16th STS-AIChE Southwest Process Technology Conference

- **Ethylene Plant Case Studies – Process Technologies and associated Critical Hazards, SIS Functions, Data Analytics, and Optimum Testing**

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- SIS SILverstone LLC *(sub of Keystone Eng. Inc.)*

Sept 22-23, 2025, University of Houston

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Speaker Bio

- Curt Miller, started up SIS SILverstone 9 years ago after being an Exida partner for 12 years. Has over 35 years of professional experience working with safety systems and process/functional safety applications.
- Graduate of Texas A&M University with a B.S. in Chemical Engineering and is an ISA - Bluebonnet (Austin & San Antonio) Past-President
- Involved with TAMU Turbo Symposium for over 12 years (Protective systems panel member, 3 tutorials, 3 short courses)
- Authored a book titled “Win/Win: A Manager’s Guide to ISA 84 Compliance” in Jan 2008. After providing persuasive arguments to invest in functional safety, it utilizes polled data from 93 participants to provide guidance in overcoming implementation gaps.

C2 Plant Case Studies – Process Technology and associated Critical Hazards, SIS Functions, Data Analytics, and Optimum Testing

- I. Case Studies Basis for this Presentation
- II. General Ethylene Process Background
  - Need for Continued Focus on Process Safety
  - Simplified Ethylene Process Flow
  - Critical Hazard Identification and Safety Integrity Level (SIL) Assignments
- III. Breakdown of Process Areas' Critical Hazards & Target Interlock SILs
  - Geneal Listing of Significant Hazards for each of 11 Areas
  - Listing of critical SIL Assignments per Case Study
- IV. SIS Instrument Data Analytics Studies
  - Data Availability & Utilization of Reliability Studies
  - Plant Operational and Maintainability KPIs Investigation
- V. Path Forward for Optimized Safety and Plant Availability

I. Ethylene Hazards Case Study Basis

Ethylene Hazards Case Study Basis

- The Following Matrix Provides Insight on the Studies Utilized for this Comprehensive Review:

User Application	U1	U2	U3	U4	U5	U6	U7	U8
Study / Area	PHA/ LOPA	SIL/ SRS	SIL Data/ Test Proc.	Furnace/ T.O. Stds.	Site Flare	CGC T&TV	CW T&TV	Site O&M KPI
1. Feed (FD)	✓	✓	✓					✓
2. Cracking Funace (HTR)	✓	✓	✓	✓				✓
3. Cracked Gas Compressor (CGC)	✓	✓	✓			✓		✓
4. Cold Box, DeMethanizer (DeC1) Section	✓	✓	✓					✓
5. DeEthanizer Section (DeC2)	✓	✓	✓					✓
6. Ethylene Splitter (C2)	✓	✓	✓					✓
7. Propane+ Product Recovery (C3+)	✓	✓	✓					✓
8. Propylene Refrigerant Compressor (PRC)	✓	✓	✓					✓
9. Etylene Refrigerant Compressor (ERC)	✓	✓	✓					✓
10. Flare System	✓	✓	✓		✓			✓
11. Other Utilities (Elect, CW, Air, T.O., etc.)	✓	✓	✓	✓			✓	✓

