Reinhold Environmental Ltd.

2008 APC Round Table & Expo Presentation

July 13-15, 2008, in Savannah, GA

TENNESSEE VALLEY AUTHORITY

Protecting Scrubber Internals

2008 APC/PCUG Conference

Savannah, Georgia

July 15, 2008

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Systems Engineer

Protecting Scrubber Internals
means understanding

1. *Component failure modes* &
2. *Selecting appropriate materials of construction*

Presentation Overview

1. Failure Categories
2. Decision Logic
3. Three major categories of FGD Materials
4. Case Study 1 - New FGD Absorber Vessel Material of Construction
    - Overview of new FGDs
    - New FGD Absorber Vessel Material of Construction
5. Case Study 2 - Paradise Outlet Ducts
    - Conversion to no reheat

1. Protecting FGD Internals

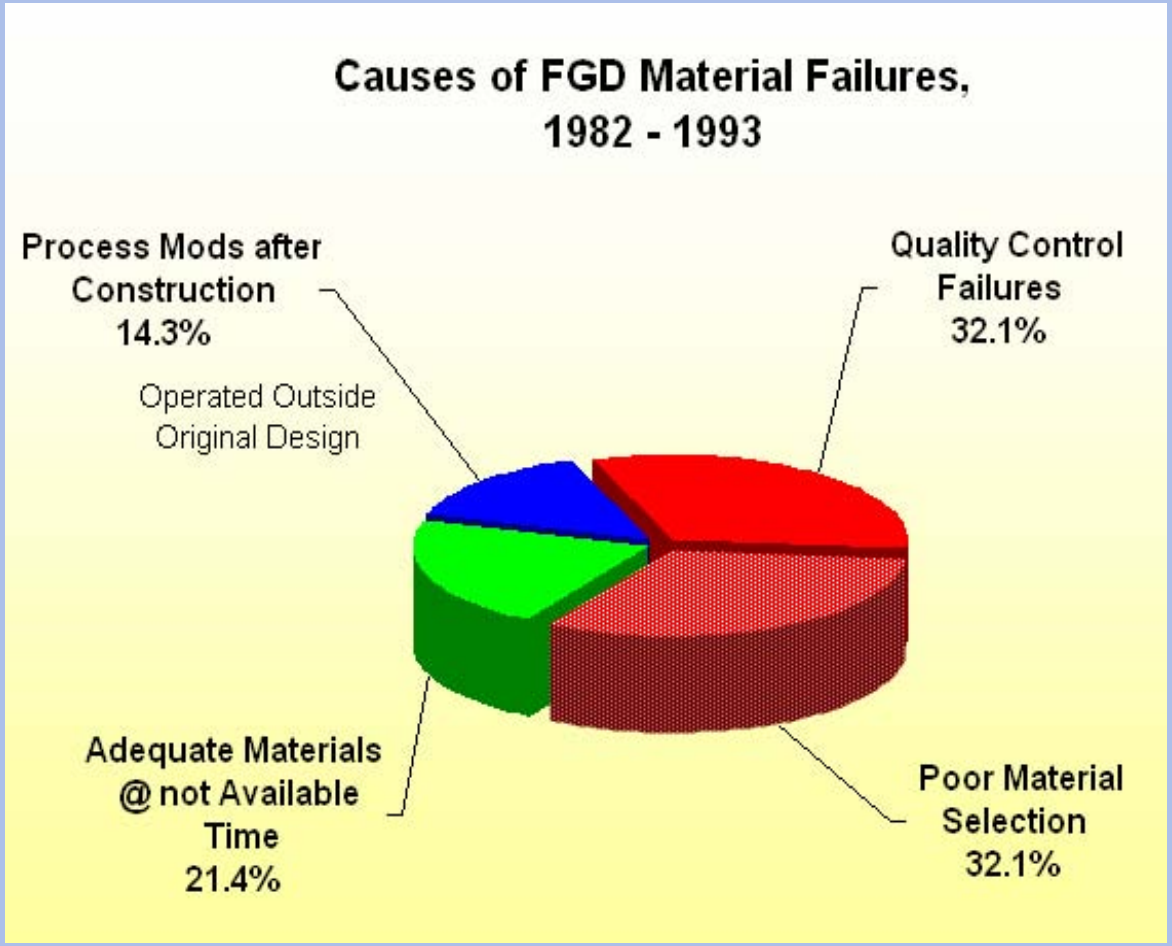
Why?? To Prevent Downtime

$$$

Trend toward One Module Operation makes understanding failure modes to protect scrubber internals even more critical

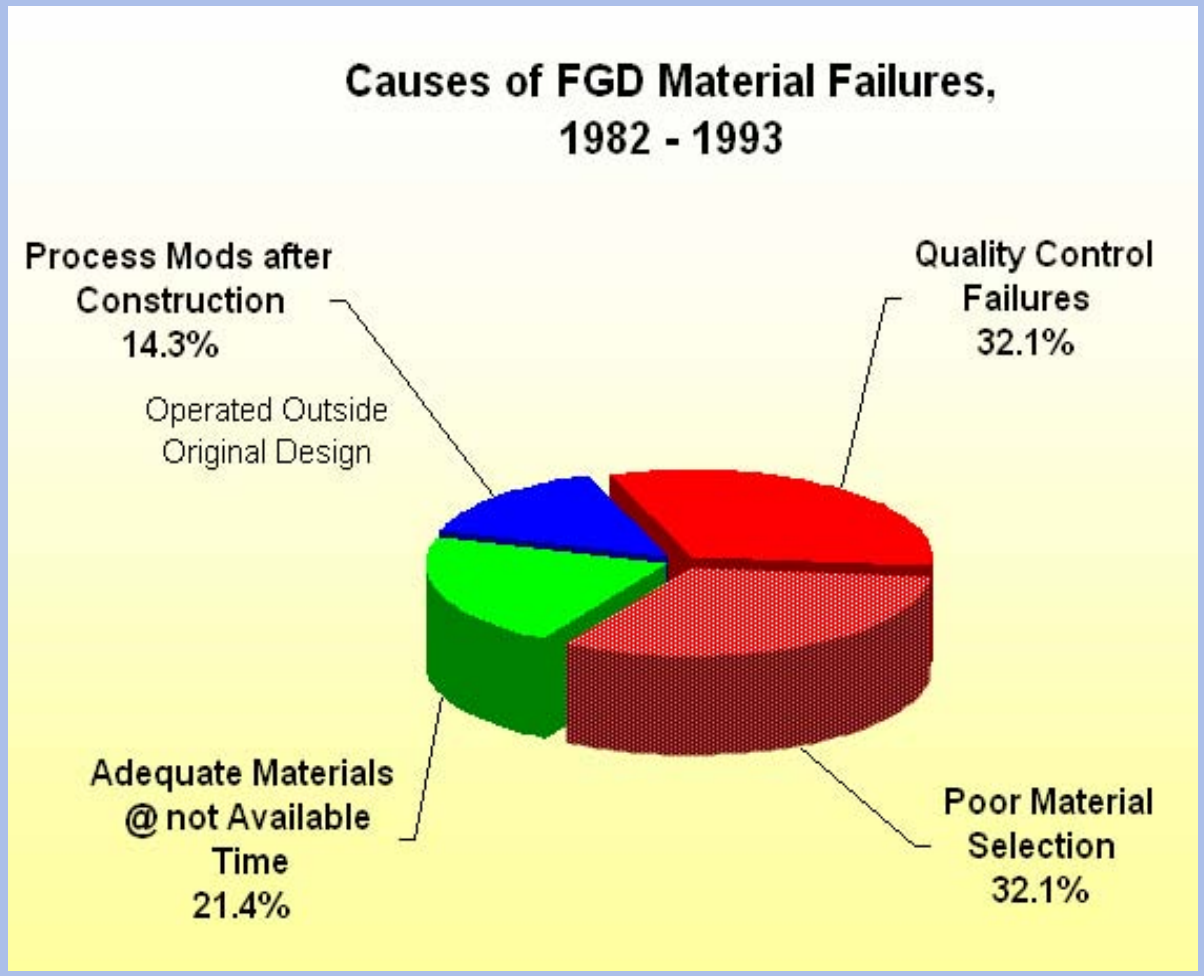
1. Four Broad Material Failure Categories

64% of FGD System Material Failures are due to premature failure of material of construction



