conventional	18Cr-9Ni
4	Tube	T91/T92	Newer Boilers	9Cr
5	Tube	NF709	Newer Boilers	20Cr-25Ni
6	Tube	HR3C	Newer Boilers	25Cr-20Ni
7	Weld Overlay	Inconel 622	Conventional	21Cr-55Ni
8	Weld Overlay	VDM Alloy 33	Conventional	33Cr-31Ni
9	Weld Overlay	Inconel 72	Conventional	44Cr-55Ni
10	Welded Coupon	T22 to 304H	Conventional	1-1/4 Cr to 18 Cr

Electric Furnace Corrosion Tests

- **Material Coupons 1/8” Thick x ¾” Wide x 1” High**
- **Deposits Produced from Reagent Grade Powders**
  - Powders Mixed (Homogenized) and Applied to Coupons as a Paste
- **Coupons Hung from Alumina Rods in Furnace Racks**
- **Test Program Utilizes Six – 6” Diameter Furnaces**
  - Furnaces Operated in Groups of 3 With a Common Gas
  - Each Group Investigates 3 Different Temperatures
  - Each Furnace Holds 30 Coupons (10 Matls-3 Different Deposits)
  - Corrosion Tests Involve 1000 Hrs of Exposure
    - Coupons Inspected & Recoated with Deposits Every 100 Hrs
- **Coupons Undergo Post Test Metallographic Evaluations**

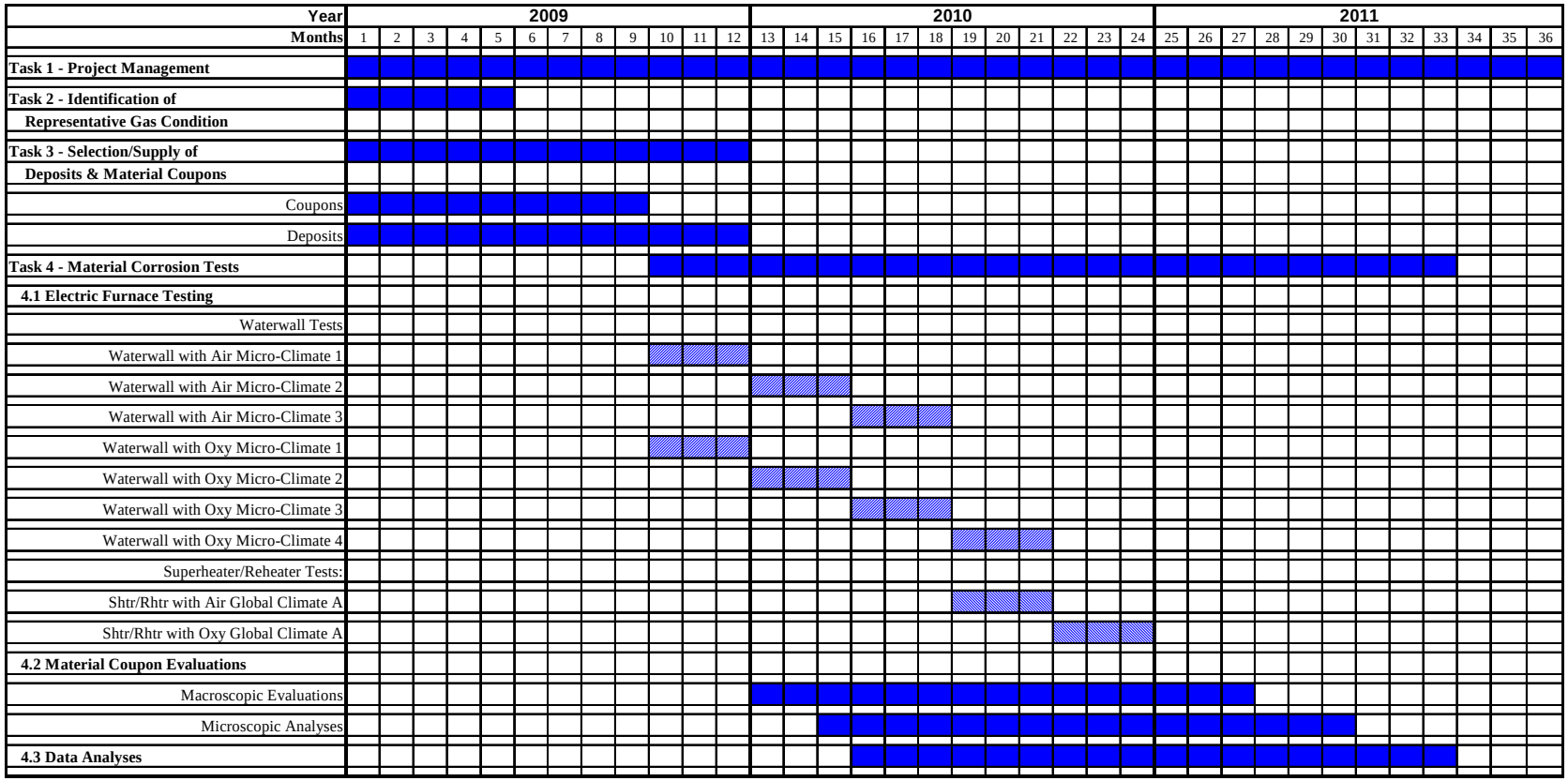
Simplified FW Electric Furnace Test Schematic