II. General Ethylene Process and Hazards Background

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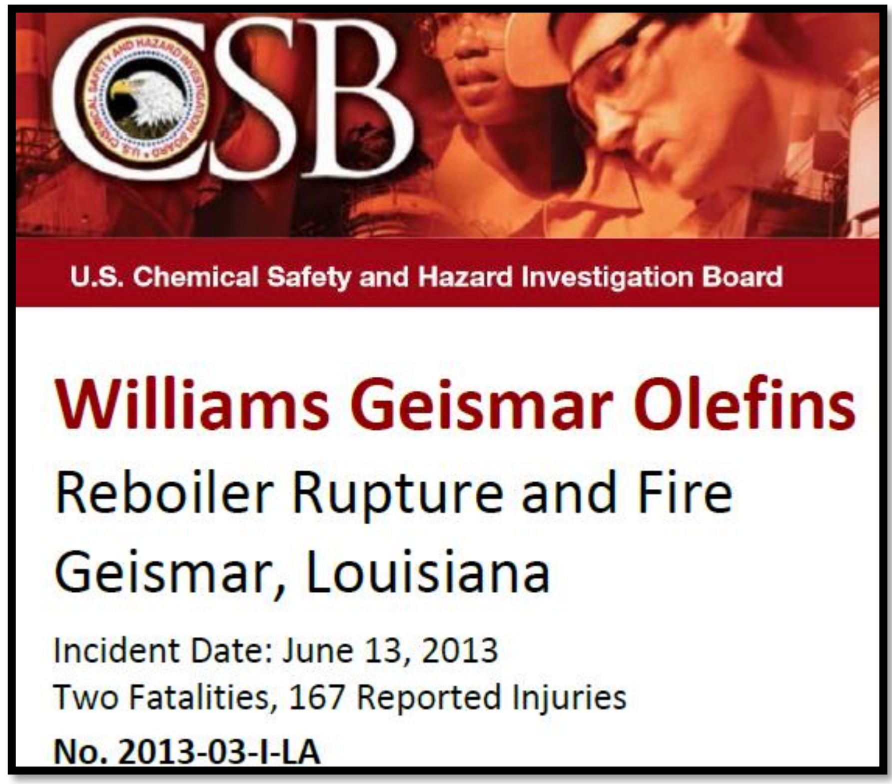
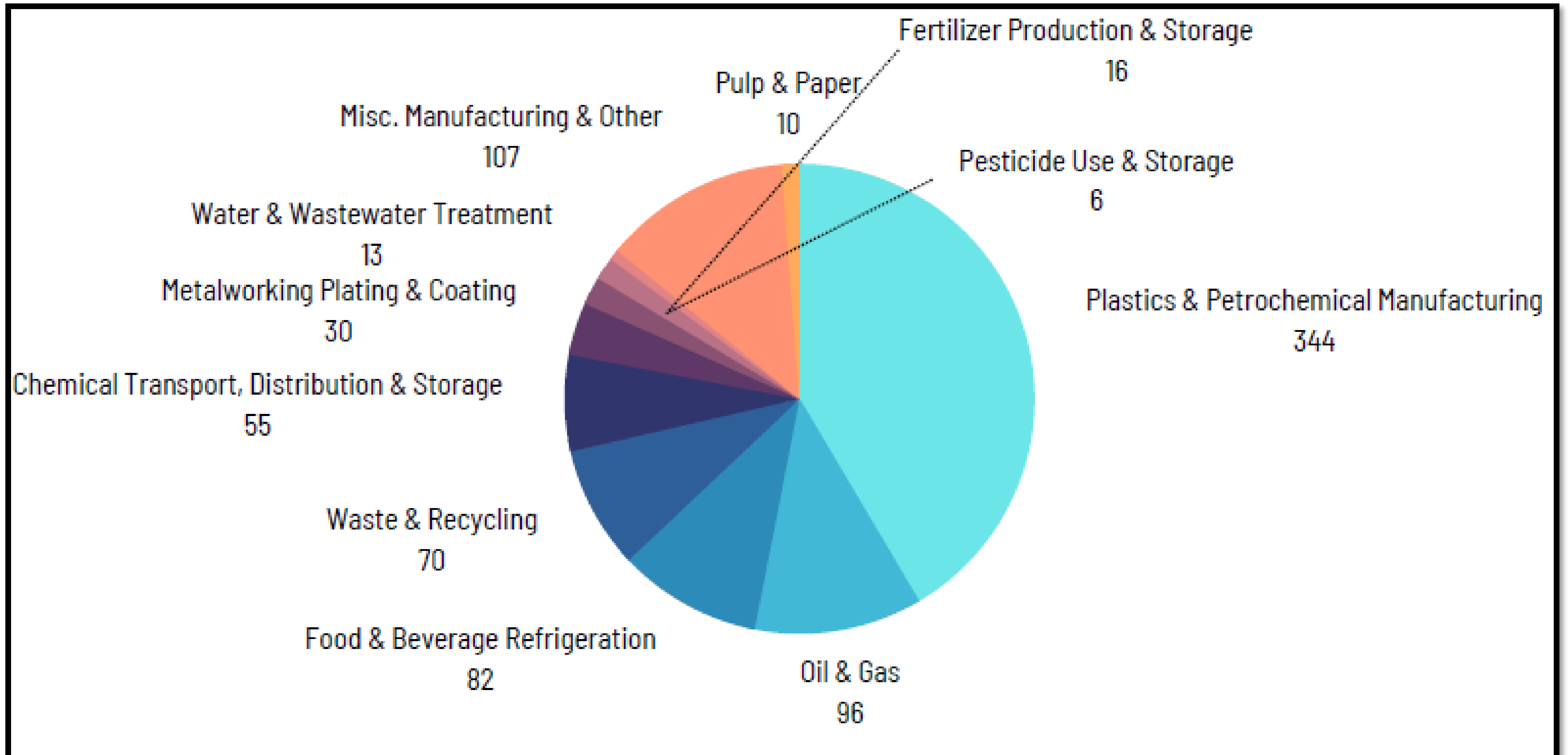


Safety Excerpts Support Focus on Ethylene Process Safety

- Accident investigation results presented at the 1994 EPC meeting show that **olefin units accounted for 26 of the 170** (15%) major hydrocarbon property losses in a 30-year period *(Analysis of Large Property Losses in the Hydrocarbon-Chemical Industries with Emphasis on the Ethylene)*
- **Shell Polymers Monaca, PA** (June 4, 2025)
- **Shell Deer Park, Texas** (May 2023)
- **Williams Olefins, Geismar, LA** (June 2013)