Source: EPRI

1. Four Broad Material Failure Categories



Quality Control Failures

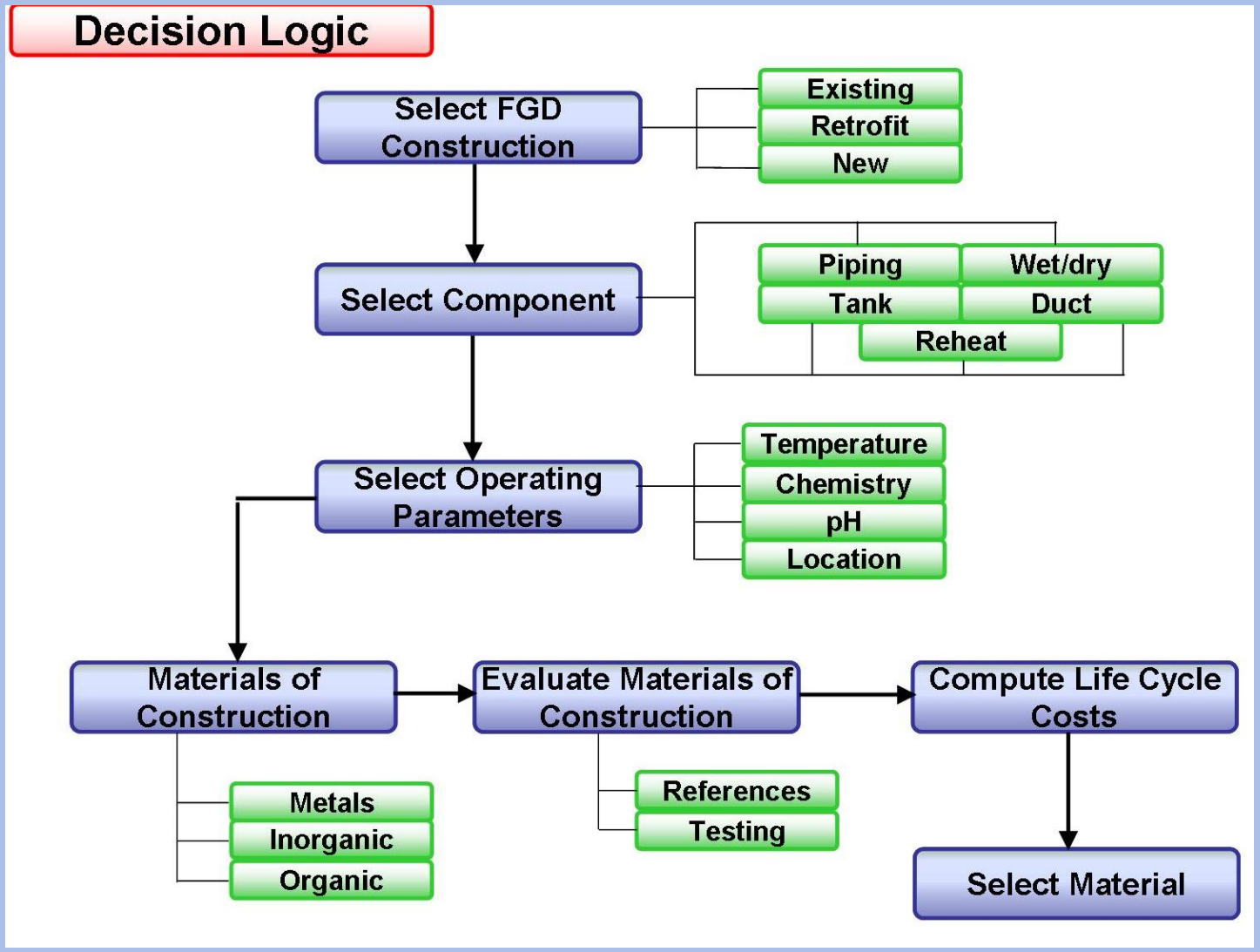
- Design modifications not followed
- Poor QC of raw material
- Poor QC during installation

Poor Material Selection

- Material Specs written contrary to known conservative practices

Source: EPRI

2. Decision Logic



3. Materials of Construction

- **Metals**
  - Carbon steel
  - Austenitic stainless steel
  - 6% Mo stainless steel
  - Duplex stainless steels
  - NiCrMo alloys
- **Non metallic Inorganic Linings**
  - Acid Resistant Bricks
  - Ceramic Tiles
- **Organic**
  - Vinyl Ester Resins
  - Epoxies
  - Rubber

