An AIChE Technology Alliance
CCPS
Center for Chemical Process Safety

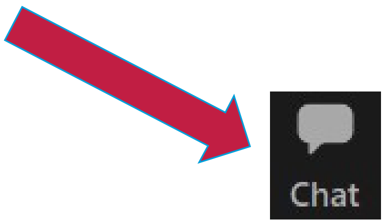
DNV

Welcome to 2022
Process Safety in Africa Webinar

4th October 2022

The webinar will begin shortly.

ZOOM HOUSEKEEPING



TECHNICAL ISSUES

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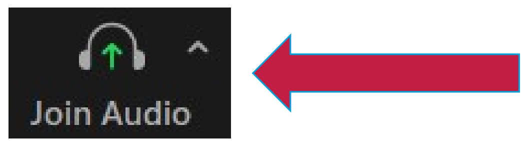

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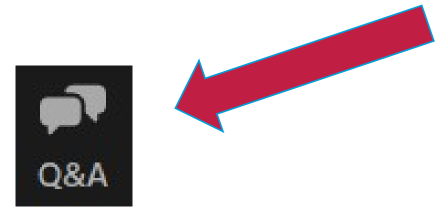

QUESTIONS

Zoom Q&A: Questions will be public to all users once they've been answered. Questions may be answered verbally or in writing.

OPENING WELCOME

Shakeel Kadri
Executive Director &
CEO, CCPS

Jan Zschommler
Market Area Manager
Middle East and Africa
MEA), Energy Systems,
DNV

CCPS 3rd Africa [Virtual] Meeting

Welcome

Shakeel H. Kadri

Executive Director & CEO, CCPS

An AIChE Technology Alliance
CCPS
Center for Chemical Process Safety

DNV

Today's meeting

- **Nearly 260 registrants**
- **About 30 countries represented**

About CCPS

- Formed on 23 March 1985 following the Bhopal Gas Tragedy
- Not for profit organization; part of AICHE
- Corporate supported by 247 members
- Global scope and mission; 53% of members outside of the USA
- Focus: preventing process incidents: fires, explosions, and toxic releases
- Petroleum production, refining, chemicals, pharma, chemical users
- Headquarter s in New York City, with offices in Frankfurt, Mumbai, Houston and in China.

CCPS Vision & Mission

A World without Process Safety Incidents

Serving as a premier worldwide resource for Process Safety knowledge and understanding

Promoting Process Safety as a key societal value and foundation for responsible, sustainable operation

Advancing Process Safety culture, technical concepts and management practices

Fostering collaboration within and across organizations, at all levels

Enhancing individual & organizational Process Safety competency

CCPS An AIChE Technology Alliance Center for Chemical Process Safety

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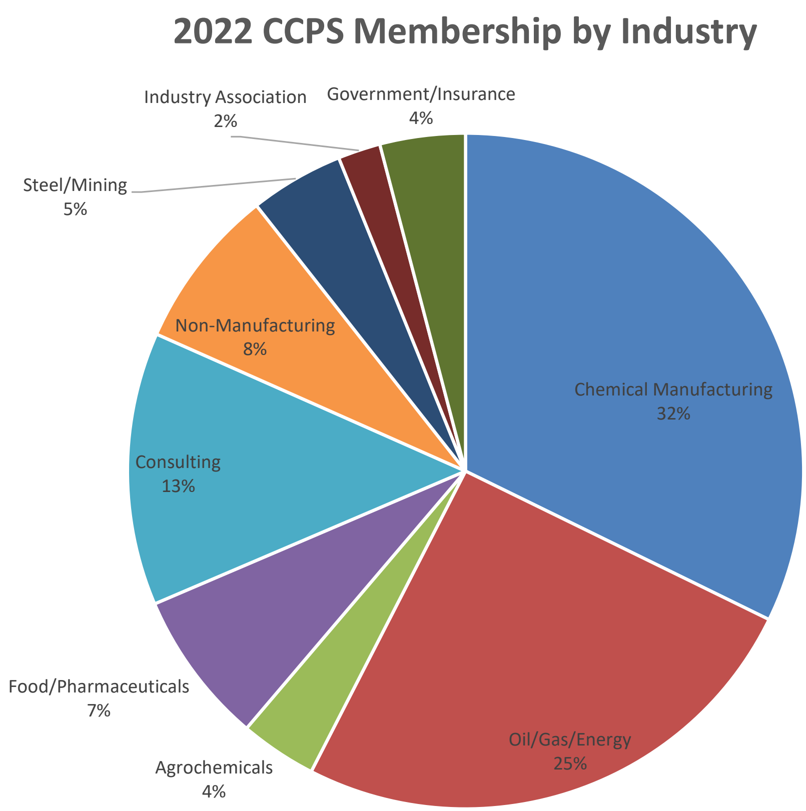
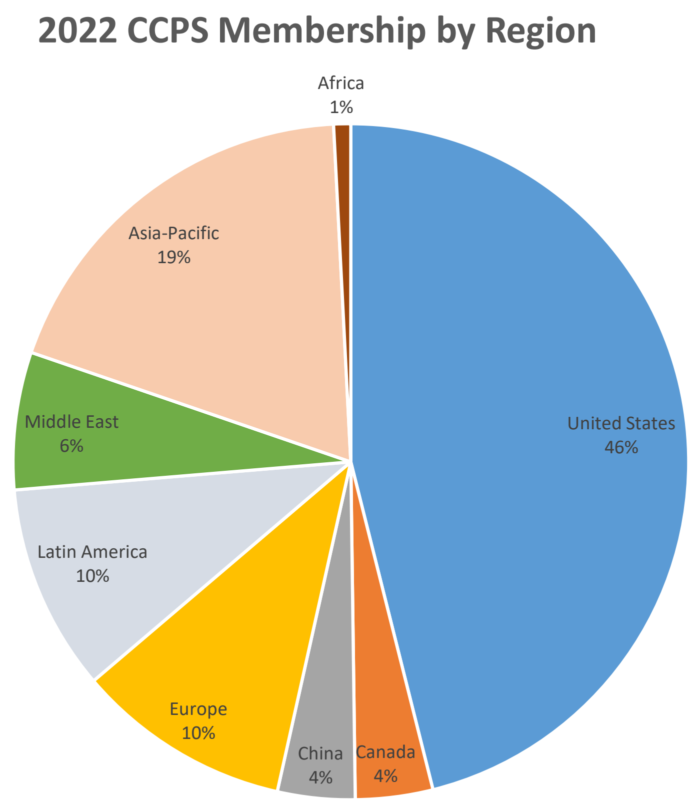
247 Member Companies (October 2022)

3M, ABIQUIM, Aarti Industries, ADNOC, AC&S Incorporated, AcuTech, ABS Group, ADAMA, AdvanSix, AE Solutions, aggreko, AIG, Air Liquide, Air Products, Arkema, Albemarle, Amgen, Ashland, asianpaints, amec foster wheeler, American Refining Group, Inc., AmSty, Baker Hughes, aperam, Aon, Bayer, Berkshire Hathaway Specialty Insurance, bhpbilliton, ADM, BMC Brunei Methanol, 北元集团 Beiyuan Group, Ascend, ARPV, Arlanxeo, avantor, bp, Bapco, BakerRisk, BASF, Ambatovy, Burns & McDonnell, Calumet, Cambrex, Canadian Natural, Cargill, Cabot, cenovus, CF, Braskem, Buckeye Partners, L.P., BYK, Buckman, AmSty, deccan, DEKRA, Dorf Ketal, Celanese, CNOOC 中国海油, CPKelco, Corteva, DNV·GL, Contra Costa Health Services, DYNO Dyno Nobel, Drew Marine, CoogeeChemicals, Cordenpharma, Cheniere, Chevron, Chevron Phillips Chemical Company LP, covestro, CSA, Chola MS, Croda, Oasis Corp., Cristal, Dexco Polymers, Dow, Exponent, Cosmo Oil, DuPont, Eastman, Ecolab, Lilly, Elanco, Emerson Process Management, Eneos, Engro Polymer & Chemicals, Equate, EuroChem, Evonik, GPIC, Grace, HRC, Exida, ExxonMobil, FinOlex Industries, Fluor, FM Global, FMC, Formosa Plastics, FutureFuel Chemical Company, Galaxy, Gatewaygroup, Gerdau, HMC Polymers, Fatima, Fauske, Gopher Resource, Honeywell, Hunt Oil Company, Huntsman, Idemitsu, IRC, India Glycols Limited, ingevity, inter pipeline, intel, GoArc, iresc, Jay Chemicals, Lummus Technology, Jordan Engineers Association, HMEL, kaypear, KBR, King Industries, Koch Industries Inc, Kraton, kuraray, Lanxess, Larsen & Toubro, Linde, ion Chemicals, ioMosaic, Jensen Hughes, Mitsubishi Chemical Group, LSPI, Lubrizol, Johnson & Johnson, lyondellbasell, Mallinckrodt Pharmaceuticals, SCGC, Massy Energy, Michelman, Merck, Mistras Group, Inc., Mitsubishi Chemical Corporation, nationalgrid, McDermott, Nutrien, Oxiquim, Petro Rabigh, Newcrest Mining Limited, Nova Chemicals, NSRP, BWXT, NWR, OXY, Olin, Optima Chemical, OQ, Orpic, Pan American Energy, Piramal Pharma Solutions, Oxiteno, Parkland, Petrobras, PCS, Petronas, Phillips 66, Phoenix Park Gas Processors Limited, pluspetrol, Opal, PLNL, PotashCorp, PPG, Saudi Chevron, Process Improvement Institute, Shell, P&G, PRCAIM, PSC, Process Safety Core Consulting, Qatar Energy, Reliance Industries Limited, Repsol, Rio Tinto, PRefChem, Southern Company, Sahara Petrochemicals, Sajjan India Limited, Satorp, SPL, Tata Steel, Sherwin Williams, Siemens, Sipchem, Solvay, sabic, Sadara, Stream Chemicals, Inc., Syngene, Saudi Aramco, TapRooT, Teijin, Chemours, TC Energy, Showa Yokkaichi Sekiyu Co., Ltd., Transpetro, SI Group, Sinopec, SIS-TECH, sphera, Starr Technical Risks Agency, Stepan, syngenta, Wanhua, Wacker, Taiyo Oil Co., Ltd., Trinseo, The National Gas Company of Trinidad and Tobago Limited, Mosaic, 圣泰工程软件 SimTech Engineering Software, TotalEnergies, TPC Group, Tronox, TÜV Rheinland, Unwin, UPL, Vertellus, Vale, Western Midstream, YPF, Yashashvi Rasayan Pvt. Ltd.

Representing 42 Countries (October 2022)

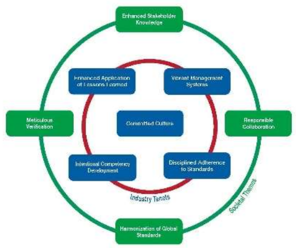
CCPS Membership by Industry and Region [2022]





Leading Process Safety Since 1985

VISION20/20
Five Company Tenets and Four Societal Themes

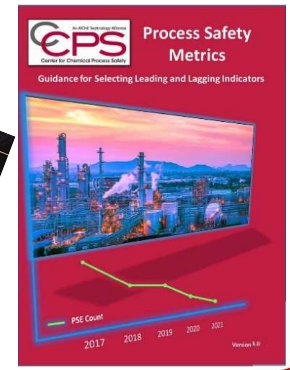


CCPSC CERTIFIED

CCPSf
CCPS PROCESS SAFETY FUNDAMENTALS CERTIFICATE

Books and Publications

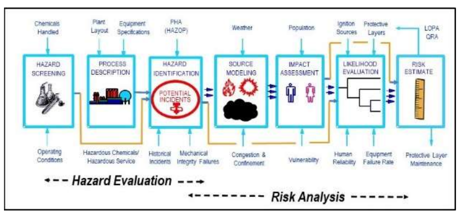
Industry-wide Tools, Programs



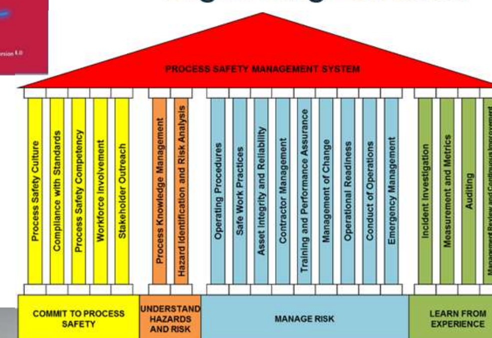
PSID
PROCESS SAFETY INCIDENT DATABASE
From the Center for Chemical Process Safety

SAChE
Safety+Chemical Engineering Education

Sharing Best Practices



Process Safety Beacon 20 YEARS ANNIVERSARY



TSC/Regional

Conducting Global Conferences and Training

Educating Educators

OPENING WELCOME

Shakeel Kadri
Executive Director &
CEO, CCPS

Jan Zschommler
Market Area Manager
Middle East and Africa
MEA), Energy Systems,
DNV