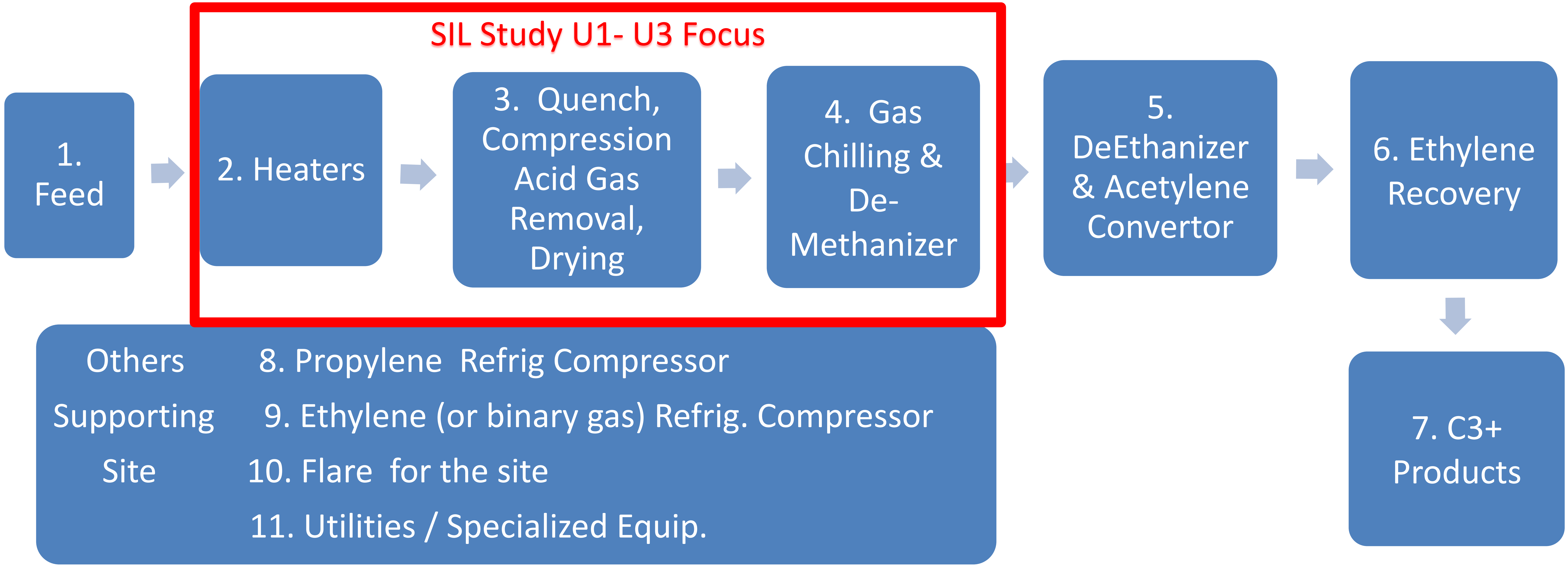


Key Findings: Chemical Incident Tracking 2021-2023

C2 Process Technologies

- The main licensors include:
  - Lummus
  - KBR
  - Technip Energies
  - Linde
- New Technologies aim to improve:
  - Efficiency (feedstock, reaction conditions, yield, energy consumption, etc.)
  - Sustainability

Simple Process Block Flow Diagram



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Critical Hazard Identification and Safety Integrity Level (SIL) Assignments

- Process Hazard Analysis (PHA) per OSHA 1910.119 PSM Requirement:
  - Identifies the Hazard of event
- Layers of Protection Analysis (LOPA, other tools) per OSHA RAGAGEP*:
  - Quantifies the risk to result in a Safety Integrity Level (SIL) target for interlocks (a.k.a. Safety Inst. Functions, SIFs) *(i.e. Gap of Risk Target & Unmitigated Event Frequency)*
- Major Factors that will affect the SIL Target:
  - Process configuration (e.g. Process technologies applied)
  - Client Risk Target
  - Consistency of PHA and LOPA processes

SIL	Reduces Event Frequency by
SIL1	Minimum factor of 10+
SIL2	Minimum factor of 100+
SIL3	Minimum factor of 1000+
Note: After accounting for other safeguards &/or factors	

**RAGAGEP is an abbreviation for "Recognized and Generally Accepted Good Engineering Practices"*

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III. Breakdown of Process Areas' Critical Hazards & Interlock Target SILs - Case Studies (U1, U2, U3)

High Level Listing of C2 Plant Critical Hazards

- Ethylene Plant Hazards include:
  - Feed low flow or high pressure

SIL Study U1- U3 Focus

  - Furnace loss of flame, re-lighting issues
  - Compressors (process/refrig.)/expander - overspeed, surge, liquid carryover, high discharge pressure
  - Tower overpressure, loss of level, high level
  - Cold section embrittlement flow scenarios
  - Flare sizing, high level knock out drum
  - Utility loss of air, cooling water, and thermal oxidizer issues

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Case Studies (U1-U3) – Safety Inst. Functions (SIFs) Comparison

- Total number of Unique SIFs per Area:

Process Area	Unique SIFs	%
1. Feed (FD)	7	5%
2. Cracking Furnace (HTR)[1]	14	9%
3. Cracked Gas Compressor (CGC)[1]	19	13%
4. Cold Box, DeMethanizer (DeC1) Section	26	17%
5. DeEthanizer Section (DeC2)	8	5%
6. Ethylene Splitter (C2)	11	7%
7. Propane+ Product Recovery (C3+)	19	13%
8. Propylene Refrigerant Compressor (PRC)[1]	11	7%
9. Ethylene Refrigerant Compressor (ERC)[1]	14	9%
10. Flare System	2	1%
11. Other Utilities (Elect, CW, Air, T.O., etc.)	18	12%
Totals	**149**	**100%**