4. Overview of New FGDs

2. New Advatech FGDs

Paradise Unit 3 – Startup 2006

Bull Run Fossil – Startup Fall 2008

Kingston 6-9 – Startup Fall 2009

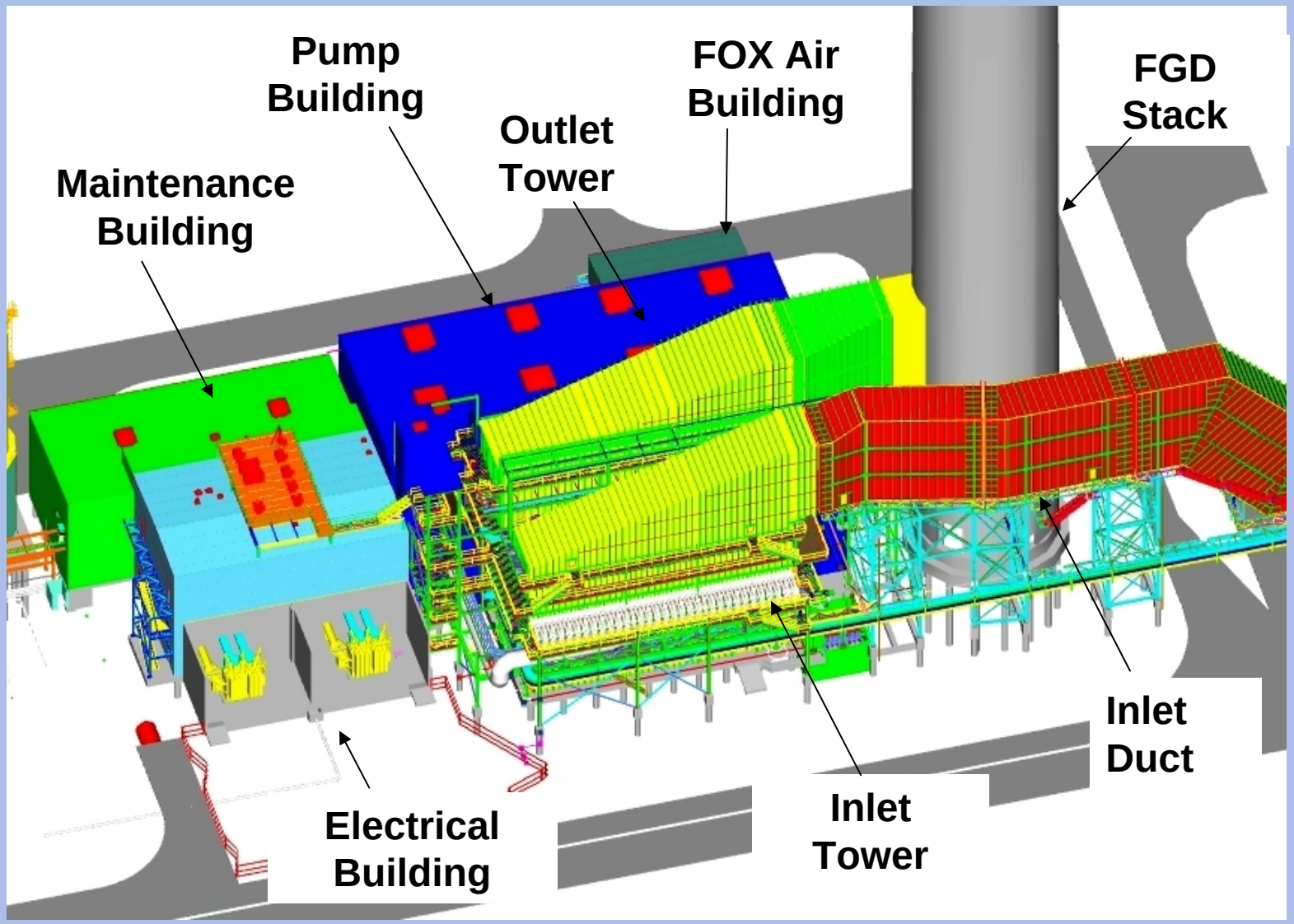
Kingston 1-5 – Startup Spring 2008

Absorber Vessel Materials of Construction - Alloy

4. Bull Run Fossil FGD

Start up - Fall 2008

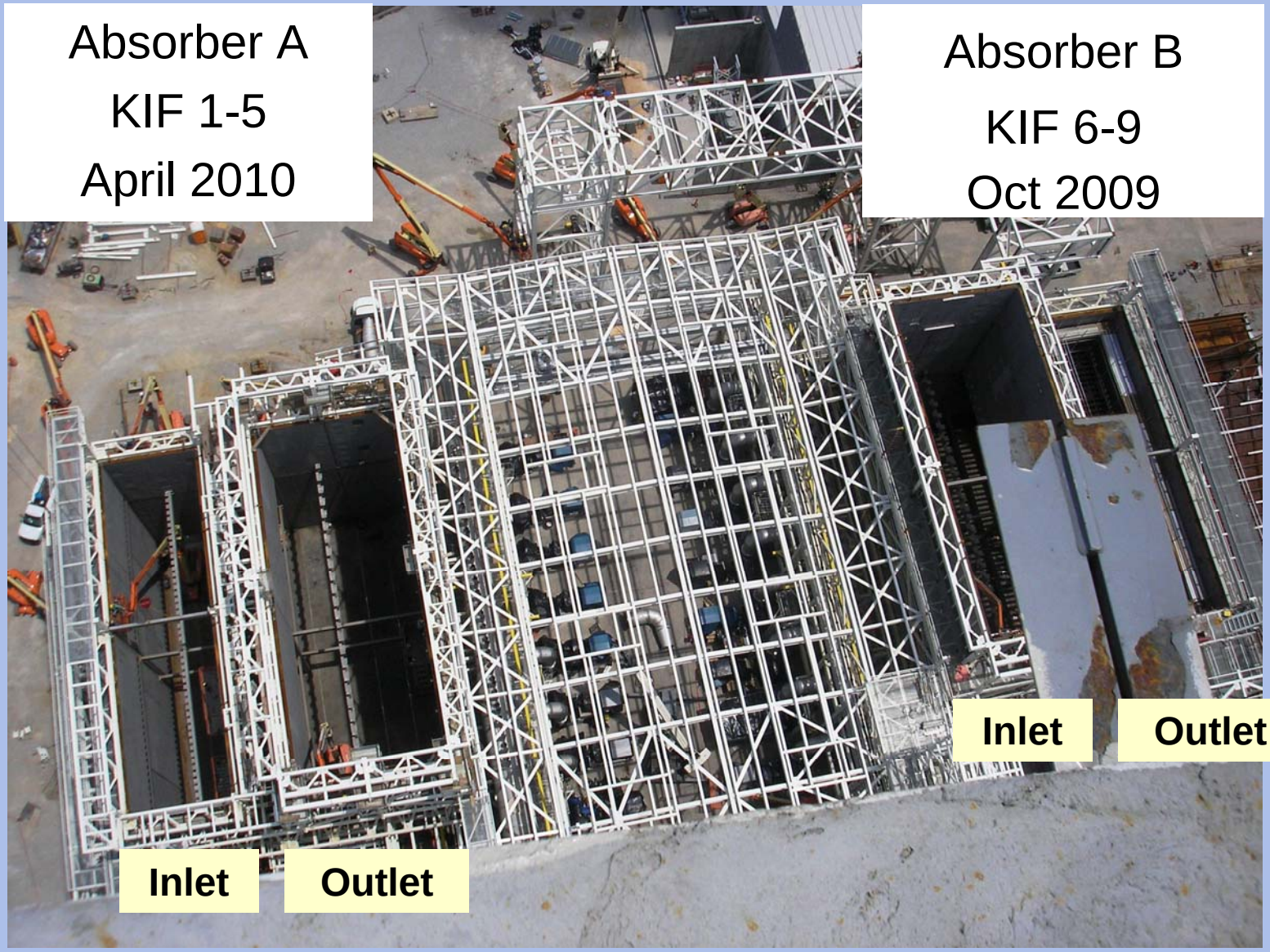
4. Bull Run Fossil FGD



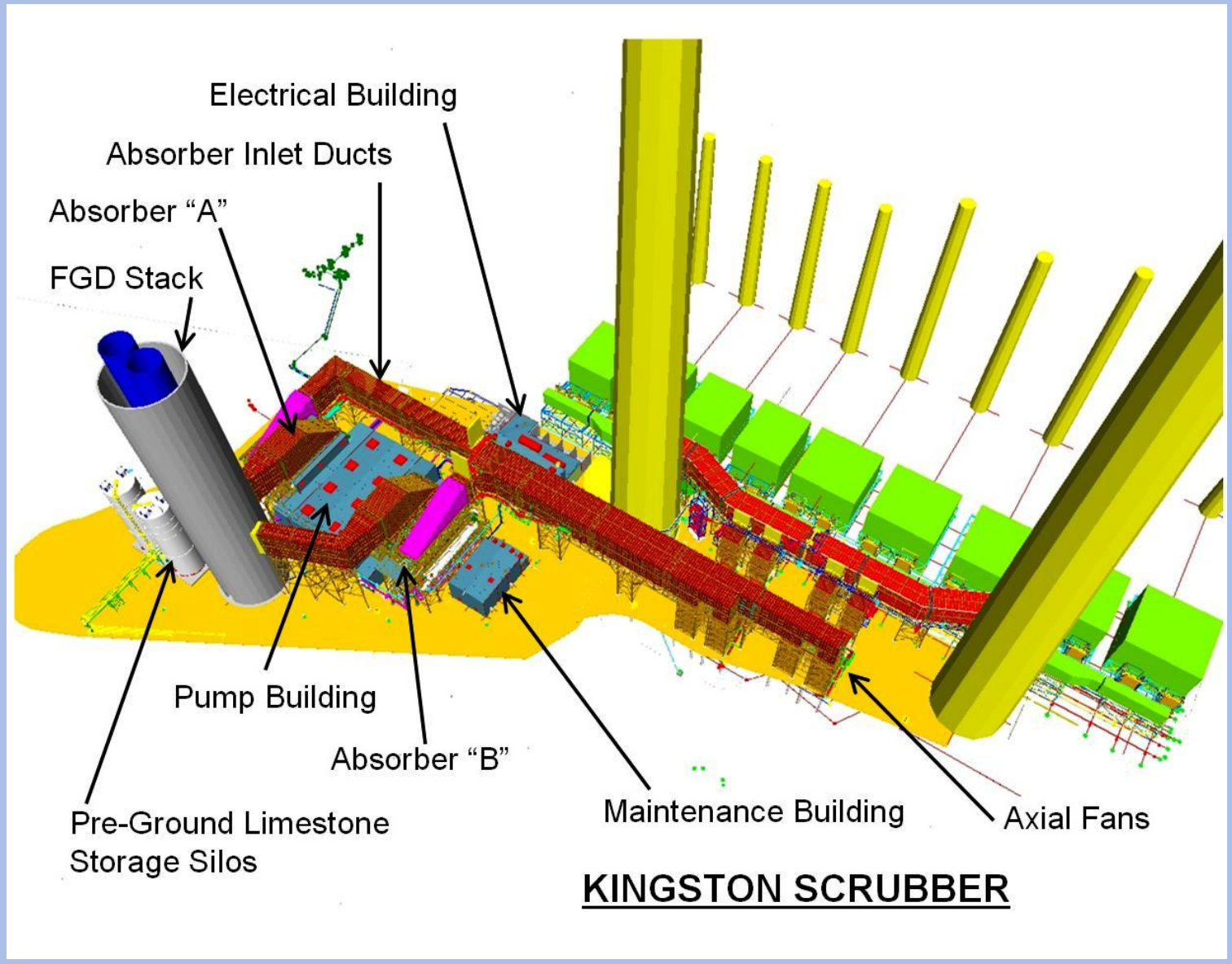
4. Kingston Fossil FGDs

Absorber A
KIF 1-5
April 2010

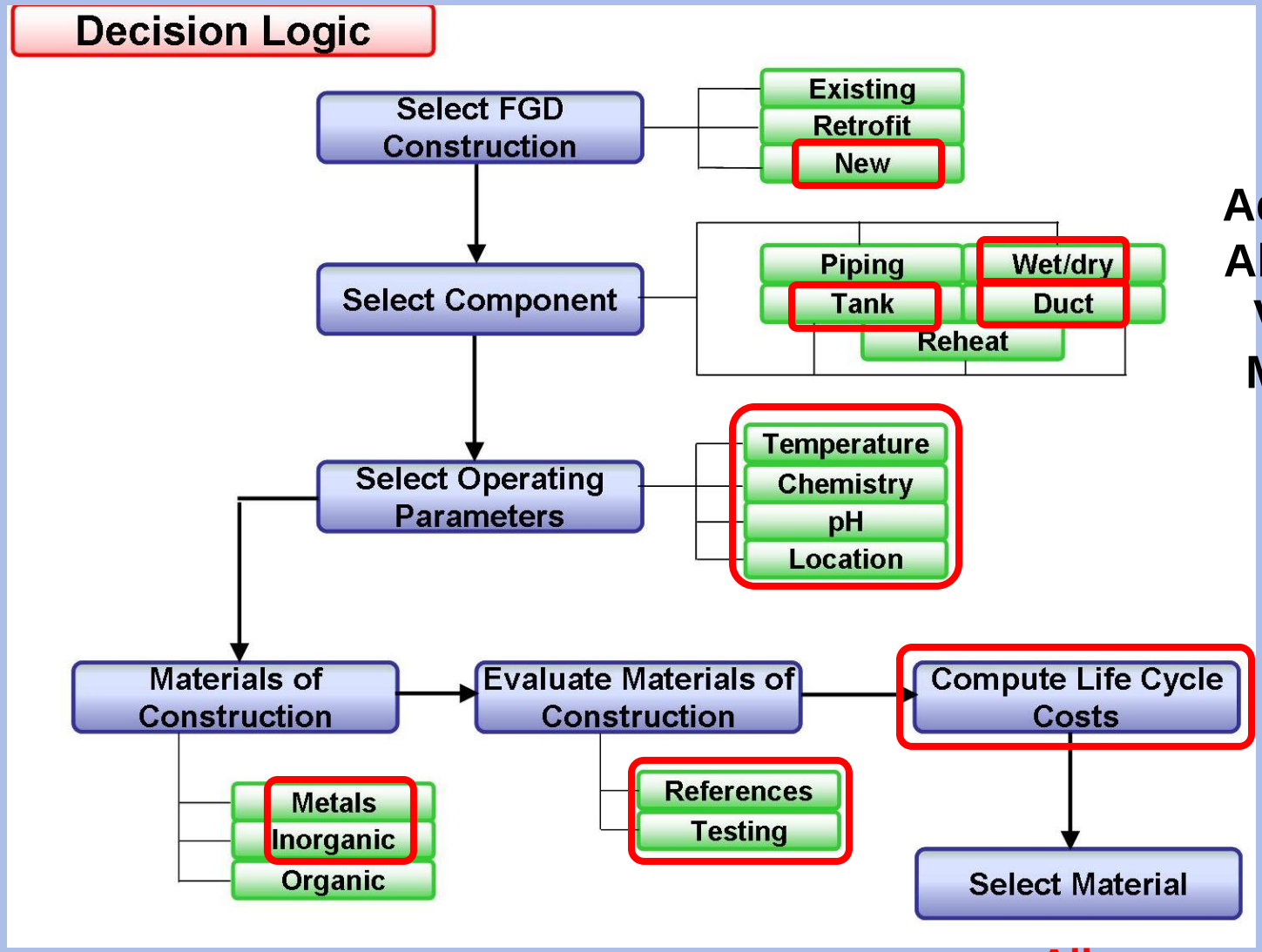
Absorber B
KIF 6-9
Oct 2009



4. Kingston Fossil FGDs