MODERATOR

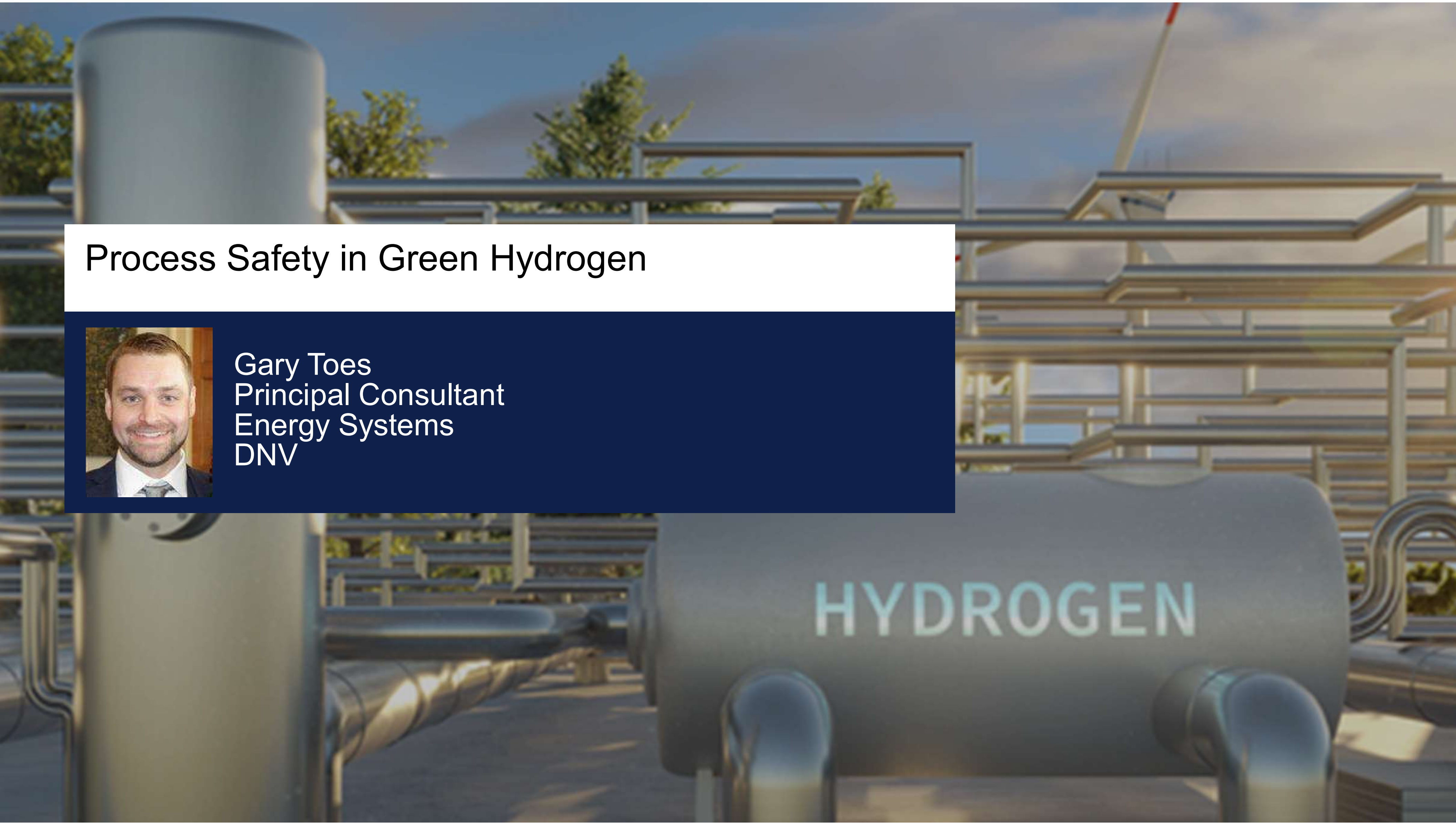
Greg van der Toorn
Market Manager
South Africa
Energy Systems
DNV

AGENDA

Timing	Sessions and speakers
2:25 - 2:55 pm	Process Safety in Green Hydrogen Gary Toes, Principal Consultant, Energy Systems, DNV
2:55 - 3:05 pm	Q & A
3:05 - 3:25 pm	An Overview of the change in MHI Regulations in South Africa Douglas Mokoena, MHI Technical Manager, Sasol
3:25 - 3:35 pm	Q & A
3:35 - 3:40 pm	Break
3:40 - 4:00 pm	Safety Instrumented Systems (SIS) Cybersecurity: Going Beyond Functional Safety Jalal Bouhdada, CEO of Applied Risk, a DNV Company
4:00 - 4:10 pm	Q & A
4:10 - 4:30 pm	CCPSC Certification and CCPSf Certificate Programs Jennifer Bitz, Lead Process Safety Engineer/Project Manager, CCPS
4:30 - 4:40 pm	Q&A
4:40 - 5:00 pm	CCPS Risk Analysis Screening Tool (RAST)- A Case Study [LG Polymers, Runaway Styrene Polymerization] Umesh Dhake, Associate Director, CCPS, Asia, Oceania & Africa Region, CCPS
5:00 - 5:10 pm	Q&A

Process Safety in Green Hydrogen

Gary Toes
Principal Consultant
Energy Systems
DNV



Topics

- Hydrogen uses
- Hydrogen properties in comparison with methane
- Effect of properties on outflow, fire and explosion hazards
- Process Safety in Design
- Barriers / Safety Critical Systems for Explosions
- Discussion / Q&A

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Hydrogen Uses

Emerging uses of Hydrogen

Heating

Mobility (FC + ICE)

Storage and use of excess electricity

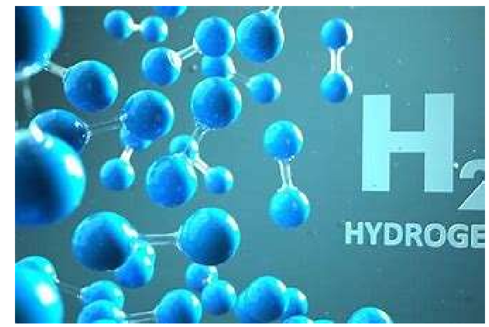
Industry – Energy intensive heating

Mining: https://southafrica.angloamerican.com/our-difference/futuresmart-mining/nugen

Hydrogen Properties

Basic Hydrogen and Methane Properties

	Hydrogen	Methane	Unit
Density*	0.09	0.72	kg/m^3
Lower Heating Value	120	50	MJ/kg
	10.8*	36*	MJ/m^3
LFL$^+$	4	5	% (v/v)
UFL$^+$	75	15	% (v/v)
Min Ign Energy	0.02	0.30	mJ



Mostly focussing on gaseous H2 in the presentation, but some aspects are also relevant to LH2

** @ STP, 0 deg C, 1 atm*

+ - Lower and Upper Flammable Limits

Gas Release

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Hazardous Gas Releases

- For large (hazardous) leaks from pipework (and ignoring compressibility):

$$Flowrate \propto \sqrt{\frac{Pressure}{Density}}$$

- Ratio of densities of methane and hydrogen ~8, $\sqrt{8} = 2.8$
- So for same hole size and pressure in the pipe:

Hydrogen <u>volume</u> flow rate will be 2.8 times that of methane
Methane <u>mass</u> flow is 2.8 times that of hydrogen
<u>Energy flow</u> of hydrogen is 2.4/2.8 = 0.86 that of methane

Jet Fires

Hydrogen Fires – Large Releases

- As energy flow in like for like conditions is similar
  - Hydrogen jet fires are very similar to methane/natural gas
  - Models for thermal radiation give reasonable predictions
- Hydrogen Jet Fire
  - 7.5 kg/s

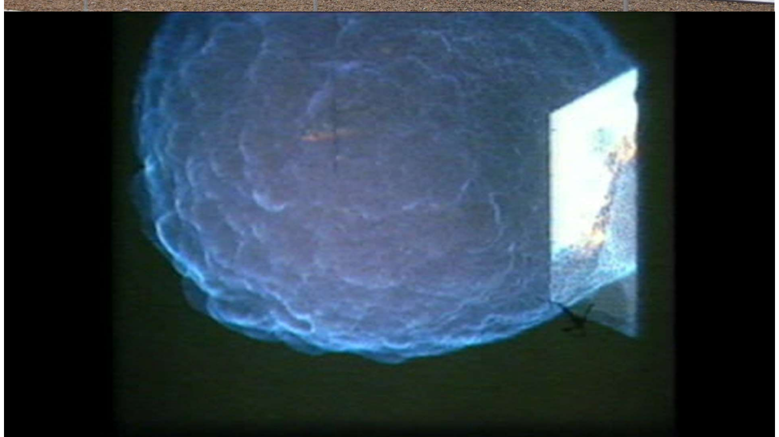
Hydrogen Jet Fires

- Thermal load inside the flame less well understood.
  - Flame temperature higher
  - Velocities higher close to the release point (<~5m)

- This may affect PFP performance
  - PFPNet contract with Thornton Tomasetti and DNV on typical fire scenarios

Explosions

Confined Explosion



- Volume expansion of the hot combustion products is restricted by confinement leading to pressure rise
- For common hydrocarbon-air mixtures and for H2-air mixtures, overpressure up to 8bar is theoretically possible
- However, structural failure occurs before this and vents the explosion

Congested Explosion

- Flame acceleration through congestion as a result of flame distortion and turbulence
- Positive feedback mechanism with repeated obstacles

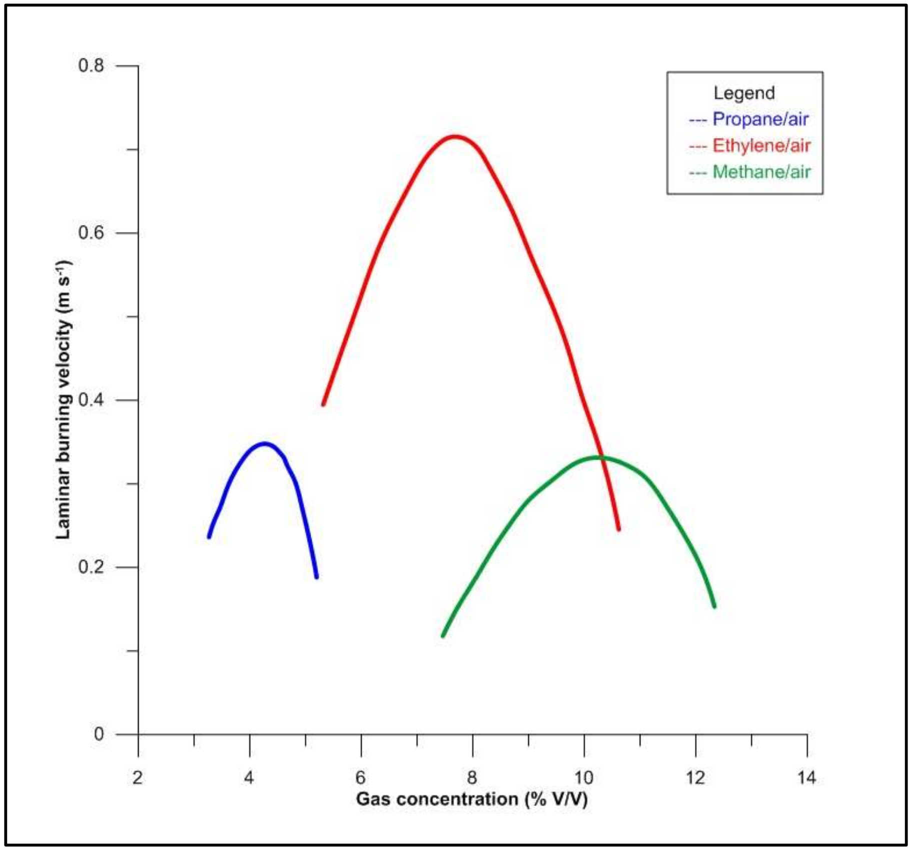
This is plot of the burning velocity for 3 common hydrocarbons

- Methane
- Propane
- Ethylene

Generally, the higher the burning velocity, the more severe the explosion

Depends on fuel type and concentration

So what about hydrogen?