[1] *Note: Duplicated SIFs (e.g. furnace, compressors not included)*

- Total number of Unique SIFs varied per User:

User Study	Interlocks per SIL Class[1]			Total[1]
	SIL1	SIL2	SIL3	
U1	35 38%	50 54%	7 8%	**92**
U2	21 33%	40 63%	2 3%	**63**
U3	33 77%	8 19%	2 5%	**43**

[1] *Note: Duplicated SIFs (e.g. furnace, compressors not included)*

- Remember, the totals were affected by plant equipment, client risk targets, and application of PHA/LOPA

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Area 2 (Cracking Furnace) – Significant Hazards – SIL Assignments

- Common SIL Assignments to the 3 Plants:

Ref	Hazard Description	U1	U2	U3
Htr#1	High Burner Fuel Gas Pressure	SIL2	-	SIL1
Htr#2	Low Burner Fuel Gas Pressure	SIL1	SIL2	SIL1
Htr#3	High Temperature Firebox	SIL2	-	SIL1

- Additional SIL Assignments:

Ref	Equipment	Hazard Description	SIL
Htr#4	Dilution Stm	Low Flow Dilution Steam	SIL1
Htr#5	BMS (pilots)	High Pilot Gas Pressure	SIL2
Htr#6		Low Pilot Gas Pressure	SIL2
Htr#7	BMS (air)	Power Failure (induced draft fan)	SIL1
Htr#8		LO-LO ID Fan Motor Wattage	SIL2
Htr#9		LO-LO ID Fan Shutdown	SIL2

Ref	Equipment	Hazard Description	SIL
Htr#10	Decoking	Low Decoking Air Pressure	SIL1
Htr#11		High Decoking Comp. Vibratio	SIL1
Htr#12	Recovery	Low level in SHP Steam Drum	SIL2
Htr#13		No Quench to DeSuperheater	SIL3
Htr#14		LO-LO Level in Steam Drum	SIL2

- API 556 is a common BMS standard and was applied in the U4 study

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Area 3 (Cracked Gas Comp. + *Quench*) – Significant Hazards – SIL Assignments

- Common SIL Assignments to the 3 Plants:

Ref	Hazard Description	U1	U2	U3
CGC#1	High Discharge Pressure	SIL2	SIL1	NSIR
CGC#2	High Level Scrubbr Carry-over	SIL2	-	NSIR
CGC#3	Overspeed Protection	SIL1	SIL2	-
CGC#4	High Suction Temp. *(e.g. No Quench)*	SIL3	SIL1	NSIR
CGC#5	High Discharge Temperature	SIL2	SIL1	-
CGC#6	Loss of Lube Oil Supply	SIL2	SIL1	
CGC#7	Low Seal Gas Pressure	SIL1	SIL2	-
CGC#8	High Vibration	SIL1	SIL2	-
CGC#9	CGC Compressor Trips, Rev Flow	-	SIL3	SIL2

- API 670 Machinery Protection Systems (6th Edition, July 2025) applies to the CGC

- Additional SIL Assignments:

Ref	Equip	Hazard Description	SIL
CGC#10	CGC	Low Bearing Oil Pressure	SIL2
CGC#11		Auto-Refrigeration 4th St	SIL1
CGC#12	Quench	Low Pressure Implosion Quench	NSIR
CGC#13		Low level Quench Bottoms Storage	SIL1
CGC#14		High level Quench Bottoms Storag	SIL1
CGC#15	Steam to Turbine	Low Pres. 200# Extraction Header	SIL1
CGC#16		Steam Quality Issue to Turbine	SIL2
CGC#17		Vacuum Condensor Hi Pres/Level	SIL2
CGC#18	Caustic	Caustic Tank Overpres. (supply	SIL1
CGC#19	Drier	Dyer KO High Pressure	SIL2

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Area 4 (Cold Box, DeC1) – Significant Hazards – SIL Assignments (*common*)

- Common SIL Assignments to the 3 Plants:

Ref	Hazard Description	U1	U2	U3
DeC1#1	Low Level leads to Overpressure of DeC2	SIL2	-	SIL1
DeC1#2	High level Demeth Carrryover/Expander dmg	SIL2	SIL1	SIL1
DeC1#3	Loss of reboiler in DeMeth	SIL2	-	SIL1
DeC1#4	Low Pres/Temp in DeMeth Bottoms	SIL2	SIL2	SIL3
DeC1#5	High Pressure in DeMeth	-	SIL1	NSIR
DeC1#6	High H2 gas temp, Methanator Runaway Rxn	NSIR	SIL2	-

Area 4 (Cold Box, DeC1) – Significant Hazards – SIL Assignments *(unique)*

- Additional SIL Assignments:

Ref	Hazard Description	SIL
DeC1#7	High Temp from DeMeth Sep, Dryer Ethyl Rxn	SIL2
DeC1#8	Carryover Methan Wash Drum, Low T Embritt	SIL2
DeC1#9	Carryover out of cold box, embrittlement	SIL2
DeC1#10	Overfill Reflux Drum, Offgas Embritt.	SIL2
DeC1#11	High level in Methanol Storage Drum	SIL1
DeC1#12	H2 Drum Hi Level to Methantor Runaway Rxn	SIL2
DeC1#13	High Level Tray Fail, Residue Gas Rectifier	SIL1
DeC1#14	Low Temp Seal Gas to Bearing for Expanders	SIL2
DeC1#15	Lo-Lo Differential PressureExpander	SIL2
DeC1#16	Expander Overspeed	SIL1

Ref	Hazard Description	SIL
DeC1#17	Expander KO high Level Trip	SIL2
DeC1#18	Low Temperature Hydrogen piping	SIL2
DeC1#19	Low Temperature Methane Gas Recycle	SIL2
DeC1#20	LP Residue Gas Low Temperature	SIL2
DeC1#21	High level to Vaporizer, Exchanger Leaks	SIL1
DeC1#22	High Pressure in Process Gas Header	SIL1
DeC1#23	PGC Flow trip stops cold H2/CH4 flow	SIL1
DeC1#24	Low T(PGC stop) AutoRefrig DeC1 Precoolers	SIL3
DeC1#25	Startup with high reflux in DeMeth	SIL2
DeC1#26	DeMeth Sep Gas Blowby OP of DeMeth (4 st)	SIL1

IV. SIS Instrument Data Analytics' Studies

Interlocks – Instrument SIL Data Requirements

- Once get SIL / RRF target through risk analysis, must design the SIF (Safety Instrumented Function) and verify through calculations that it meets the SIL / RRF target
- Choices in SIF design include choosing:
  - Technology (Safety PLC, smart devices, switches, relays, etc.)
  - Configuration (simplex, redundant, fault tolerant)
  - Test and maintenance frequencies
- SIL verification (i.e.) reliability calculations prove the SIL target was attained
  - Data for interlock devices based on “stiction” (i.e. dormant, operate-by-exception mode) is key to optimum performance
  - For many mechanical devices (e.g. valves & motor controls), such data may be hard to get from venders (if not SIL assessed) or site records..

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SIL Instrument Data Resources

- Industry (Oreda, SINTEF, exida, others):
  - Not application specific and product specific
- Manufacturers:
  - Not application specific, but product specific to vender
- Reliability Model Studies (e.g. FMEDA, others):
  - Product specific, but not application field proven
- User Detailed Field Failure studies **** BEST ****
  - Both application and product specific
  - Unfortunately, most users haven't collected a statistically supported database