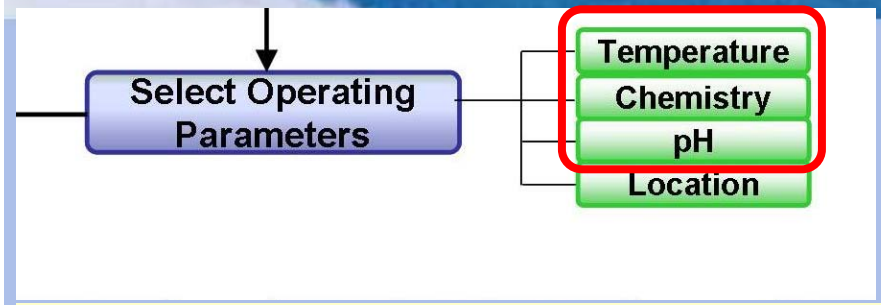
4. Advatech Absorbers Vessel Alloy Selection



Advatech Absorber Vessel Module

Alloy

4. Advatech Absorbers Vessel Alloy Selection



PAF U3

- 1150 MW
- Inlet gas 350 ^{O}F
- Slurry 135 ^{O}F
- Wet Stack
- 3.4% sulfur
- 98% removal
- L/G = 146 gpm/kcfm
- Chlorides = 1800 ppm
- 30% slurry solids
- 5.7-5.8 pH

Bull Run

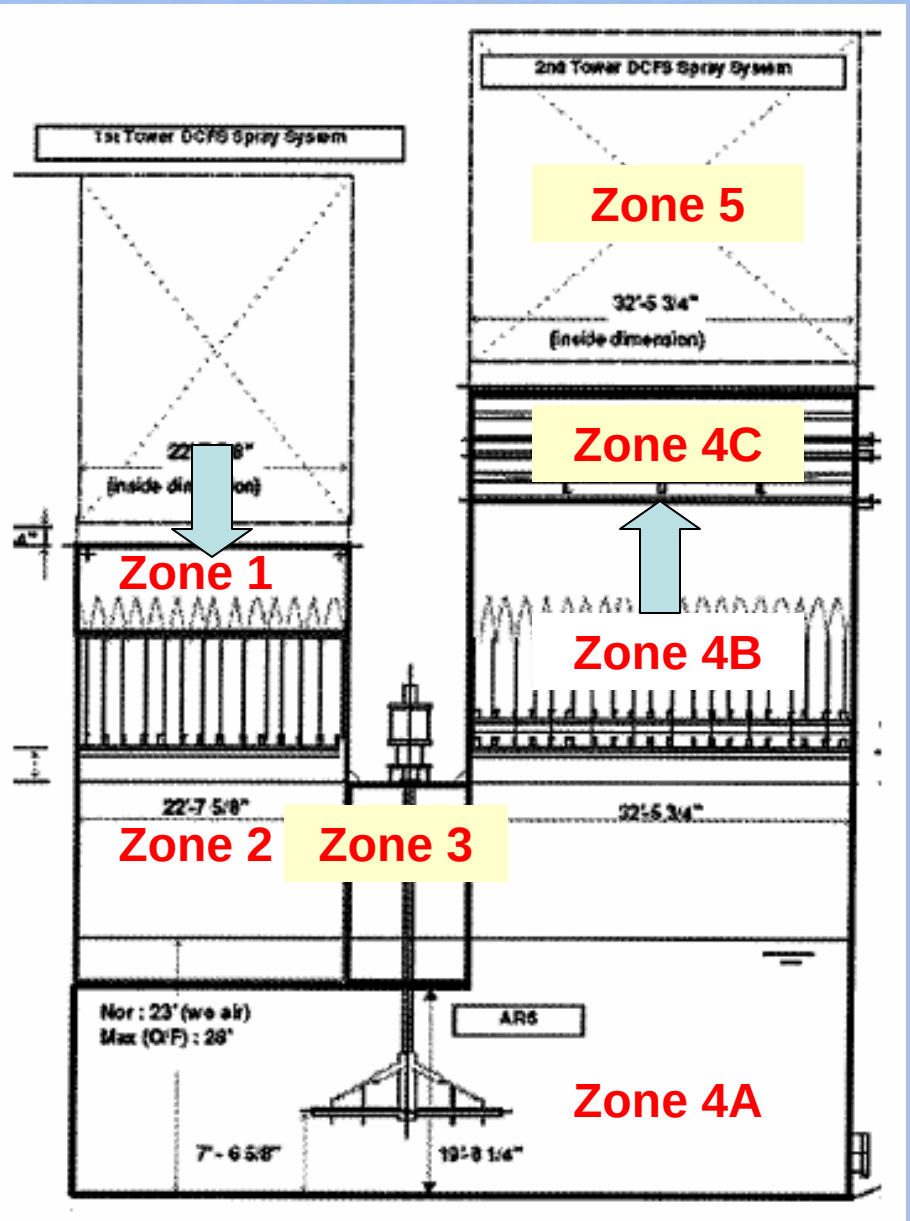
- 950 MW
- Inlet gas 350 ^{O}F
- Slurry 135 ^{O}F
- Wet Stack
- 3.1% sulfur
- 98% removal
- L/G = 140 gpm/kcfm
- Chlorides = 1400 ppm
- 30% slurry solids
- 5.7-5.8 pH