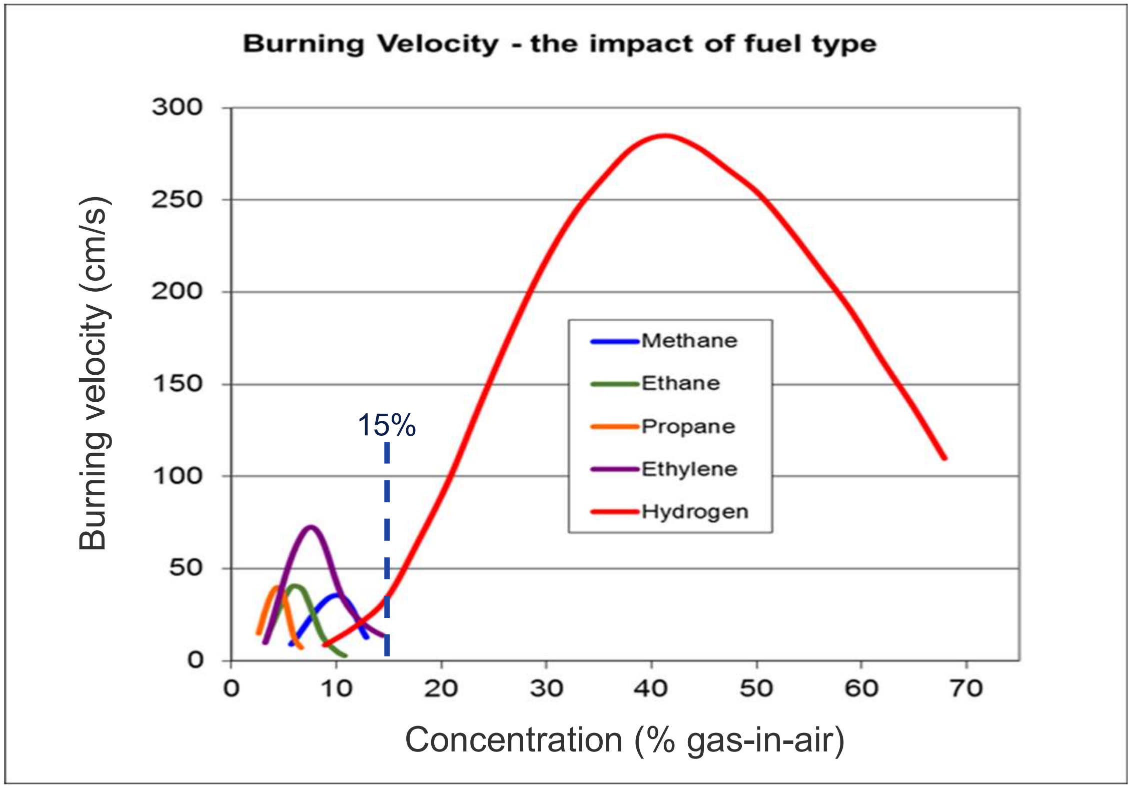


Key Hydrogen Properties - Burning Velocity

Hydrogen has a much higher burning velocity than hydrocarbons

Again, the higher the burning velocity, the more severe the explosion

However, if the hydrogen concentration is kept below ~15% then no worse than natural gas



Methane & Hydrogen Explosion Comparison

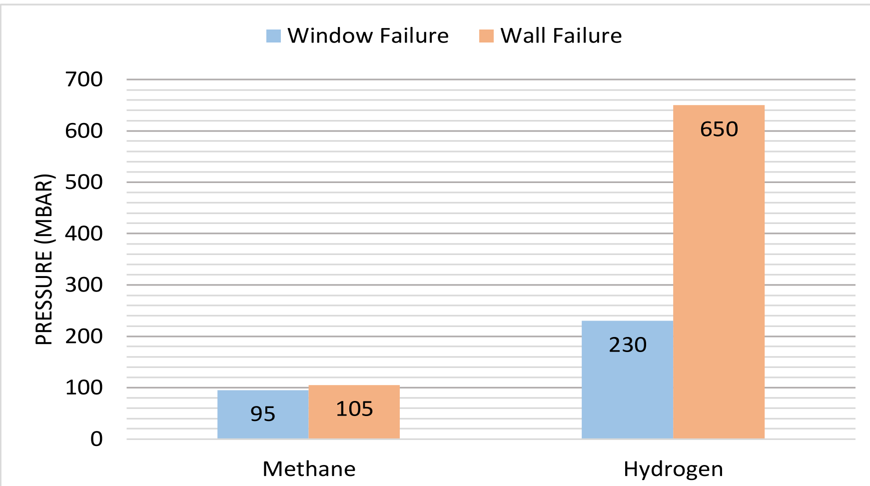
Methane and Hydrogen releases at same pressure and with same hole size

Methane (10%vol layer)

Hydrogen (20%vol layer)

Confined Explosion

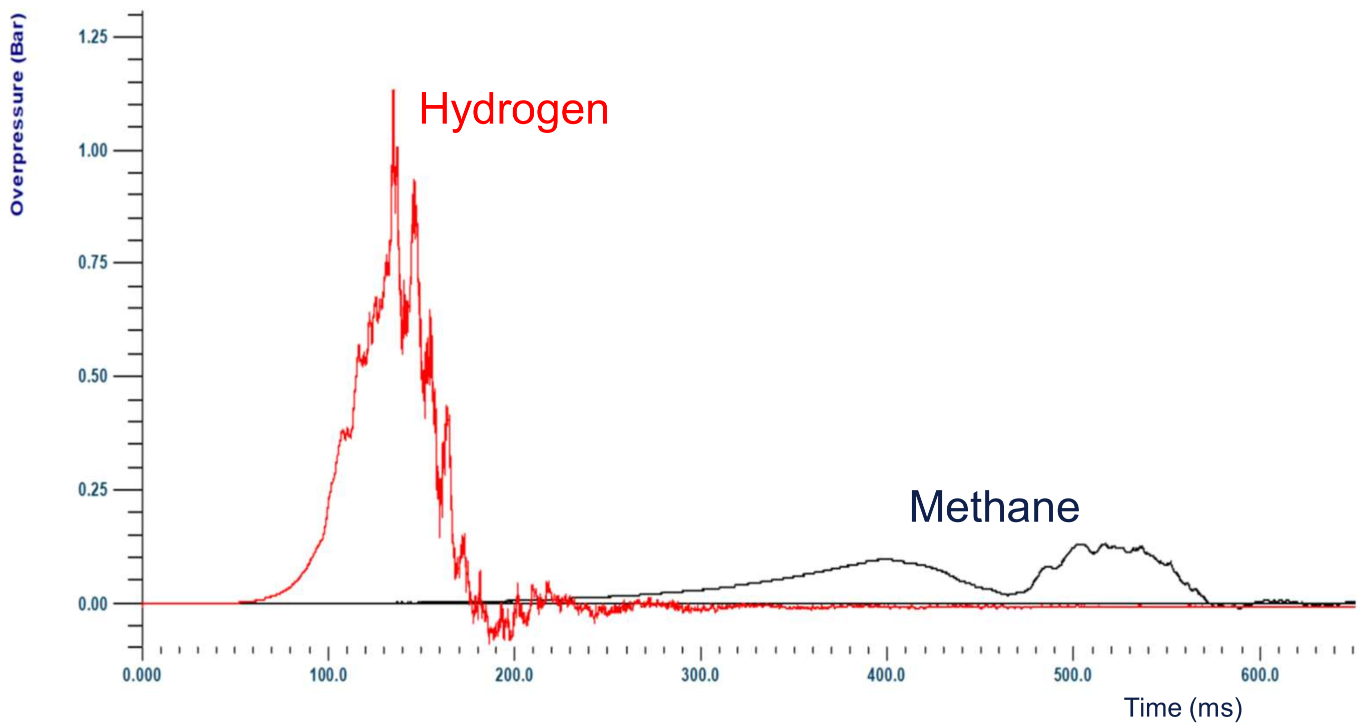
- Videos aligned to window failure but pressures very different



- Pressures in hydrogen experiment far exceeded the minimum required failure pressure of window and wall.
- Why?

Internal Pressures

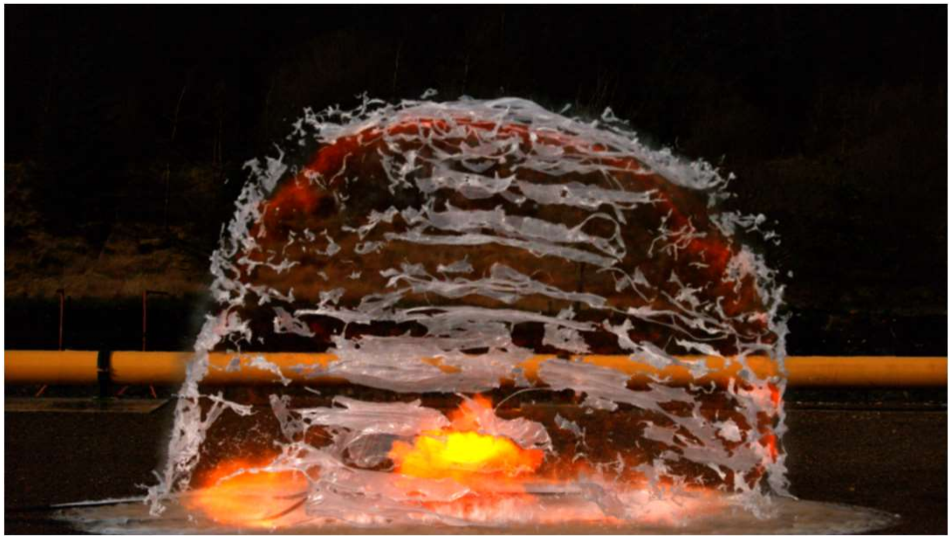
- Peak rate of pressure rise:
  - Hydrogen ~10 mbar/ms
  - Methane ~ 0.5 mbar/ms
- Time taken for structural failure is critical for hydrogen
- Results in much higher pressures being generated



Deflagration to Detonation Transition (DDT)

Detonation

- Shock wave of 20 bar compresses fuel mixture to auto-ignition temperature
- Immediate combustion of fuel provides energy to maintain the shock wave
- Self sustaining and will propagate through the flammable mixture at 1800 m/s



Deflagration to Detonation Transition

Observed major industrial explosions in process plant

The experiment involves flame accelerating in two congested pipework regions with DDT at the exit

Detonability

- Detonation occurs when sufficient energy is concentrated in a small volume
- Can achieve this with high explosives

Fuel	Minimum Mass tetryl (g)
Hydrogen	**0.8**
Methane	16,000
Propane	37
Ethylene	5.2

- Natural Gas detonations ~NEVER happen
- Hydrogen detonations are entirely credible – factor of 20,000 reduction in energy required (compared to methane)
- Currently in final stages of agreeing a JIP on DDT conditions