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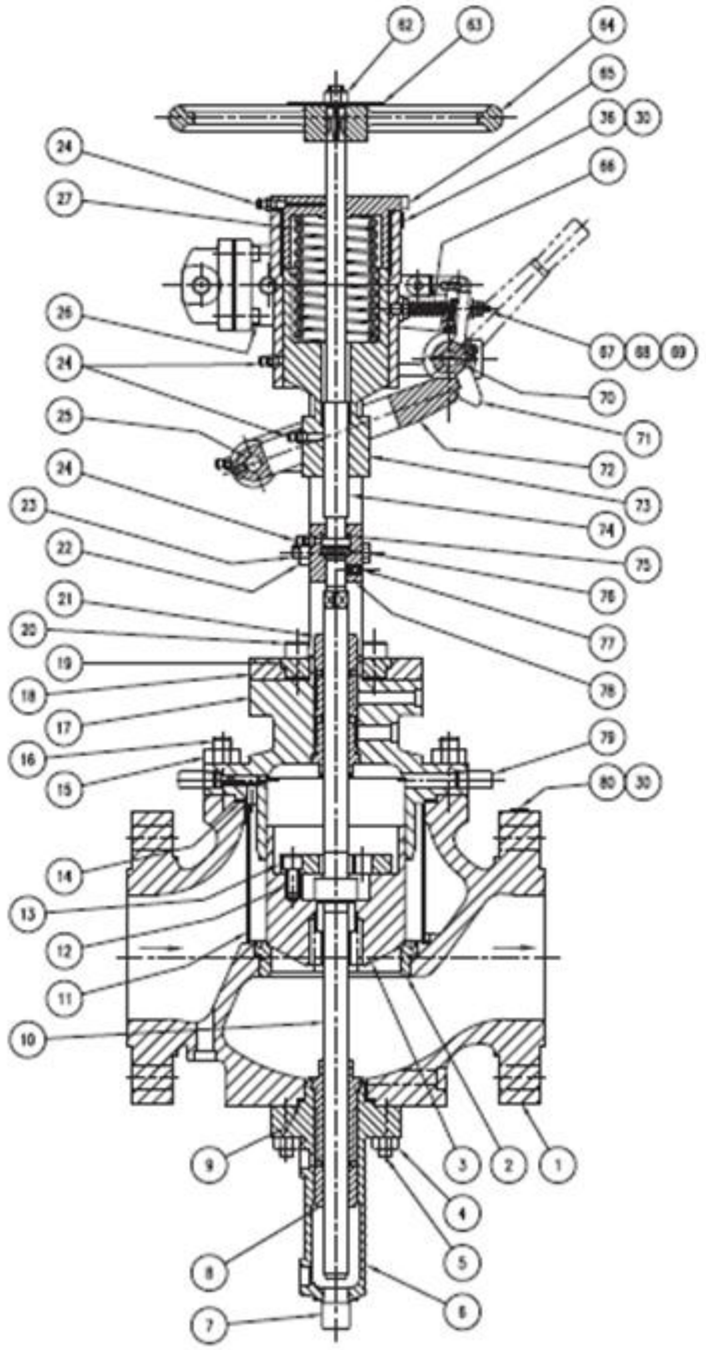
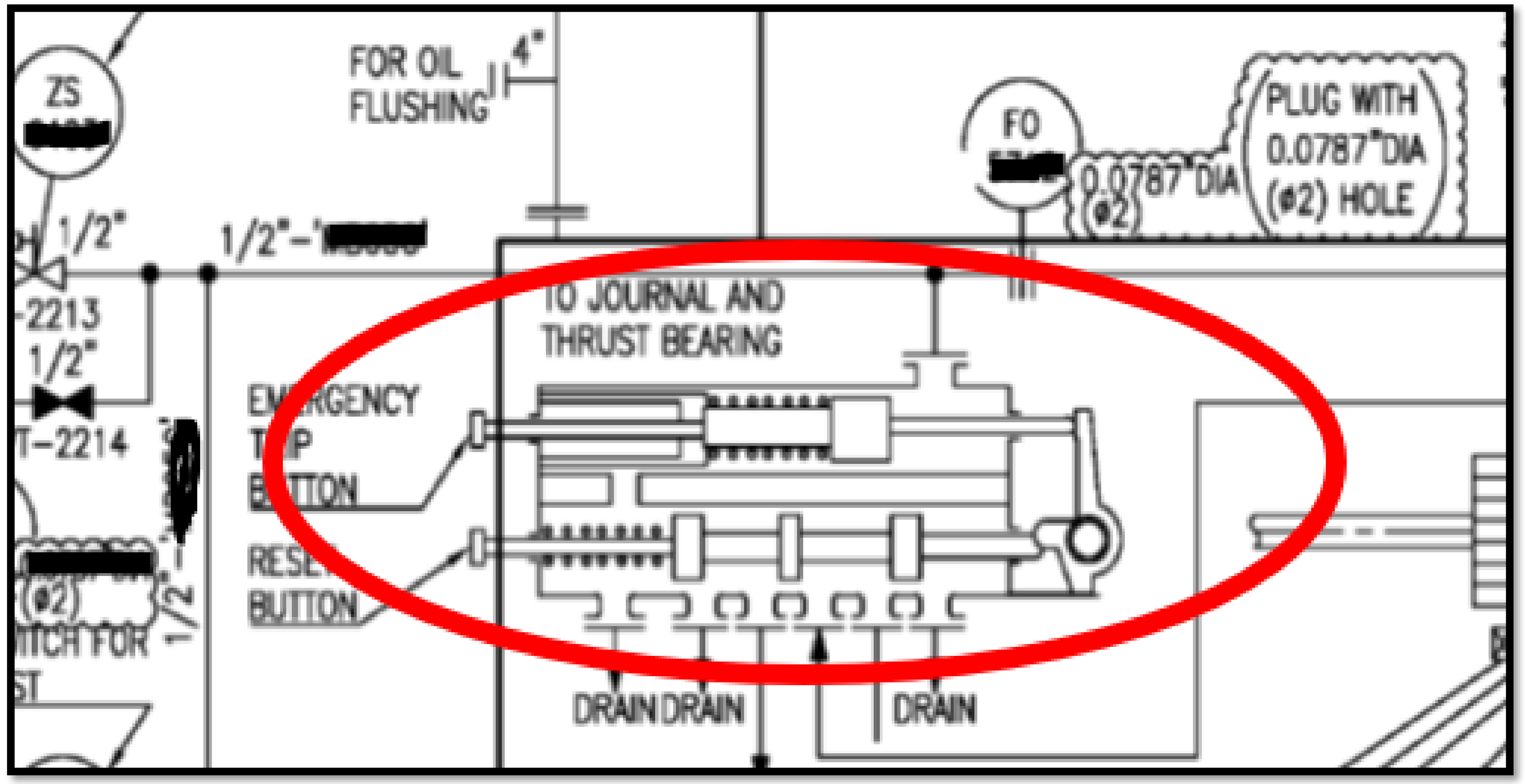
Component SIL Data - Case Study (U7): CW T&TV

- SIL2 requirement for a steam turbine driven cooling water pump trip:
  - Data for "trip & throttle valve" was non-existent
  - As a comparison, globe valve would achieve only **SIL1**
- User elected to go with a Failure, Modes, Effects, & Diagnostics Analysis (FMEDA) reliability study
  - Break down into piece/parts and assign failure rates/diagnostic coverages
- **SIL2** attained with the new data, online test, and assuming "Prior Use" justification
- User will continue monitor installation and adjust if necessary