Kingston 1-5 & 6-9

- 760 MW each module
- Inlet gas 350 ^{O}F
- Slurry 135 ^{O}F
- Wet Stack
- 3.1% sulfur
- 98% removal
- Chlorides = 1640 ppm
- 30% slurry solids
- 5.7-5.8 pH

4. Kingston Absorber Vessel Alloy Selection (typical of all new FGDs)

Area	Location	Corrosion	Erosion
1	Wet/Dry	Very Severe	Mild
2	1st Tower Spray Contact	Moderate	Moderate
3	Crossover	High	Mild
4A	Recycle Tank	Low	Low
4B	2nd Tower Spray Contact	Low	Moderate
4C	Mist Eliminator	Low/ Moderate	None
5	Outlet Transition	Low/ Moderate	None
6	Outlet Ductwork	Low/ Moderate	None



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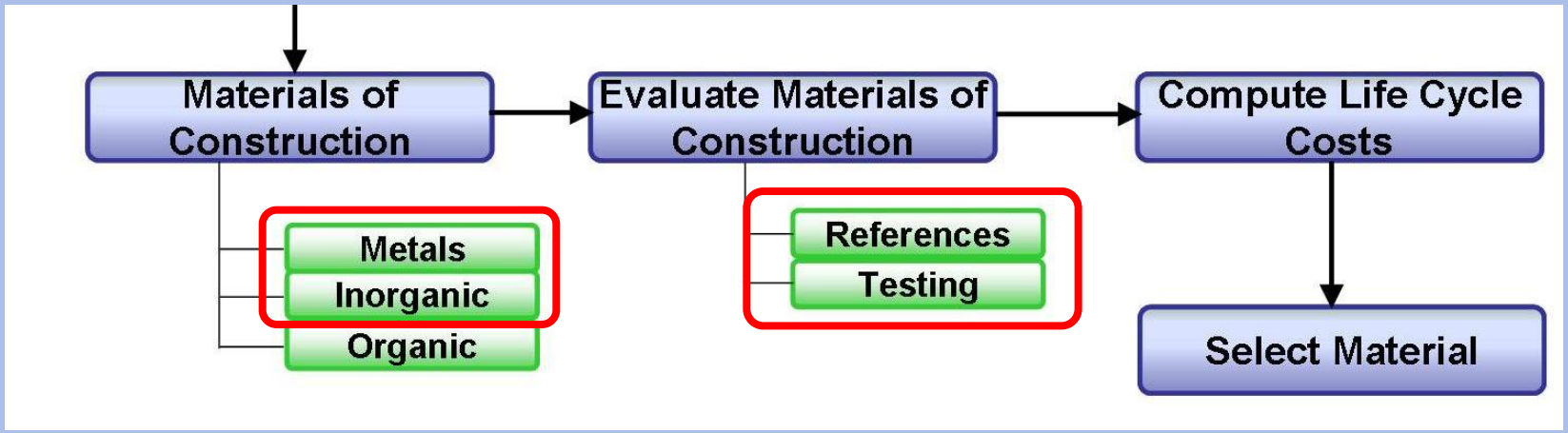


1. Advatech Evaluated Alloy and Concrete
2. Provided Engineering Studies filled with references, previous testing, and computed life cycle costs.
3. Selected the following alloys for the Absorber Vessel Module

4. Advatech Absorbers Vessel Alloy Selection

Zone	Vessel Location	Corrosion	Metal	PAF	BRF	KIF
0	Inlet Duct	Mild	Corten A588	Corten A588	Corten A588	Corten A588
1	Wet / Dry	Very Severe	NiChMo	C-276	C-276	C-276
2	**1st Tower Spray Contact**	**Moderate**	**Duplex SS**	**255**	**2205**	**2205**
3	**Crossover**	**High Low / Moderate**	**SuperA SS Duplex SS**	**254 6% Mo**	**2705 Duplex-SS**	**2705 Duplex-SS**
4A	Recycle Tank	Low	Duplex SS	2205	2205	2205
4B	2nd Tower Spray Contact	Low	Duplex SS	2205	2205	2205
4C	Mist Eliminator	Low/Moderate	Austenitic SS	317L	317L	317L
5	Outlet Transition	Low/Moderate	Duplex SS	2205	2205	2205
6	Outlet Ductwork	Low/Moderate	Duplex SS	2205	2205	2205