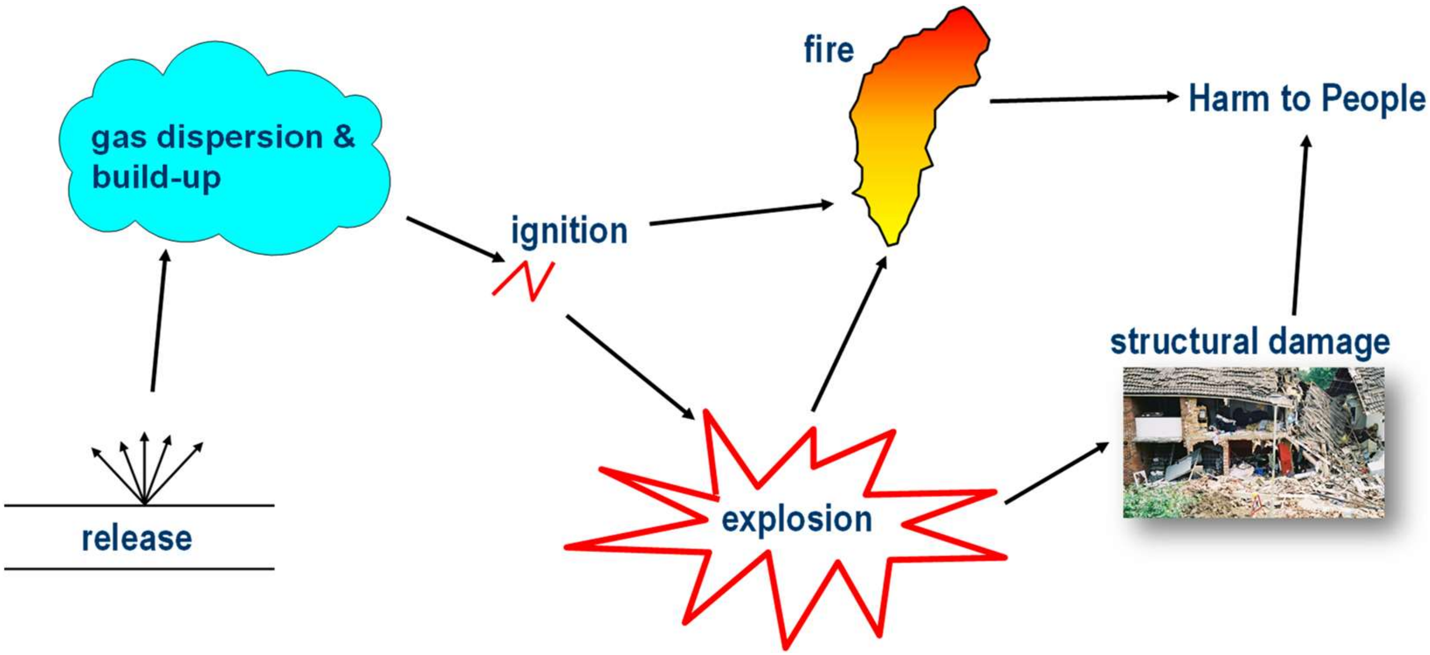
Process Safety in Design

Design Philosophy

Design to prevent or break the chain of events

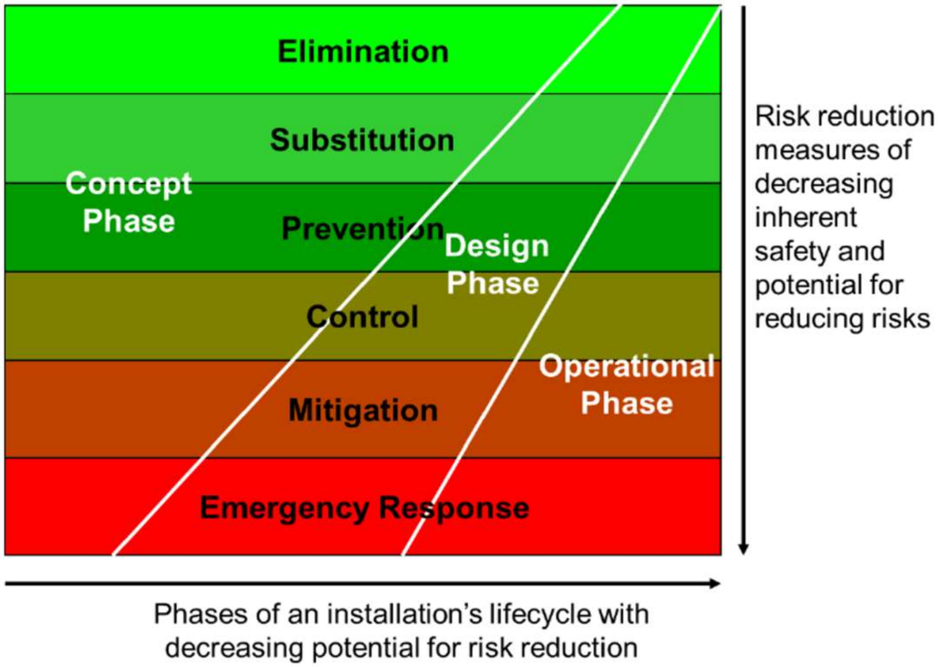
Techniques are nothing new – standard for any oil & gas project

The key difference is the properties of hydrogen

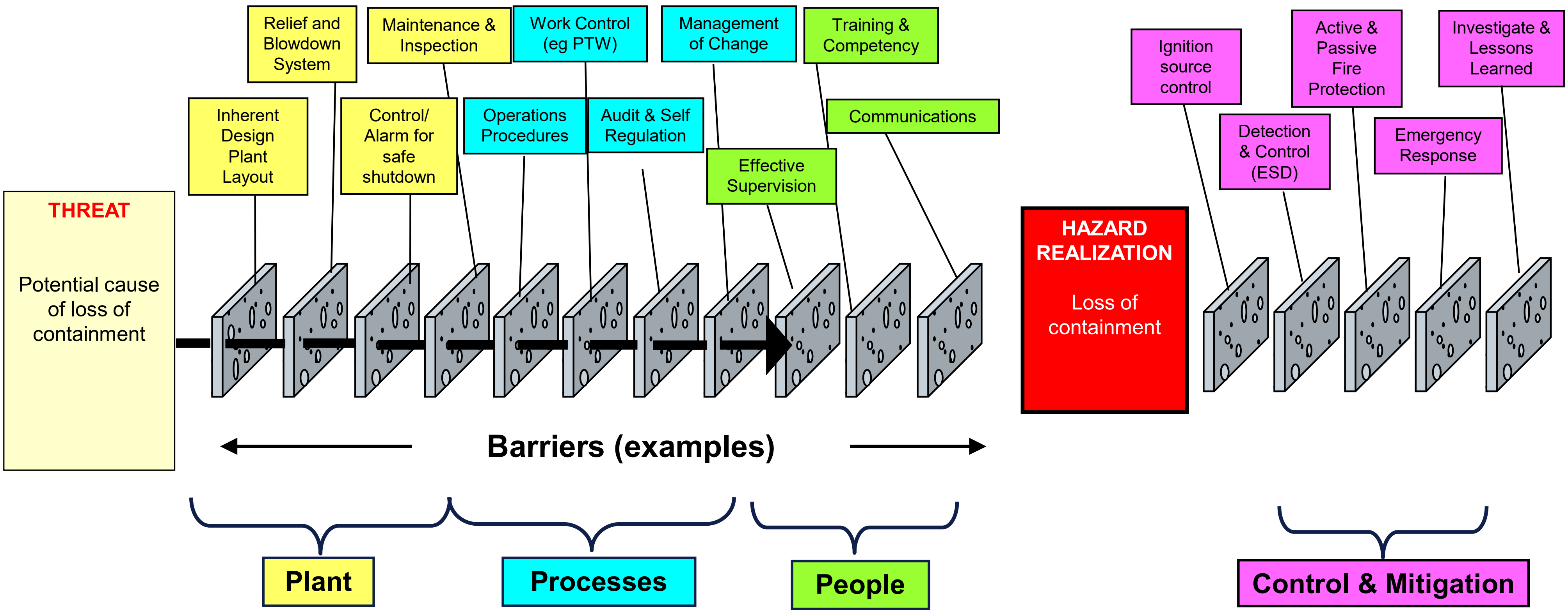


Design Philosophy – Inherently Safer

- Though definitions vary, ‘inherently safer design’ involves design changes that improve safety without the need for active protective systems
- Where practicable, inherently safer design can be very effective and has reduced uncertainty
- For example:
  - Reduction in inventory or pressure
  - Separation of hazardous inventories from people
  - Passive barriers that prevent escalation
  - Using our understanding of hydrogen properties to reduce risk



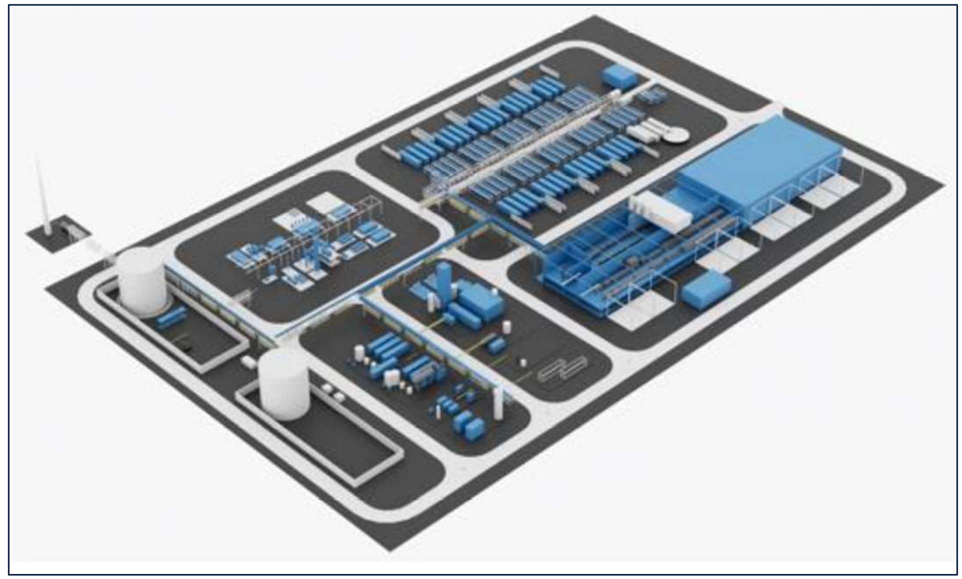
Design Philosophy - Barriers



Barriers / Safety Critical Systems for Explosions

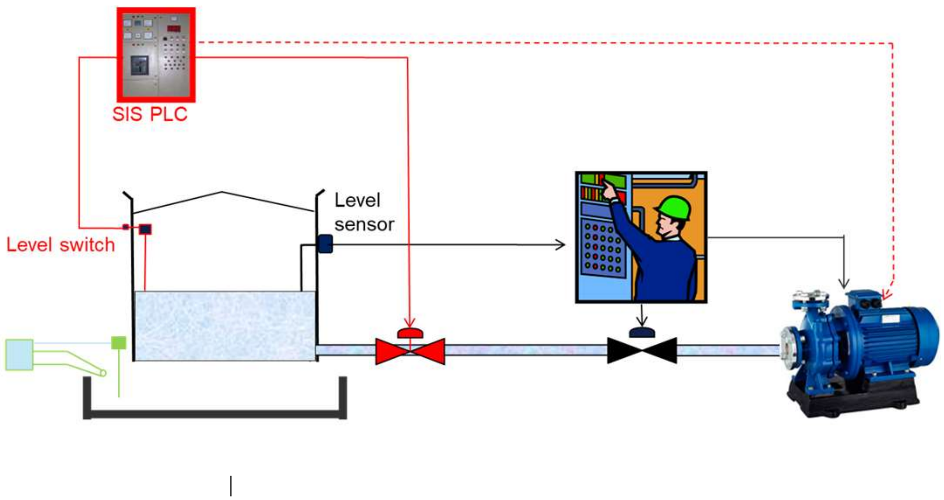
Plant Layout

- Explosions can be more severe and detonation much more credible
- Research into DDT ongoing but still significant uncertainty
- Therefore, inherently safe design is important
  - Avoiding/minimising confinement & congestion
  - Ensuring separation between confined/congested areas and leak sources
  - Separation between plant and people



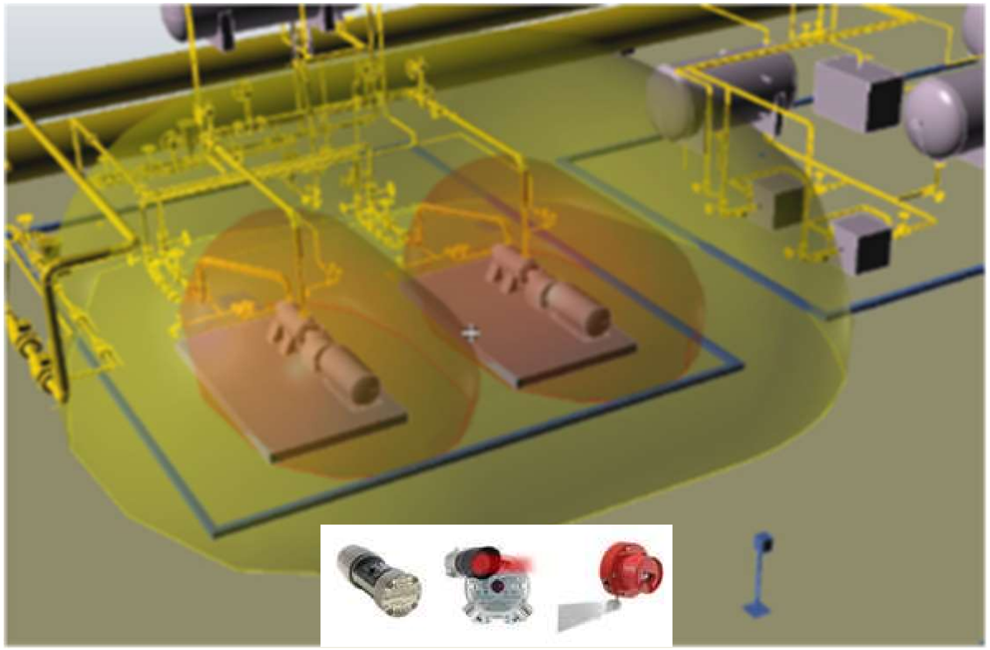
Process Alarms and Trips

Functional Safety	Management of safety systems that implement safety functions necessary to achieve a safe state for the plant or to maintain a safe state
Keeping the plant within the defined safe operating envelope	Assess through Layers of Protection Analysis (LOPA) to ensure multiple independent protection layers



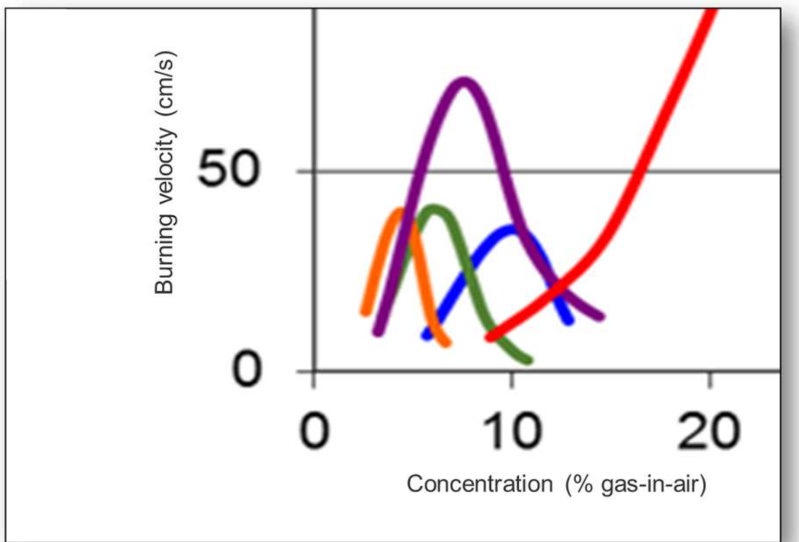
Hydrogen Detection

- Detect hydrogen releases before they reach flammable levels
- Possible actions:
  - Alarm to notify operator
  - Isolation to reduce inventory available for release, release duration and flammable cloud concentration
  - Depressurisation
  - De-energise electrical equipment
  - Increase ventilation (i.e. start a fan)



Ventilation

- If the concentration of hydrogen is kept below ~15% then the explosion severity is no worse than natural gas



- Ventilation is a critical aspect of hazardous area classification (e.g. IEC 60079-10-1, EI 15)
- However, it is an essential control measure in its own right and should be assessed as such
- Outdoors is inherently safer, but many hydrogen applications require enclosures
- Can make use of the buoyant nature of hydrogen but need to ensure that this does not invalidate the purpose(s) of the enclosure (e.g. weather protection)
- Forced ventilation is an alternative but more complicated

A common control that may not be effective for hydrogen…Explosion Relief

Remember these videos…?