Component SIL Data - Case Study (U6): CGC T&TV *(slide1)*

- User required a SIL2 for a large steam turbine driven Cracked Gas Compressor
- Key SIL2 issues that needed to be addressed:
  1. No data for "trip & throttle valve"
  2. Extended offline testing at 6+ years
  3. Newly discovered failure mechanism - "Emergency Trip Device (ETD)" failure would disable the trip action by not dumping the hydraulic fluid fast enough
- First run on the SIL calcs only yielded a low SIL1



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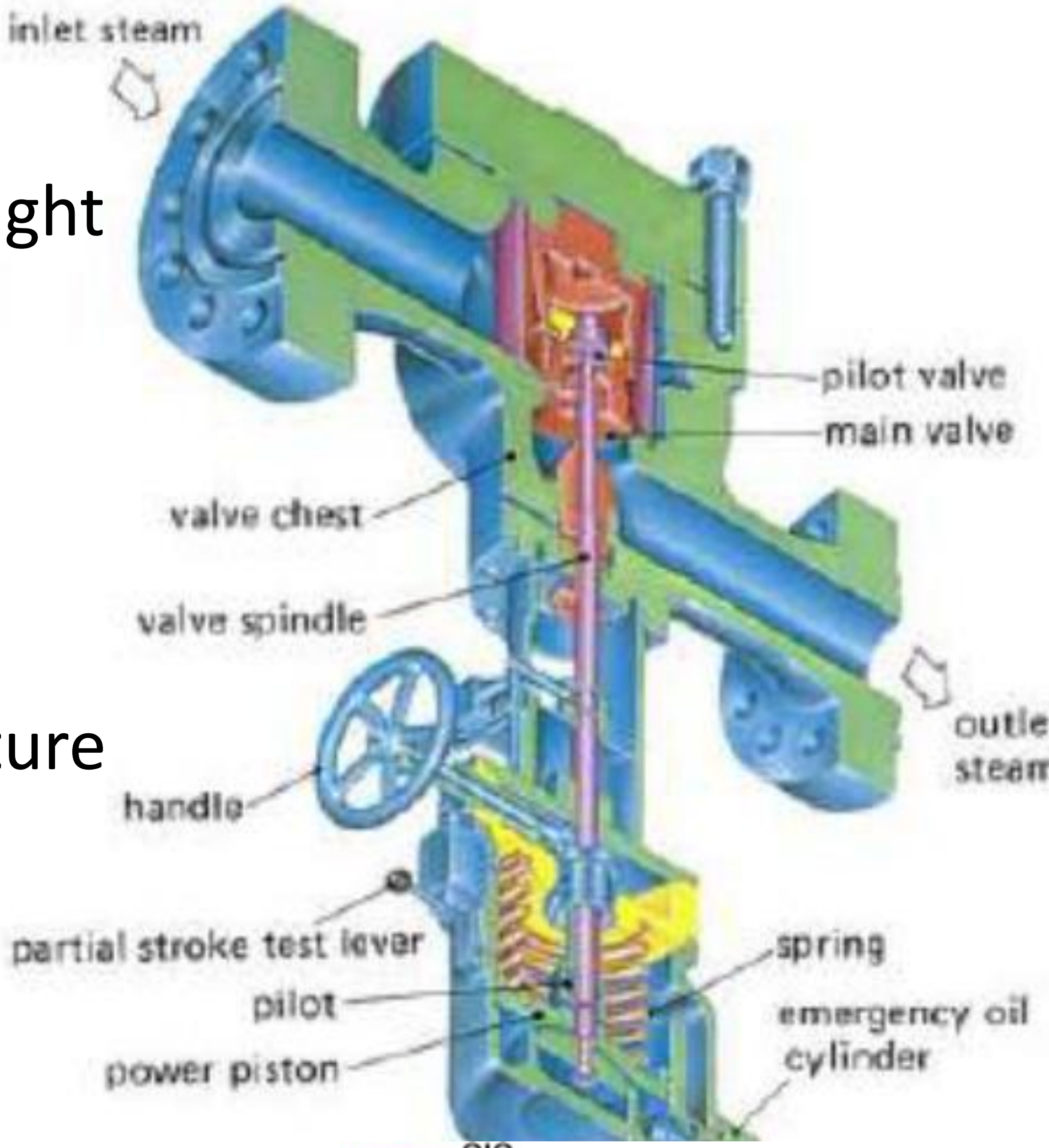
Component SIL Data - Case Study (U6): CGC T&TV *(slide2)*

- Solutions??
  1. The hydraulic pump design was altered to nullify its impact
  2. User commissioned a FMEDA reliability study to provide data insight
- User obtained **SIL2** by applying the new data requiring:
  - Partial stroke testing quarterly
  - Rebuilding the valve on every turnaround
- User will continue monitor installation and adjust if necessary, in future



Undersized Flare - Case Study (U5)

- New Petrochemical Site had Undersized Flare to Support Global Issue:
  - Use quantitative analysis, not client's prescriptive flare guidance
- Limiting Scenarios that Needed to be Reviewed:
  - Global cooling water and power failure scenarios
  - Had to breakout for both mass and radiant flows
  - Had limitations on both Hot and Cold Flares

Case 1 - Total Cooling Water Failure				
		PFDavg*	Event Likelihood	
	PFDavg*	2.04E-03	2.5.E-06	yr
Initating	1.22.E-02	Propylene Fractionator		
Cause Rate	Quench (2oo8 furnaces)	4.37E-03	5.3.E-06	yr
0.1		Propylene Compressor Fails		
Cooling Water	2.04E-03	4.37E-03	8.91E-07	yr
Failure	Propylene Fractionator	Propylene Compressor Fails		
Total Flare Rupture Event Freqency Based on Loss of Cooling Water			8.7.E-06	yr

- Results of the study
  - Visualized with event trees
  - New SIL requirements placed on equipment referred to as HIPPS (High integrity pressure protection system). These elevated the SIL for 3 of the 4 interlocks..