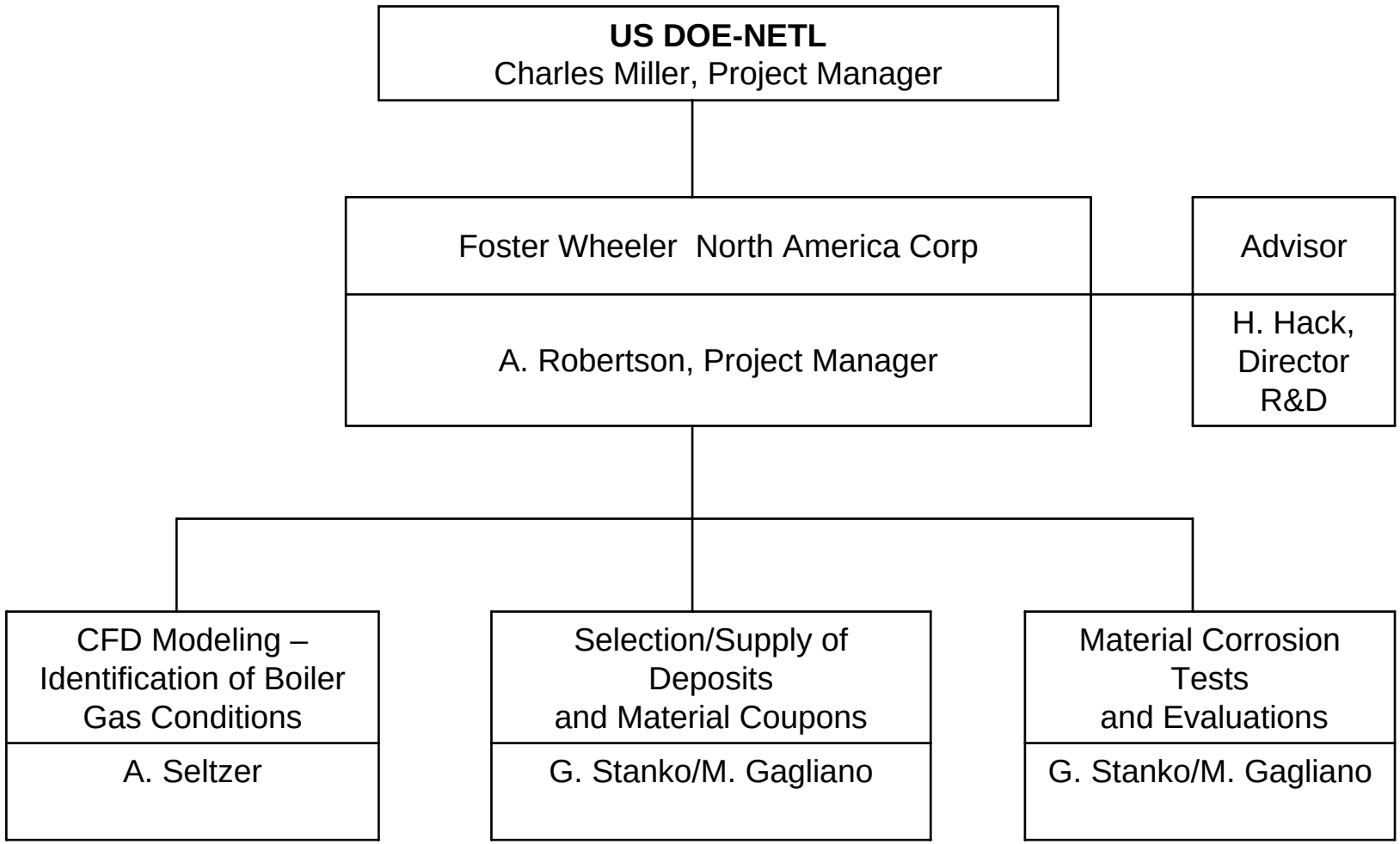
Overview of Project Tasks

- **Task 1 Project Management and Planning**
  - Provide Technical Oversight, Track Costs, and Maintain Schedule
  - Issue Periodic Reports
- **Task 2 Identification of Representative Gas Conditions**
  - Conduct CFD Modeling to Identify Flue Gas Bulk and Micro Climates
- **Task 3 Selection / Supply of Deposits and Material Coupons**
  - Select / Procure / Fabricate Materials, Deposits, and Gases
  - Conduct Pretest Analyses of Material Coupons and Ready Furnaces
- **Task 4 Material Corrosion Tests**
  - Expose Deposit Coated Matls to Oxy and Air Flue Gases for 1000 Hrs
  - Evaluate Condition of Materials
  - Assess Oxy-Combustion Corrosiveness and Recommend Materials

Project Schedule with Test Details



Project Organization



Project Costs in $1000s

Budget Period	1	2	3	Totals
Calendar Year	2009	2010	2011	
Costs	945.3	705.3	341.2	**1991.8**
FW Share @ 20%	189.1	141.1	68.2	**398.4**
DOE Share @ 80%	756.2	564.2	273.0	**1593.4**