Methane & Hydrogen Explosion Comparison

Methane and Hydrogen releases at same pressure and with same hole size

Methane (10%vol layer) | Hydrogen (20%vol layer)

30 DNV© 16 JUNE 2022 DNV

- The rate of pressure rise for hydrogen is such that explosion relief may not respond fast enough
- The basis for explosion relief and risk reduction claimed must be robustly demonstrated

Summary - Hydrogen

Hydrogen Properties

Hydrogen has high reactivity and is much more detonable than hydrocarbons

Need to avoid situations where high (>15%) hydrogen concentrations are present as much as practicable

Use natural buoyancy where possible

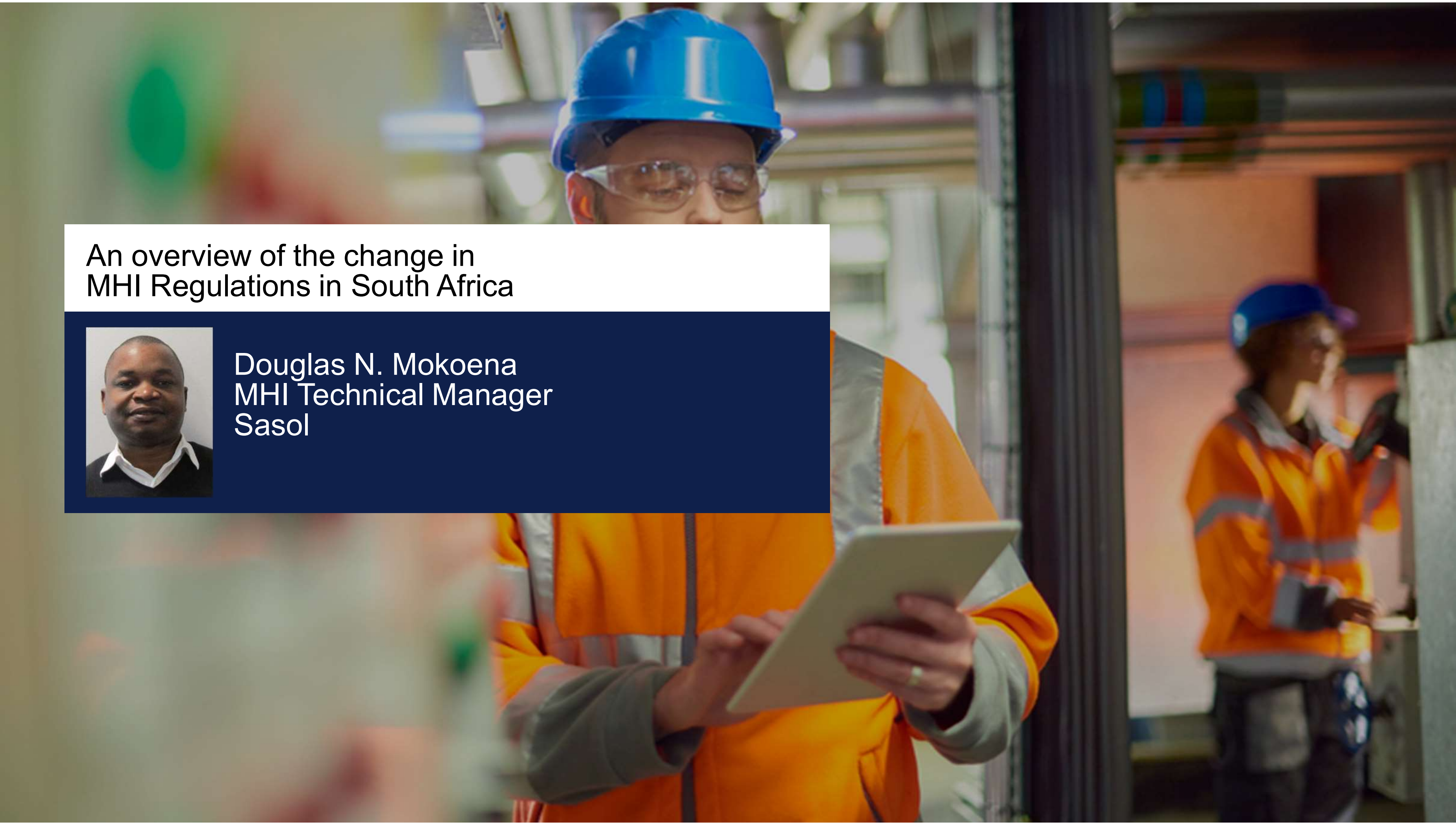
Safety in Design

Management through barriers to a major accident

Hierarchy from avoidance to emergency response

Inherently safer design is important and not necessarily expensive in early design

Questions?



An overview of the change in MHI Regulations in South Africa

Douglas N. Mokoena
MHI Technical Manager
Sasol

SOUTH AFRICA MHI REGULATION CHANGES DISCUSSION
CCPS VIRTUAL AFRICA MEETING

4th October 2022

Major Hazard Installation Regulation changes in South Africa

- A Major Hazard Installation (MHI) facility may be defined as industrial facility that manufactures and/or stores listed quantities of hazardous substances, which if there was a process safety incident/loss of containment would result in adverse effects (such as fires, explosions and releases of toxic materials) that could cause harm to plant personnel and the public near the facility.
- The focus of any MHI facility should be on the quantity of the stored hazardous material/process facility relative to its location (site boundary) as these influences the effects of process safety incidents to the members of the public.
- It is required under the South African Occupational Health and Safety Act No. 85 of 1993 (under which the MHI Regulations are promulgated) that every MHI facility conduct a MHI Risk Assessment, this is a Quantified Risk Assessment (QRA) of the facility which considers the potential effects of the process safety incident together with the likelihood of its occurrence.
- The required MHI Risk Assessments are conducted by an Approved Inspection Authority (AIAs) which are accredited by the South African National Accreditation Systems (SANAS). The results of the risk assessment, which is documented in a form of a Risk Assessment report, will highlight the level of risk posed by the installation to the members of the public. This report is then submitted to the relevant local, provincial and national authorities. The MHI Risk Assessments are required to be updated on a five-yearly basis.

Major Hazard Installation Regulations changes in South Africa cont.

Challenges with the current MHI Regulations:

- Inconsistencies in the interpretation and application of the current MHI Regulations
- Which facilities are MHIs, and which are not
- Different QRA report formats and contents
- Public Impact interpretation (criteria)
- Notification processes not clear
- A limited list of substances to be considered in the MHI identification
- Exempted facilities

Major Hazard Installation Regulations changes in South Africa cont.

The MHI Regulations have been revised with the objective of addressing current challenges, these are to be promulgated soon (date not confirmed).

Main changes are :

- Establishment vs installation
- Introduction of three hazard levels
- Classification criteria
- List of named substances has been expanded (Annexure A1, A2 and A3)
- Reporting requirements - SANS 1461, 2018
- MHI Emergency Response Planning – SANS 1514, 2018
- Additional notification requirements

Major Hazard Installation Regulations changes in South Africa cont.

- **Establishment vs Installation**
- Sites are now called establishments, not installations
- An establishment is made up of the installations on the site
- An establishment is under one business management
- An establishment is a company (e.g. ABC Limited) or an organization

Major Hazard Installation Regulations changes in South Africa cont.

- **Three Major Hazard Levels:**
  - High Hazard Establishment
  - Medium Hazard Establishment
  - Low Hazard Establishment
- **Criteria for Classification of Establishment**

  Classification is based on maximum inventory of hazardous material that is handled or stored on-site (like the UK's COMAH Regulations), not in each container.
- **Expanded list of qualifying substances**
  - The list of qualifying substances has been expanded to include named and grouped substances
- **Reporting**
  - QRA reports to comply to SANS 1461 requirements
- **Emergency Response Planning**
  - Emergency response planning to comply to SANS 1514 requirements

Major Hazard Installation Regulations changes in South Africa cont.

- **Criteria for Classification of Establishment**
  - Classification is based on maximum inventory of hazardous material that is handled or stored on-site (like the UK's COMAH Regulations), not in each container.

Annexure 1 named substance (tonne)	Hazard category		
	Low	Medium	High
Ammonia anhydrous	5	50	200
Bromine	2	20	100
Chlorine	1	10	25
Hydrogen chloride	2,5	25	250
Hydrogen fluoride	0,5	5	20
LPG and natural gas	5	50	200

Major Hazard Installation Regulations changes in South Africa cont.

High Hazard Establishment	Medium Hazard Establishment	Low Hazard Establishment
Quantitative Risk Assessment	Quantitative Risk Assessment	Quantitative Risk Assessment
Emergency Preparedness Plan	Emergency Preparedness Plan	Emergency Preparedness Plan
Major Accident Prevention Policy	Major Accident Prevention Policy	
Safety Report		

Major Hazard Installation Regulations changes in South Africa cont.

Comment:

- Aligned with international standards (UK's COMAH Regulations)
- Significant investment in will be required to ensure compliance as some facilities which were not previously classified as MHI may become MHI (due to lowered qualifying inventory and clarity on definition) – not greater than the benefits of safety.

Questions?

Safety Instrumented Systems (SIS) Cybersecurity: Going beyond functional safety

Jalal Bouhdada
CEO of Applied Risk
DNV

Security of Safety Instrumented Systems SIS

- Safety instrumented systems (SIS) are designed to take the process to a safe state in trip conditions
- SIS increasingly integrate with process control systems (BPCS)
- Could the safety of our process facilities jeopardized because of Cybersecurity issues under SIS/BPCS?

Aligning Functional Safety (IEC 61508) and Cybersecurity (IEC 62443)

- **Principle 1: Protection of safety functions**
  Security effectively prevents safety against negative influences of threats.
  Safety evaluations are based on the assumption of effective security measures.
- **Principle 2: Compatibility of implementations**
  Security does not interfere with safety and vice versa.
- **Principle 3: Protection of security countermeasures**
  Safety implementations do not negatively impact the effectiveness of security implementations.