Site Equipment	SIL Target	
	PHA/LOPA	HIPS Study
Quench Tower	0	SIL1
Ethylene Tower	0	SIL2
Propylene Tower	0	SIL2
Propylene Refrig. Comp.	SIL2	SIL2

SIL KPI Data Analytics – Benchmarking Case Study (U8)

- The following table provides key benchmarks for functional safety:

#	SIS Instrument Key Performance Indicators (KPI)	Management Basis
1	**SIF Demand Rate**	*Should line up with the PHA derived rates*
2	**SIF Fails to Act on Demand**	*Basically, never occur if systematic error free*
3	**SIF Failed Proof Test**	*Discovered failure rates should be within bounds of data applied in SIL calculations*
4	**Online Instrument Health**	*Diagnostics are good if correctly applied and should not be excessive*
5	**Average and Maximum (Peak) Bypass Duration**	*Good indication of maintenance capability*
6	**Mean-Time-Between- Failures (MTBF)**	*Help support current practices or need to improve*
7	**Mean-Time-To-Repair (MTTR)**	*Should meet maintenance performance goals*

SIL KPI Data Analytics –Single Refrigeration Compressor Interlock Focus

- The metrics from this focus study are shown in the table below:

#	Key Performance Indicator (KPI)		Refrigeration Compressor SIFs (20 total)		
			(Basis: 3 level, 9 pres., 7 temp., 1 speed, 5 vibration sensors, 2 valves, 1 SIS		
			Theoretical Frequency	SIS SOE Log (# recorded)	Manual Records (#)
1	SIF Demand Rate		1/4 yr	✗ (17)	✗ (2)
2	SIF Fails on Demand		1/11,050 yr	✗ (Not config.)	✓ (0)
3	SIF Failed Proof Test		1/21 yr	✗ (Not config.)	✓ (0)
4	Instrument Health	BadPV	1/1.4 yr	✗(19)	-
		Deviation	1/2.7 yr	✗(15)	-
5	Avg & Max Bypass Duration		12.3/yr	✓ (17)	✗(2)
6	MTBF		XMTR:1/200yr, XV: 1/70yr	-	✗(2)
7	MTTR		< 72 hrs per SRS	✓ (0)	-
X1	Spurious Trip Rate		1/2.3 yrs	*Not reviewed*	✓ (0)
X2	Systematic Failure		*Not specified*	-	-

Legend: ✗ = Exceeds expected rates, ✓ = Meets expected rate, "-" not applicable,

SIL KPI – Study Key Takeaways

- Utilization of KPIs could support an active program to optimize both safety and operational reliability
- Based on the study, the following KPI recommendations were warranted:
  - Set-up a data collection program for SIS, IPL, & cause devices
  - Clear the spurious transmitter Bad PV and DEV alarms that are not true failure notifications
- Once the program is running well, the number of data points to be analyzed will be manageable as shown in the table for a complete site with 200 SIFs

SIS Components in KPI Program (~200 SIFs)	Quantity
Total Number of Components	566
Expected Annual Analytics/ Year*	41
**Based on true failure rates, advanved diagnostics, and no systematic contributions*	

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V. Path Forward for Optimized Safety and Plant Availability

Path Forward to Optimized Safety and Plant Availability

- Update safety programs to applicable standards with practical guidance:
  - Use quantitative, not qualitative data to support decisions
  - Consistency of application will be gained through well defined hazard scenario definitions (e.g. Normal causes, consequence severity boundaries, conditional & enabling modifiers, and applicable safeguards)
- Institute a SIS KPI program that uses incremental results to support larger investments:
  - Start with 2 most impactful KPIs
  - Grow with manual collection until site fully "buys in"
  - Apply software for additional efficiencies
  - Program should be "Little Data – Precisely Collected"SM
- If testing resources are lacking at your site, consider investing in a "data pilot" program to optimize the testing requirements (both frequency and effort needed)
  - Initial impact would compare current testing frequencies to known failure data
  - Pilot data generate further justification for further optimization

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SIS SILverstone Company Overview

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Functional Safety- Process Safety Management- SIS Lifecycle Management

- PHA/HAZOP facilitation / reviews
- Layer of Protection Analysis - LOPA
- Safety Instrumented System (SIS) studies and specification (SRS)
- SIL verification
- Fault Tree Analysis
- Alarm Management (ISA 18.2)
- Cybersecurity (IEC62443 – ISA 99)
- Digital Transformation in FS
- Instrument reliability
- RAM studies
- Data Analytics
- Maintenance and Reliability programs
- SIS Testing and Optimization