PARADISE UNITS 1&2

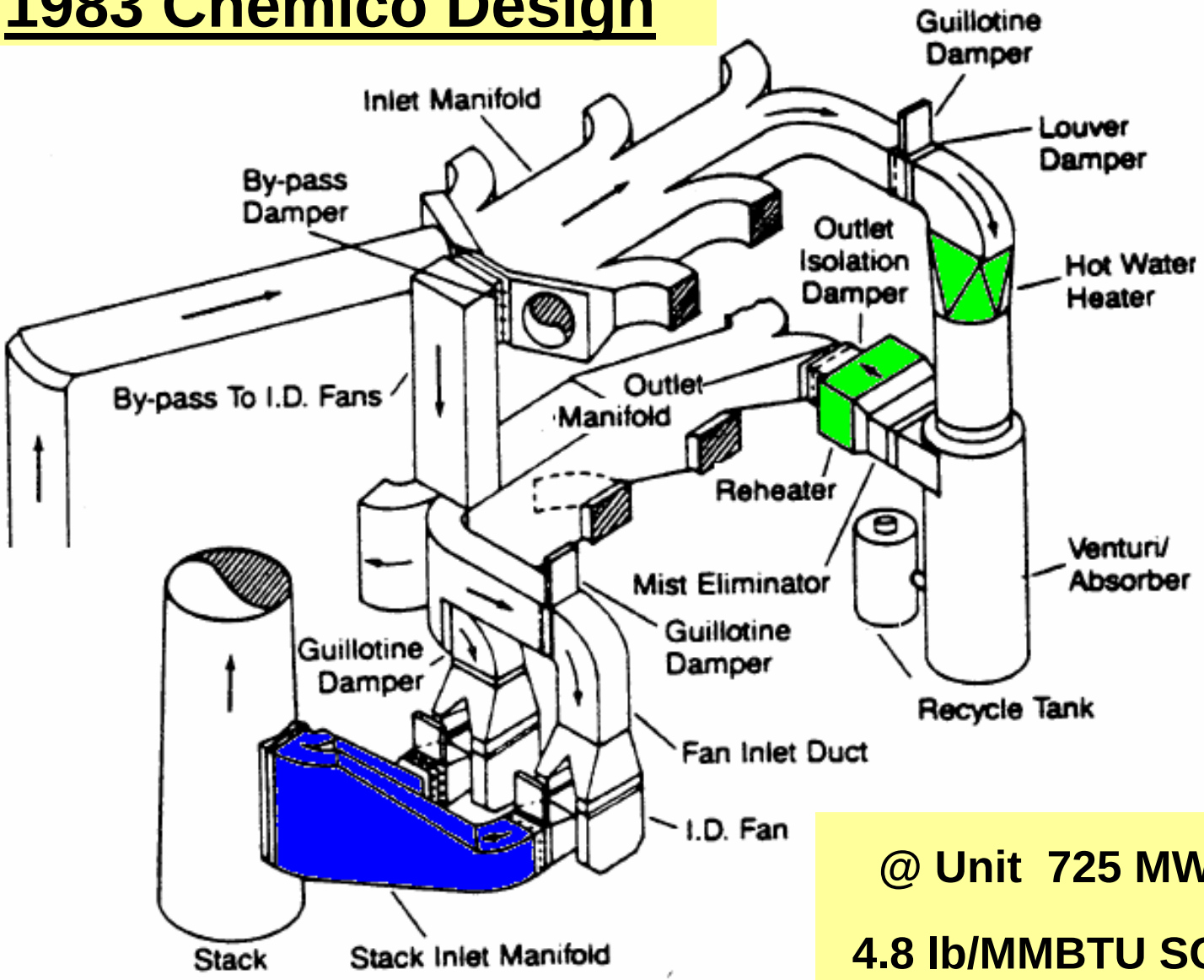
OUTLET DUCTS

Materials of Construction

Conversion to no Reheat

5. Scrubber Outlet Ducts PAF Units 1&2

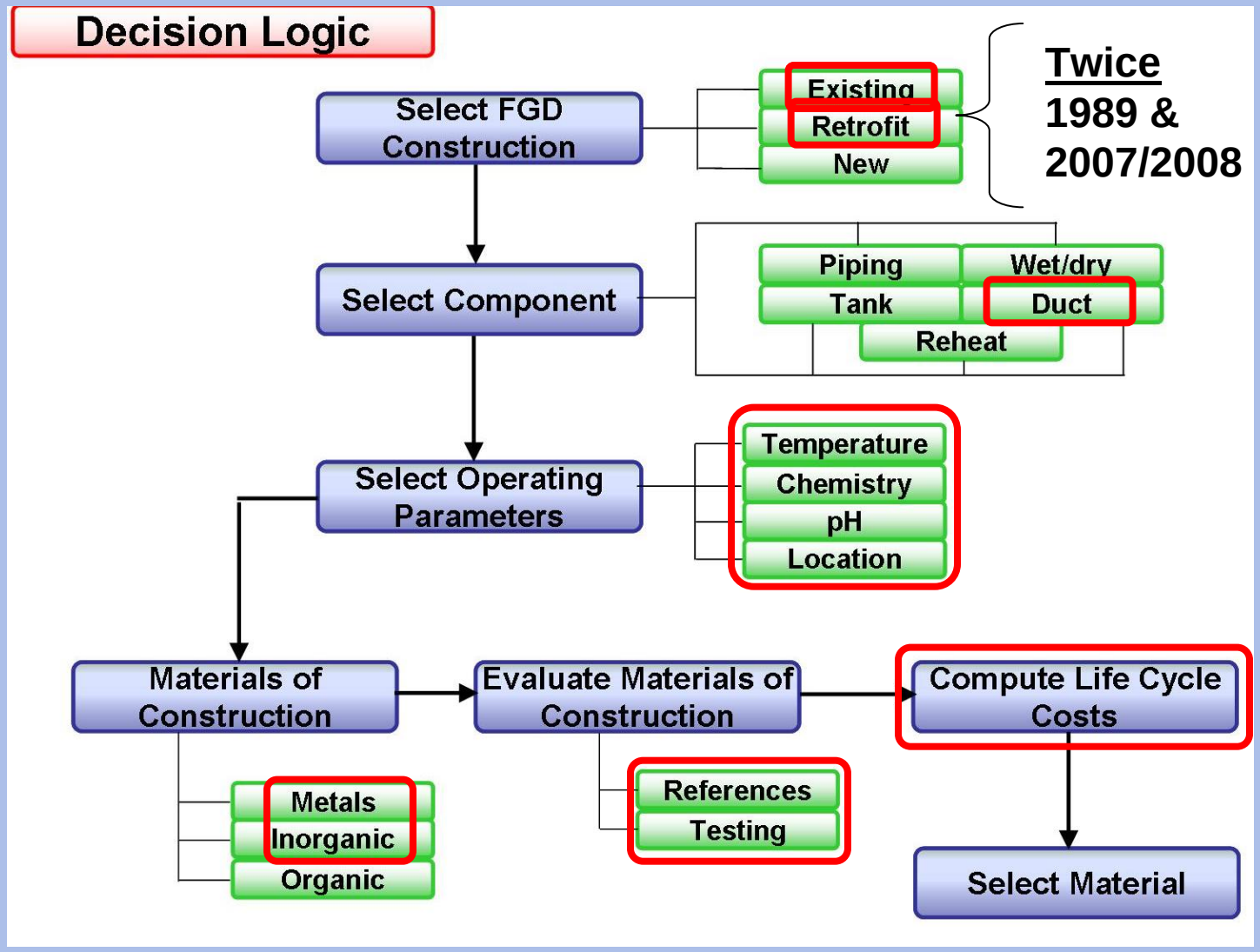
1983 Chemico Design



@ Unit 725 MW

4.8 lb/MMBTU SO_2

5. Scrubber Outlet Ducts PAF Units 1&2

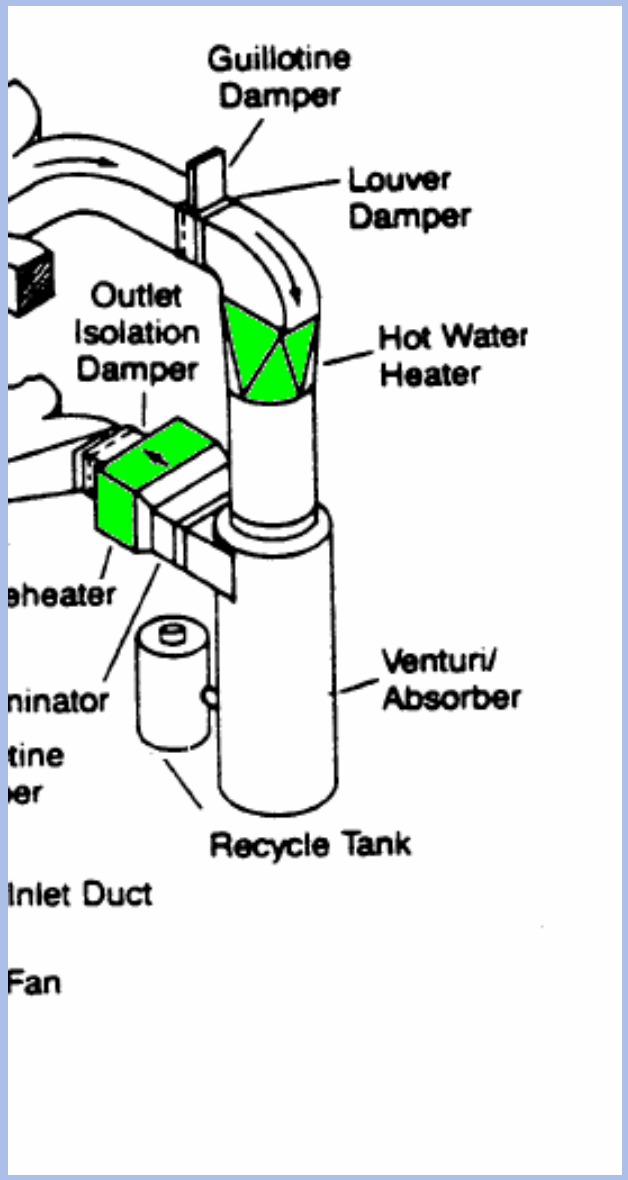


Scrubber Outlet Ducts
PAF Units 1&2

Paradise Units 1&2

Original Reheat Design

- **Designed** to heat FGD saturated outlet gas to 170^{O}F
- Closed loop boiler quality H_2O recycled system.
- **FGD Inlet** – Flue gas cooled and H_2O located in reheat coils is heated.
- **FGD Outlet** - Heated H_2O in the reheat coils transfers the heat to the scrubber outlet flue gas.