Wake-up Call for the industry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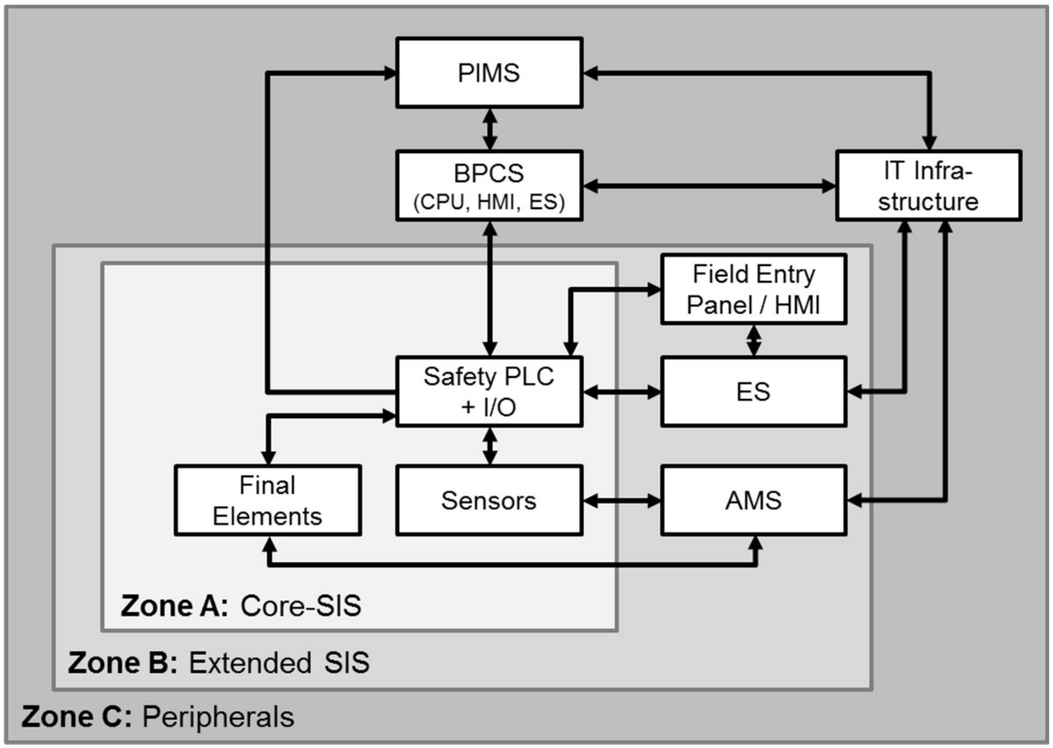
Triton: hackers take out safety systems in 'watershed' attack on energy plant

Sophisticated malware halts operations at power station in unprecedented attack which experts believe was state-sponsored

SIS Cybersecurity challenges

- **These systems, despite their importance, are not intrinsically secure and have flaws** that are the result of poor testing, code quality, and engineering
- Legacy insecure by design features or legacy patterns are still present, and likely to be present for the foreseeable future
- Asset owners are unlikely to adequately secure these systems unless CVEs are disclosed (don’t know, don’t care mentality)
- Oddly enough, it is limited to only the following OS: Windows NT, Windows XP, or Windows 7 (odd it stops there, maybe the vendor does not support them officially, but will be present anyways)
- Protecting an industrial organization’s safety systems should be an outmost priority in Operational Technology (OT) Health, Safety and Environment (HSE). But to reiterate, regardless of purpose, there is a common thread here:
  - **All embedded systems are very likely to have vulnerabilities within them**
  - Their **security is absolutely dependent on their deployment configuration and it’s adjacent environment**
  - They **require integrated vulnerability and risk management, but also compensating controls** from deployment to retirement (grave/destruction)

Systems Under Consideration (SuC)



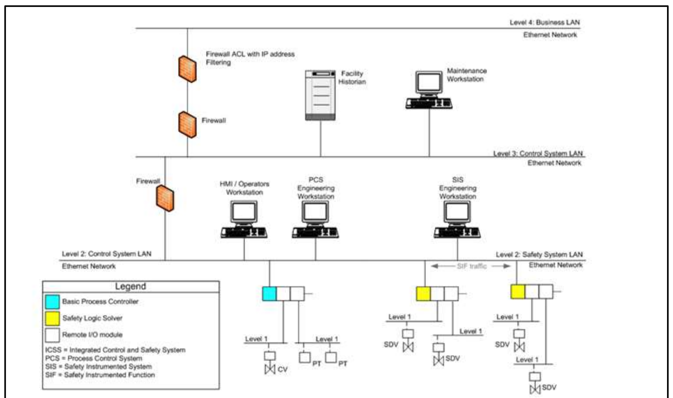
- Hardware
- Software
- Data
- Processes
- Organizations
- Persons
- Connections

NAMUR NA 163

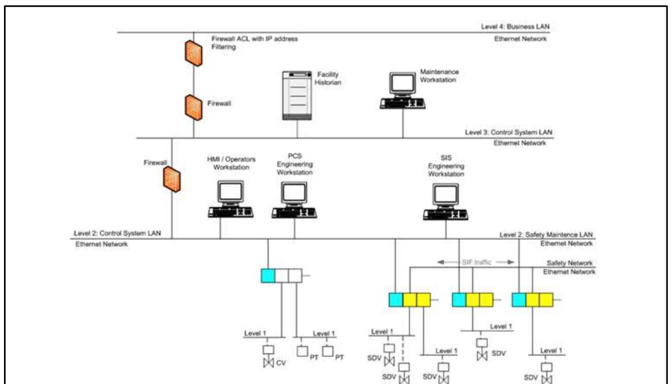
Architecture

The SIS and BPCS can be totally separate, interfaced or integrated, yet separate.

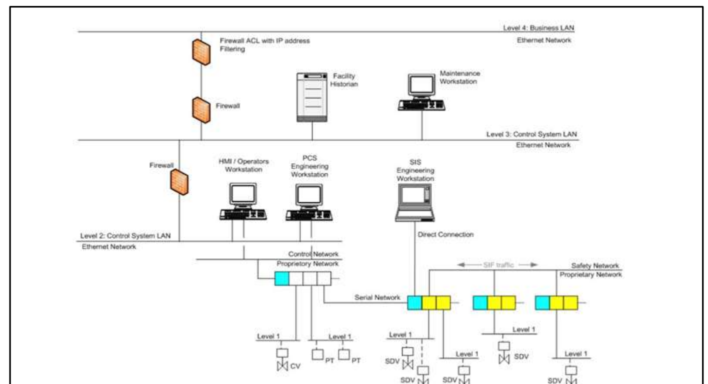
- A separated SIS completely disconnected and independent from the BPCS
- An interfaced SIS connected to a BPCS by means of industrial protocols (typically Modbus)
- An integrated SIS interconnected to a BPCS, but sufficiently isolated to meet cybersecurity standards



Integrated Control and SIS, Architecture A



Integrated Control and SIS, Architecture B



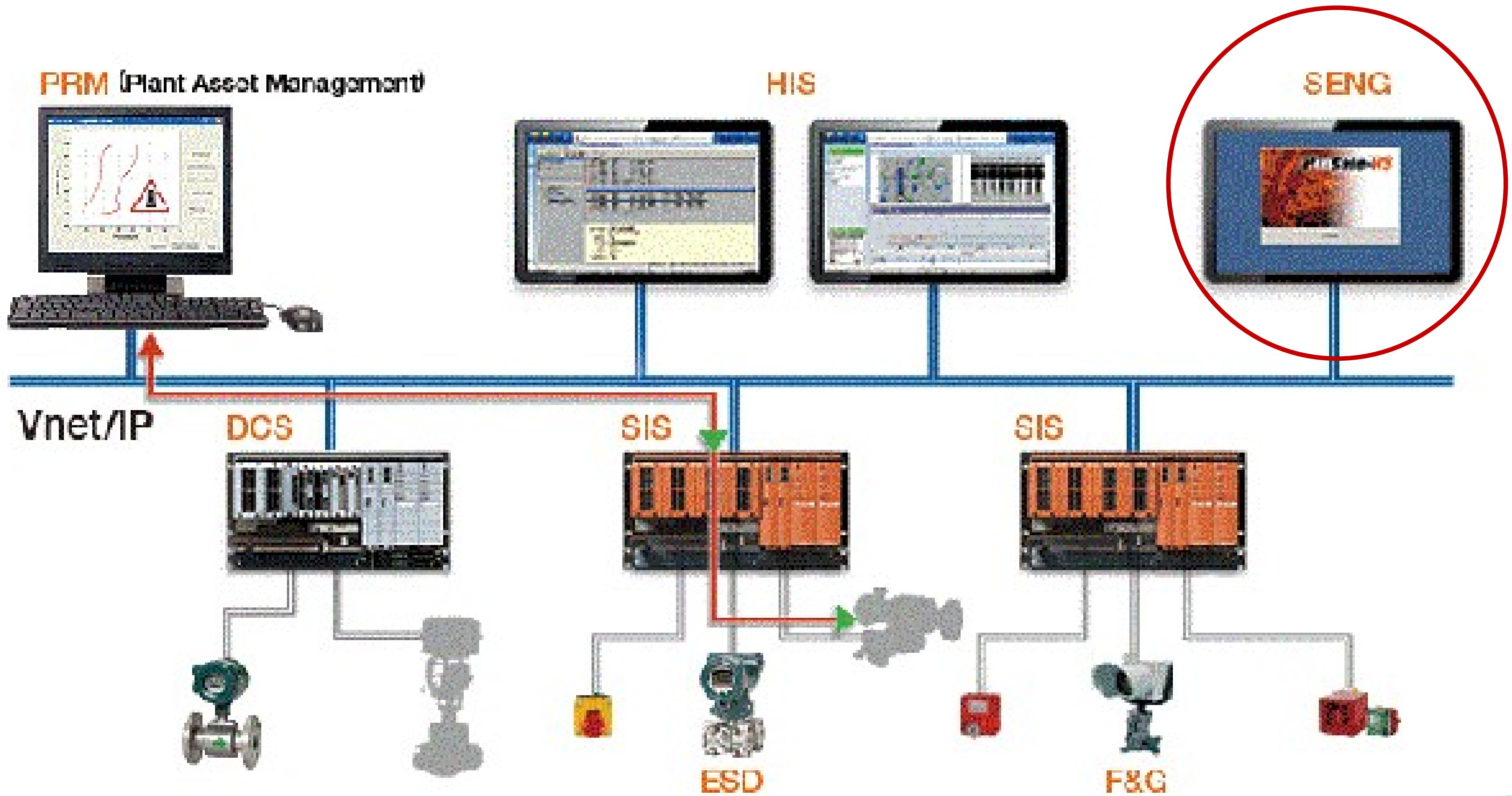
Integrated Control and SIS, Architecture C

Safety controller hardware and firmware

- Hardware security and firmware integrity is an area which is not always addressed
- The processor system and communication processor are separated. In this way, safe operation is always ensured, even if the communication processor is attacked
- Many safety controllers allow users to monitor the checksum (CRC) via SCADA programs. Every download and reload can be monitored and reported, thus allowing immediate detection of program changes performed by hackers.

REVERSE ENGINEERING CYCLIC REDUNDANCY CODES

Safety Engineering Workstation (SENG)



Key switch

System variables serve to protect against manipulations despite the direct access possible with the appropriate programming environment.

For example, key switches can be used for:

- Reload deactivation
- Force deactivation
- Read only in run

Interfaces

- Modbus
- ModSafeEthernet
- VNET/IP
- ProfiSafe
- Safety Over EtherCat
- CIP Safety
- CC-Link Safety
- Open Safety
- Proprietary
- Industrial Wireless

Safety protocols on top of communication protocols

Instrument Asset Management System (IAMS)

“The real safety and reliability impacts come from manipulating physics not data”

Asset Management software is deployed to higher levels in IACS network and typically has complete access to all enabled field devices. It provides a top-down route into the field devices and bootom-up route into the control and enterprise networks for information extraction or network manipulation.

People & Processes

Technology alone will not stop successful threat actors attacking your critical assets. Senior management must lead the way in planning implementing and monitoring effective security initiatives.

Commitment

Preparedness

Discipline

Preparedness

Identify

Governance model
Asset identification and prioritization
Risk Assessment

Protect

Network Segmentation
Access control
System hardening
Patch management
gement of Change (MoC)

Preparedness

Respond

Incident response capability
Disaster recovery planning

Detect

Detect anomalies and events

Key takeaways

Regardless of the belief of state-sponsored cyber attacks, these recommendations are example steps for any organization looking to prevent cyber attacks to their SIS.

- Conduct Risk and Vulnerability Assessment (RVA) to determine your risk profile
- Follow a defense in depth model (Beyond architecture)
- Monitor your safety networks and interfaces to BPCS
- Put your Incident Response plan into warm mode, dust it off, or exercise it
- Restrict Access Control and apply System Hardening
- Invest in offensive activities including system build review, penetration testing, red/purple teaming…etc
- Partner with your DCS/SIS vendors
- Stay sharp and vigilant.

If it's Not Secure, It's not Safe

Questions?

CCPSC Certification and CCPSf Certificate Programs

Jennifer Bitz
Lead Process Safety Engineer/ Project Manager, CCPS

CPSC

CCPS PROCESS SAFETY
PROFESSIONAL CERTIFICATION

CPSf

CCPS PROCESS SAFETY
FUNDAMENTALS CERTIFICATE

Comparison

CCPSf (courses)	CCPSC (qualification exam, no courses)
Certificate granted following completion of courses. Content for the courses included in cost.	Certification granted following application and exam that tests knowledge, skills, and competency.
Ideal for students, early career professionals, and mid-career professionals adding process safety to their responsibilities.	Ideal for mid to late career professionals with process safety experience.
No degree or experience required. Good for students, early career professionals and mid-career professionals adding process safety to their responsibilities.	Requires STEM degree and at least 5 years professional experience (or 10 years with no STEM degree).
Completion of 24 online SAChE courses – 2 hours each. Short quizzes demonstrate understanding of course content at the end of each course. No final exam at the end of all courses.	No courses. Competency measured against RBPS standards, by application and 4-hour exam.
Usually listed on a resume detailing education.	Credentials to be listed after one's name: CCPSC
No ongoing requirements.	Has ongoing requirements in order to maintain; including PDH and renewal fees.

CCPSf

CCPS PROCESS SAFETY
FUNDAMENTALS CERTIFICATE

CCPSf Certificate

CCPS Certified Process Safety Fundamentals

- New offering from CCPS
- No experience requirement
- Certificate program based on 24 courses (48 hours total)

- AIChE® Foundation thanks the following companies for their support to the Doing a World of Good campaign, supporting SAChE courses: Supporting Companies

CCPSf Certificate

CCPS Certified Process Safety Fundamentals

- Recognizes those who
  - Focus on process safety
  - Take 24 AIChE Safety and Chemical Engineering Education (SAChE) courses
- Courses
  - Five sections of 3–6 courses each
  - 24 courses total

CCPSf Course Groups

Twenty-four courses in

- Process Safety Basics
- Introduction to Hazards
- Understanding Risk
- Practical Applications for Managing Risk
- Risk Based Process Safety (RBPS) Pillars

CCPSf Completion Certificate

This certifies that

Sample Name

Has successfully completed the

CCPS Process Safety Fundamentals Certificate Program

And is therefore credited with 48 Professional Development Hours [PDHs] which is equivalent to 4.8 Continuing Education Units [CEUs]

Date Awarded: **7/14/2021**

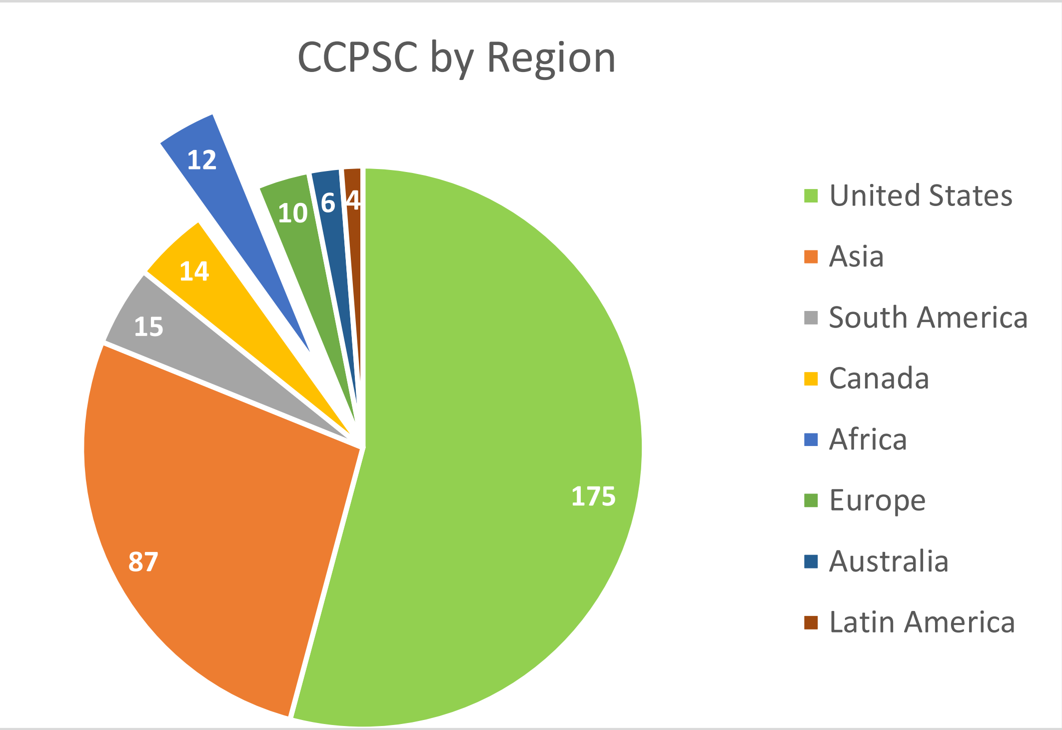
Shakeel Kadri, Executive Director, CCPS

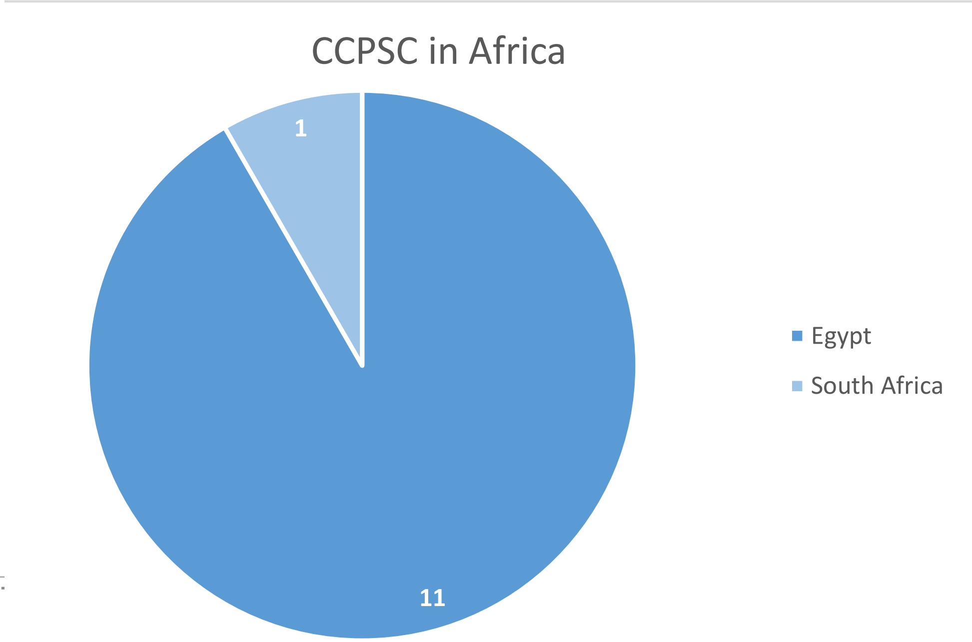
CCPSC – Why get certified?

CCPS Certified Process Safety Certification

- Demonstrate process safety competence in 20 elements of RBPS
- Demonstrate true expertise in process safety, not just training
- Prove your expertise to your colleagues and managers
- Gain a global certification, not limited by region
- Improve chances of getting hired in a PSM role

CCPSCs by Region (as of 7/2022)





CCPSC

CCPS Certified Process Safety Certification

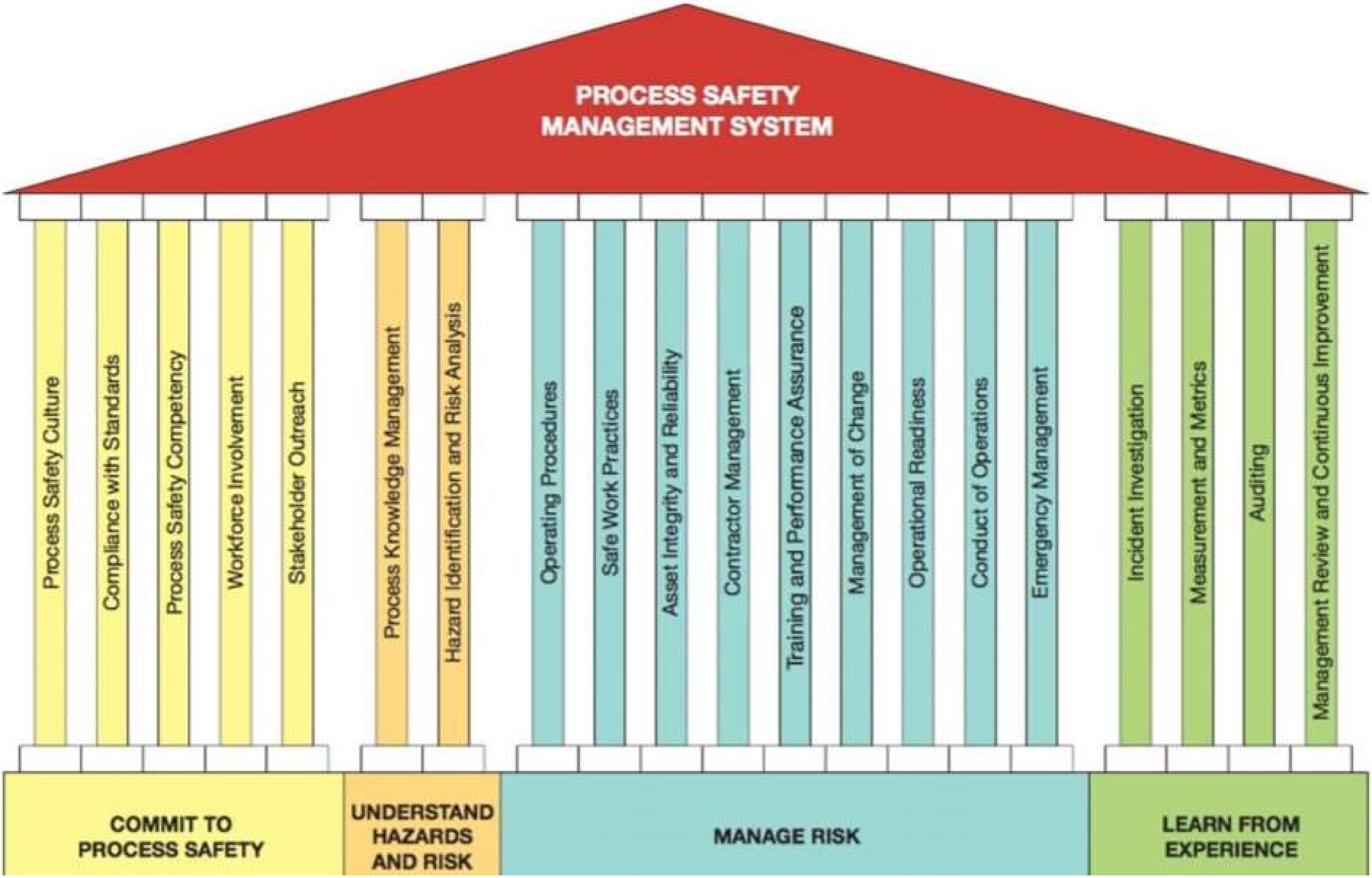
- Certification based on career experience
- No specific course materials included

Before you apply

- Education – bachelor degree in a STEM Field
- Work Experience - 5 years with a degree in a STEM field; 10 years no STEM field degree

Before you apply…Readiness Check

- Process Safety Experience –20 elements of Risk-Based Process Safety
- Review RBPS Elements and document personal experience
- If most of your experience is with just a few elements (PHA, audit, MOC, etc), you may not be ready


PROCESS SAFETY
MANAGEMENT SYSTEM
Process Safety Culture
Compliance with Standards
Process Safety Competency
Workforce Involvement
Stakeholder Outreach
Process Knowledge Management
Hazard Identification and Risk Analysis
Operating Procedures
Safe Work Practices
Asset Integrity and Reliability
Contractor Management
Training and Performance Assurance
Management of Change
Operational Readiness
Conduct of Operations
Emergency Management
Incident Investigation
Measurement and Metrics
Auditing
Management Review and Continuous Improvement
COMMIT TO PROCESS SAFETY
UNDERSTAND HAZARDS AND RISK
MANAGE RISK
LEARN FROM EXPERIENCE

Application

- Education
- Process safety work experience
- RBPS Element experience
- Professional references
- Fee

Application – RBPS Elements

- List up to 5 bullets of specific **personal** experience for each RBPS element
  - Example – "I trended incident root causes for 2 years to reduce fire events at the FCC, 2009-2010"
  - Not – "My company tracked incidents electronically"
  - Not – a definition of the element
- Complete accomplishments for as many elements as possible

Application – References

- List at least three(3) references or two (2) references plus a list of peer reviewed work that you have written.
- Advise your references to give meaningful responses.
    - "Mohamed investigated 14 process safety incidents"
    - "He has improved PS Culture through regular meetings with the workforce"
    - NOT – "confirm" or "agree"

Application Review

- Application is considered complete after application fee and three references are received
- After application is complete, it will be reviewed. This can take 4 weeks.
- After approval, you will be able to sign up for an exam

Preparing for the Exam

- Gather Resources
- Read and Study
- Document process safety experience
- Fill knowledge gaps

RBPS Elements Reference Material

- Short summary of RBPS Elements (2 pages): good overview
- Longer Summary of RBPS (38 pages): good reference for filling out the application
- Definitive Guide for RBPS (768 pages): best reference for detailed preparation

Preparing – Fill Knowledge Gaps

- From your knowledge gap log, select resources to fill gaps
  - AIChE Academy
  - CCPS Books – CCPS Member companies get free and discounted books

CCPSC Exam

- 4 hour, open book, online exam
- Three exam periods per year – March, July, November
- Topics – 20 RBPS Elements plus PS technical questions
- 120 multiple choice questions
- 6 essay questions
    - Each essay is worth more than each multiple choice
    - Copy / paste answers receive no credit

Links and e-mails

CCPSf	https://www.aiche.org/ccps/resources/certification/process-safety-fundamentals-certificate-program
CCPSC	https://www.aiche.org/ccpsc
CCPSC/ CCPSf contact	Jennifer Bitz at jennb@aiche.org or ccps-certified@aiche.org
CCPS Corporate Membership contact	ccps@aiche.org

Questions?