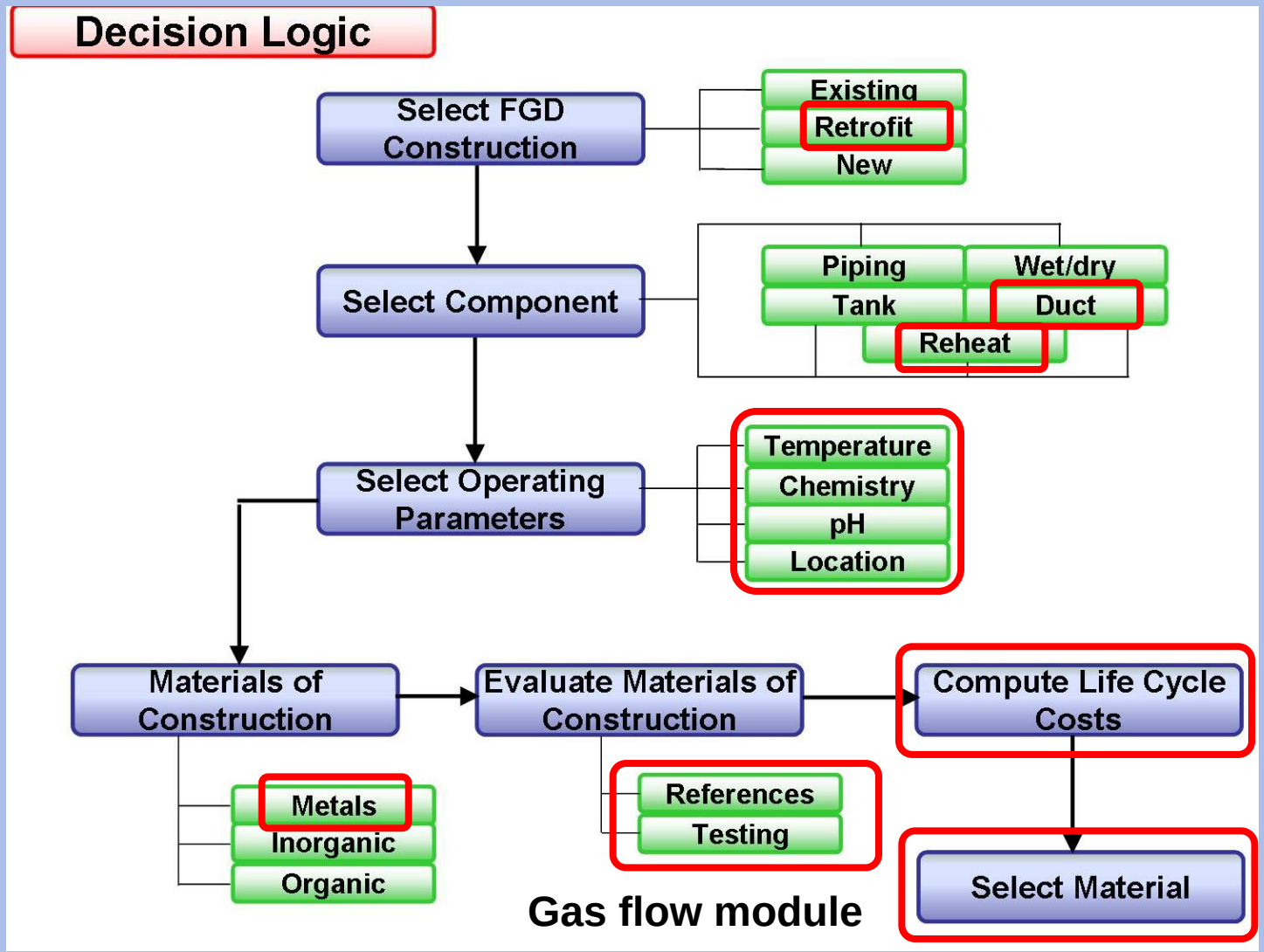
Scrubber Outlet Ducts
PAF Units 1&2

Historically, flue gas reheat justified based on:

- Improve dispersion of pollutants – (Still valid)
- To reduce the visible plume – (Still valid)
- Avoid stack rainout – Mitigated by improvements in duct/stack design
- Avoid corrosion problems on downstream materials – Had only a limiting effect on preventing corrosion. In fact, corrosion was a major problem with the re heater itself.

5. Scrubber Outlet Ducts PAF Units 1&2

#1 Retrofit 1989 / 1990



1989 / 1990 Design Change to remove reheat

5. Scrubber Outlet Ducts PAF Units 1&2 (1989/1990)

- **FGD Construction** –1990 Retrofit due to change in process conditions – Design change to remove reheat
  - 1983 – Units 1&2 FGD installed with reheat (shell and tube)
  - 1989 – Decided to remove existing reheat and operate in wet stack mode
    - Due to capital project cost of replacement of reheat tubes
    - Observed liquid draining from stack (even with reheat in service)
- **New Operating Parameters** –
  - Original ID Fan Inlet Temp = 170 ^{O}F & Outlet Temp = 185 ^{O}F
  - New ID Fan Inlet Temp = 125 ^{O}F & Outlet Temp = 135 ^{O}F

5. Scrubber Outlet Ducts PAF Units 1&2 (1989/1990)

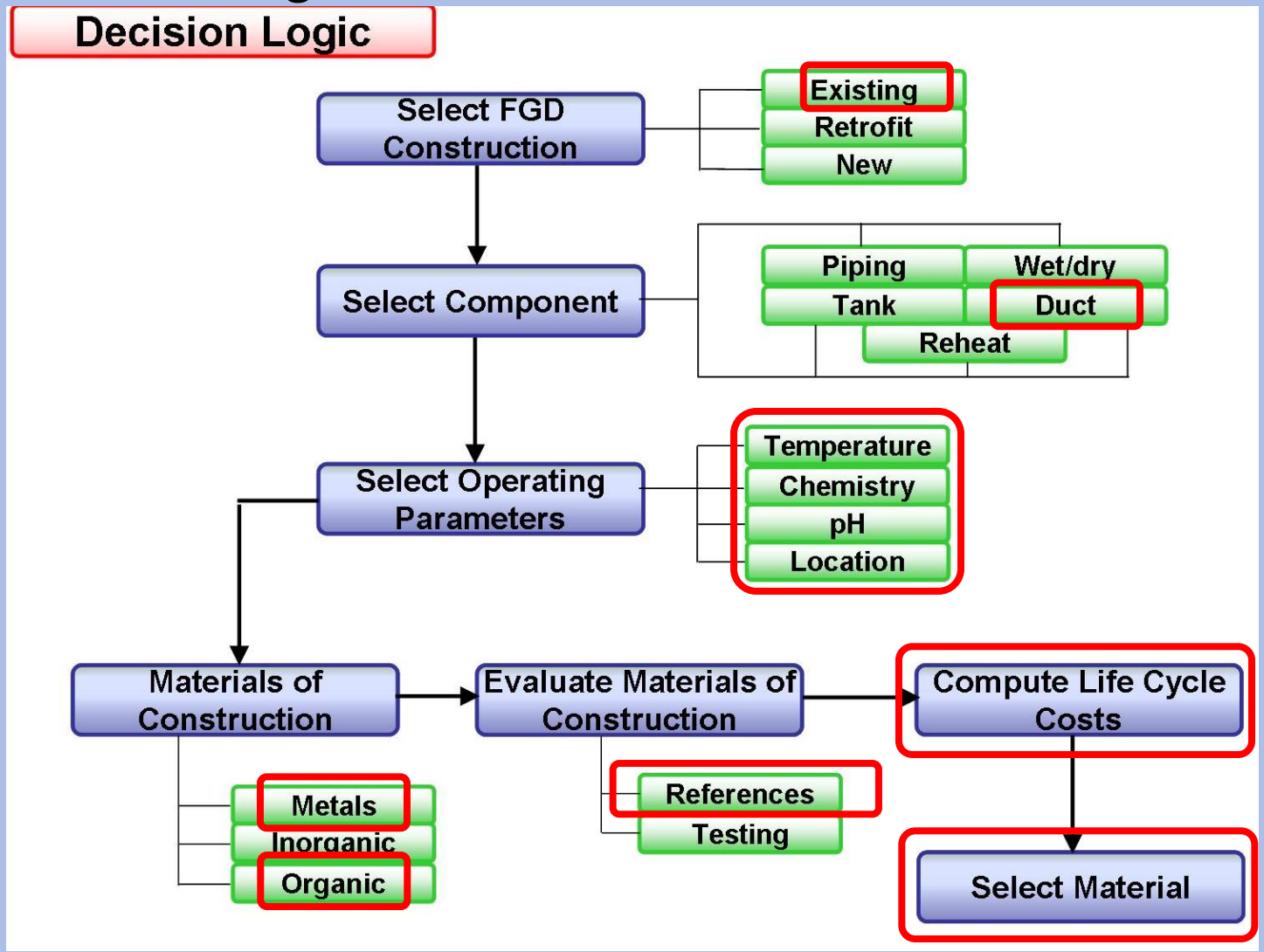
Impact on original carbon steel outlet duct??

5. Scrubber Outlet Ducts PAF Units 1&2 (1989/1990)

- **Propose Materials of Construction**
  - Based on known industry practices in the 1980s wallpaper and cladding of carbon steel outlet duct with alloy was accepted
- **Evaluate Materials of Construction**
  - Reviewed original 1980 flow moduling
  - Modified Outlet Duct with additional liquid collectors
  - Added stack pressurization system
- **Select Material of Construction**
  - In 1990 the original carbon steel outlet duct downstream of ID Fans 317L cladded and liquid collectors added.

5. Scrubber Outlet Ducts PAF Units 1&2

#2 Existing - 2007/2008



2006/2007 Relined the 317L cladded duct with Vinyl Ester Resin (VER)

5. Scrubber Outlet Ducts PAF Units 1&2 (2007 / 2008)

- **Existing FGD Construction**
- **Components**
  - **The Outlet Duct ID from the outlet damper expansion joint flange to stack inlet**
- **Operating Parameters**
  - Gas 135 ^{O}F and liquid puddles with pH < 2.
- **Possible Materials of Construction**
  - Replace with new 2205 duct
  - Reline with organic coating

5. Scrubber Outlet Ducts PAF Units 1&2 (2007 / 2008)

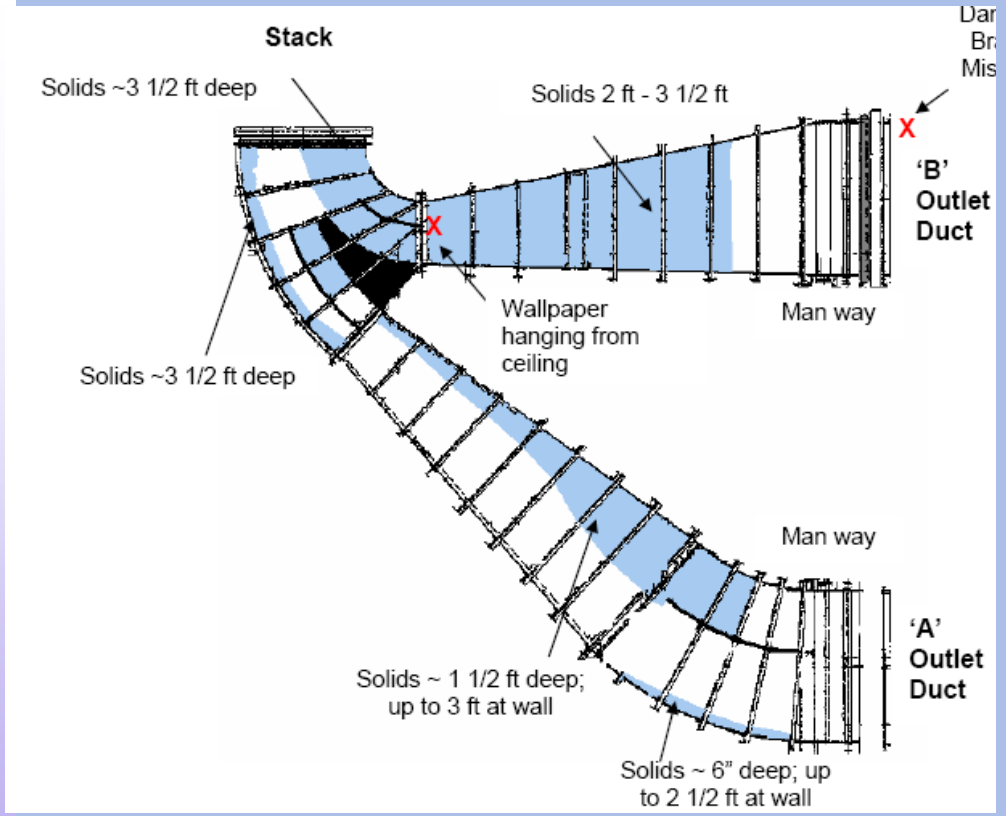
- **Computed Life Cycle Costs**
  - **between new duct and reline with organic coating**
- **Selected Vinyl Ester Resin (VER) – Proven Experience**
- **Installation**
  - Fall 2007 – Unit 1 Outlet Duct Relined with Ceilcote 140 VER
  - Spring 2008 – Unit 2 Outlet Duct Relined with Ceilcote 282 VER

5. Scrubber Outlet Ducts PAF Units 1&2 (2007 / 2008)

Fall 2007 – Unit 1 Outlet Duct Relined with Ceilcote 140 VER

Issues / Lessons Learned

1. **Previous MEs allowed solids build up on floor approximately 3.5 ft deep, up to 6 ft deep in some areas.** In addition, walls, turning vanes, structural supports, liquid collectors, expansion joints and drains covered with buildup



5. Scrubber Outlet Ducts PAF Units 1&2 (2007 / 2008)

Poorly working mist eliminators caused heavy buildup in outlet ducts (mist eliminators had been replaced in 2006 and wash system upgraded).

Module 250 – Mist Eliminator Panel

View From Reheat Section

5. Scrubbe PAF Units 1&2 (2007 / 2008)

To clean the duct, the high pressure was to remove solids.

Fall 2007 – Unit 1 Outlet Duct Relined with Ceilcote 140 VER

Issues / Lessons Learned

2. Used high pressured water to remove solids.

Water entered the area between the 317L liners and the carbon steel. It then permeated the stainless liner at the plug welds and weld seams. This contaminated the welds and the areas adjacent to the welds. In some areas solids precipitated out on the welds.

5. Scrubber Outlet Ducts PAF Units 1&2 (2007 / 2008)

Fall 2007 – Unit 1 Outlet Duct Relined with Ceilcote 140 VER

Issues / Lessons Learned

- Had to allow time for the duct to dry out. Drafting through the stack and sandblasting helped assist with drying out.
- Striping the welds was not sufficent to clean the area prior to application and patches were placed over some welds to protect the lining system from the solids.

5. Scrubber Outlet Ducts PAF Units 1&2 (2007 / 2008)

Fall 2007 – Unit 1 Outlet Duct Relined with Ceilcote 140 VER

Issues / Lessons Learned

3. Plug welds and weld seams that attached the 317L to the carbon substrate, were covered with glass mat patches. The patches were placed over the welds for serveral reasons. The additional patches slowed production and increased costs.

- 1. Glass mat over holes in 317L liner greater than a certain diameter.
- 2. Provide additional structural support where needed.
- 3. Matt over plug welds and weld seams that were precipitating moisture and solids.
- 4. Ensure applicator passed holiday test.

5. Scrubber Outlet Ducts PAF Units 1&2 (2007 / 2008)

Fall 2007 – Unit 1 Outlet Duct Relined with Ceilcote 140 VER

Issues / Lessons Learned

4. First time TVA ever coated flue gas duct. Experience in tank lining. The specification called for installation of a flake glass vinyl ester resin (VER) filled troweled system (Ceilcote 140). This system is a heavy duty, chemical resistant lining for protection of steel against aggressive chemicals in immersion service. Since the outlet duct in not a tank, further investigation revealed several spray applied systems that are also appropriate for FGD outlet ducts.

5. Scrubber Outlet Ducts
PAF Units 1&2 (2007 / 2008)

Spring 2008 - Unit 2 Outlet Duct Relined with Ceilcote 282 VER

Issues / Lessons Learned from Unit 1 Outage

Unit 1	Unit 2
Do not pressure wash duct	Remove solids from duct by shovel. Sandblast removed buildup on walls.
1. Glass mat over holes in 317L liner greater than a certain diameter.	1. Mat over holes in the 317 liner greater than specified is still required.
2. Provide additional structural support where needed.	2. Glass mat to provide additional structural support is still required.
3. Mat over plug welds and weld seams that were precipitating moisture and solids.	3. An alternate method of cleaning is recommended that will reduce the amount of water that will become trapped between the 317L and carbon substrate. See #3 below.
4. Ensure applicator passed holiday test.	4. If QC holiday test is not passed, an additional coating of material can be sprayed over weld.

5. Scrubber Outlet Ducts PAF Units 1&2 (2007 / 2008)

Spring 2008 - Unit 2 Outlet Duct Relined with Ceilcote 282 VER

Issues / Lessons Learned from Unit 1 Outage

During the Unit 1 installation, the specification called for installation of a flake glass vinyl ester resing (VER) filled troweled system (Ceilcote 140). This system is a heavy duty, chemical resistant lining for protection of steel against aggressive chemicals in immersion service. Since the outlet duct in not a tank, further investigation revealed several spray applied systems that are also appropriate for FGD outlet ducts.	Use a **spray applied system** on Unit 2 that is appropriate PAF outlet ducts. The coating system must be able to withstand flue gas operating temperatures of 135F and a pH < 2. The advantage of a spray system over the troweled system is it is less expensive and not as time consuming.

Scrubber Module Inlet Duct – CUF Units 1&2

Decision Logic