CCPS Risk Analysis Screening Tool (RAST)- A Case Study [LG Polymers, Runaway Styrene Polymerization]

Umesh Dhake
Associate Director, CCPS, Asia, Oceania & Africa Region,
CCPS

RAST

Case Study – LG Polymers

Disclaimer:

It is sincerely hoped that the information presented in this document will lead to an even more impressive safety record for the entire industry; however, neither the American Institute of Chemical Engineers, the European Process Safety Centre, its consultants, CCPS Technical Steering Committee and Subcommittee members, EPSC members board, their employers, their employers officers and directors, warrant or represent, expressly or by implication, the correctness or accuracy of the content of the information presented in this document. As between (1) American Institute of Chemical Engineers, its consultants, CCPS Technical Steering Committee and Subcommittee members, their employers, their employers officers and directors, and (2) the user of this document, the user accepts any legal liability or responsibility whatsoever for the consequence of its use or misuse.

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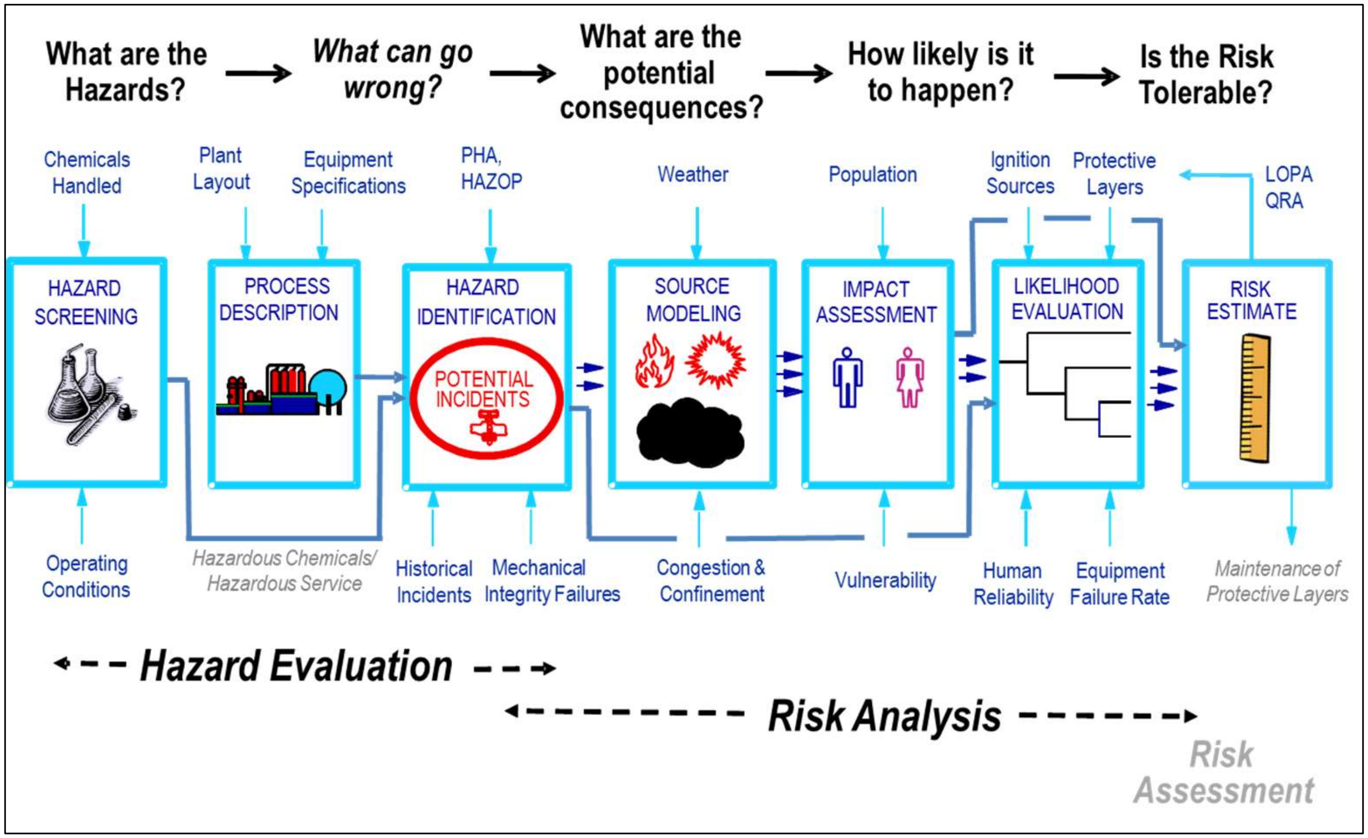
Center for Chemical Process Safety

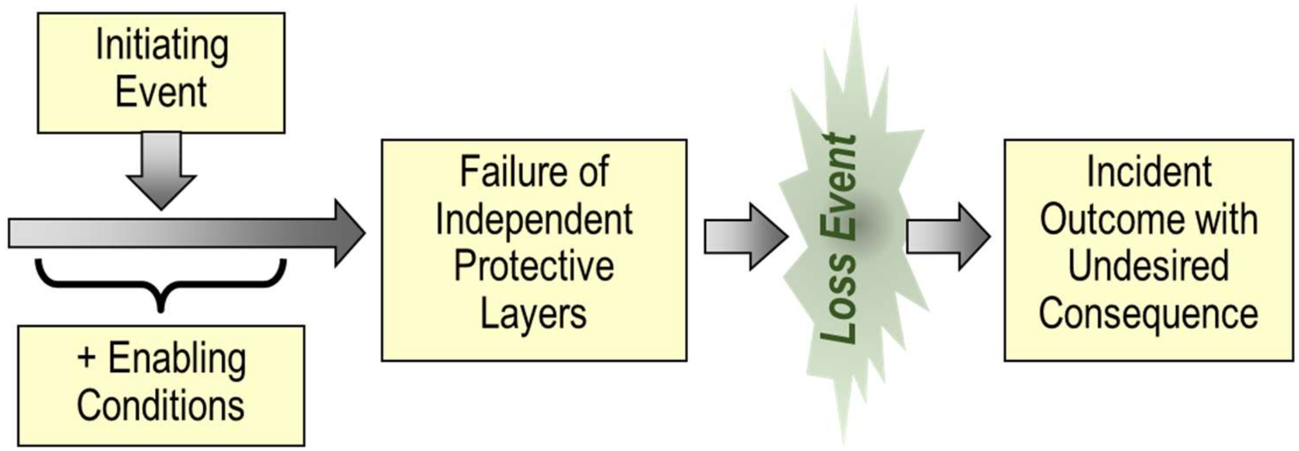
RAST is based on an a high level work process for Hazard Evaluation and Risk Analysis



Freely Downloadable from CCPS Website:
https://www.aiche.org/ccps/resources/risk-analysis-screening-tool-rast-and-chemical-hazard-engineering-fundamentals-chef

How do you use RAST?

You can use RAST to **screen and identify** potential hazardous scenarios (such as those used in HAZOPs)



Scenario = Initiating Event + Loss Event + Incident Outcome

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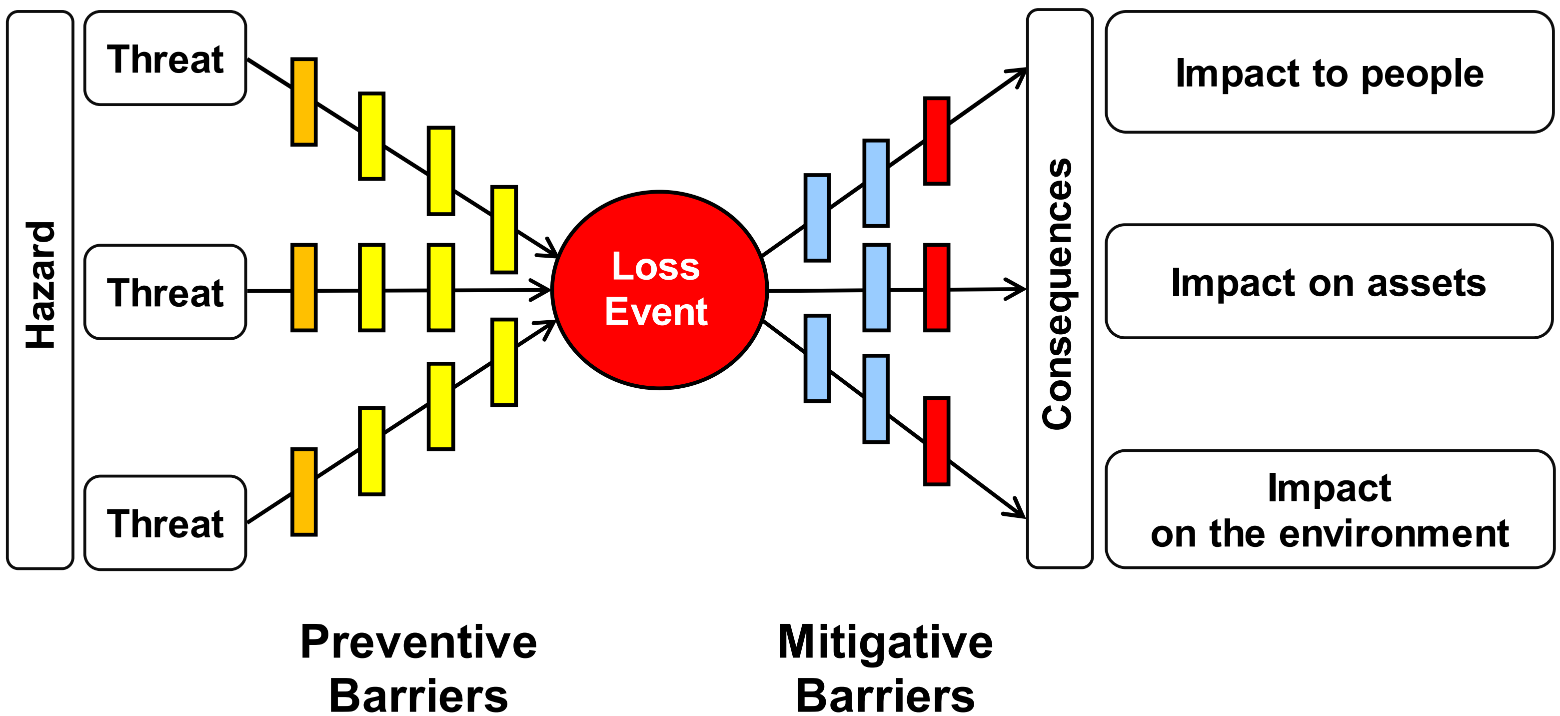
How do you use RAST?

Once you identify scenarios, then you can use the “Bow Tie” method in RAST to **screen and identify** potential barriers (your protection layers)



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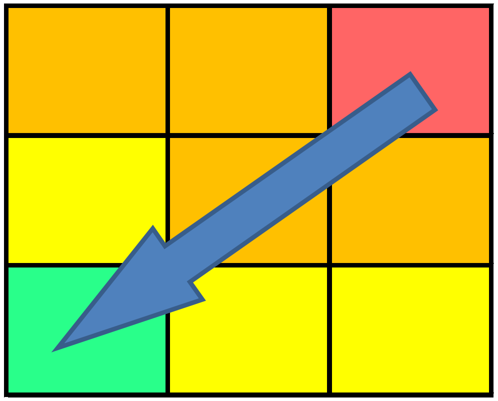
How do you use RAST?

Once you screen and identify these protection layers, you can use RAST to **evaluate their effectiveness** using a Layer of Protection Analysis (LOPA)

To help meet your company's

risk tolerance (risk matrix)



Likelihood or Frequency

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RAST is used to Screen for Scenarios

Increasing Process Risk Analysis **Detail**

Detail Level	Type of Risk Assessment
Qualitative	Process Safety Review Checklist Analysis
Simplified (semi-quantitative)	Hazards and Operability Study (HAZOP) Barrier Analysis (e.g. Bow Tie) Layers of Protection Analysis (LOPA) Risk Analysis Screening Tool (RAST)
Quantitative Risk Analysis (QRA)	Fault Tree Analysis Detailed Dispersion Modeling Detailed Explosion Modeling Human Vulnerability Analysis

RAST is used to Document Parameters

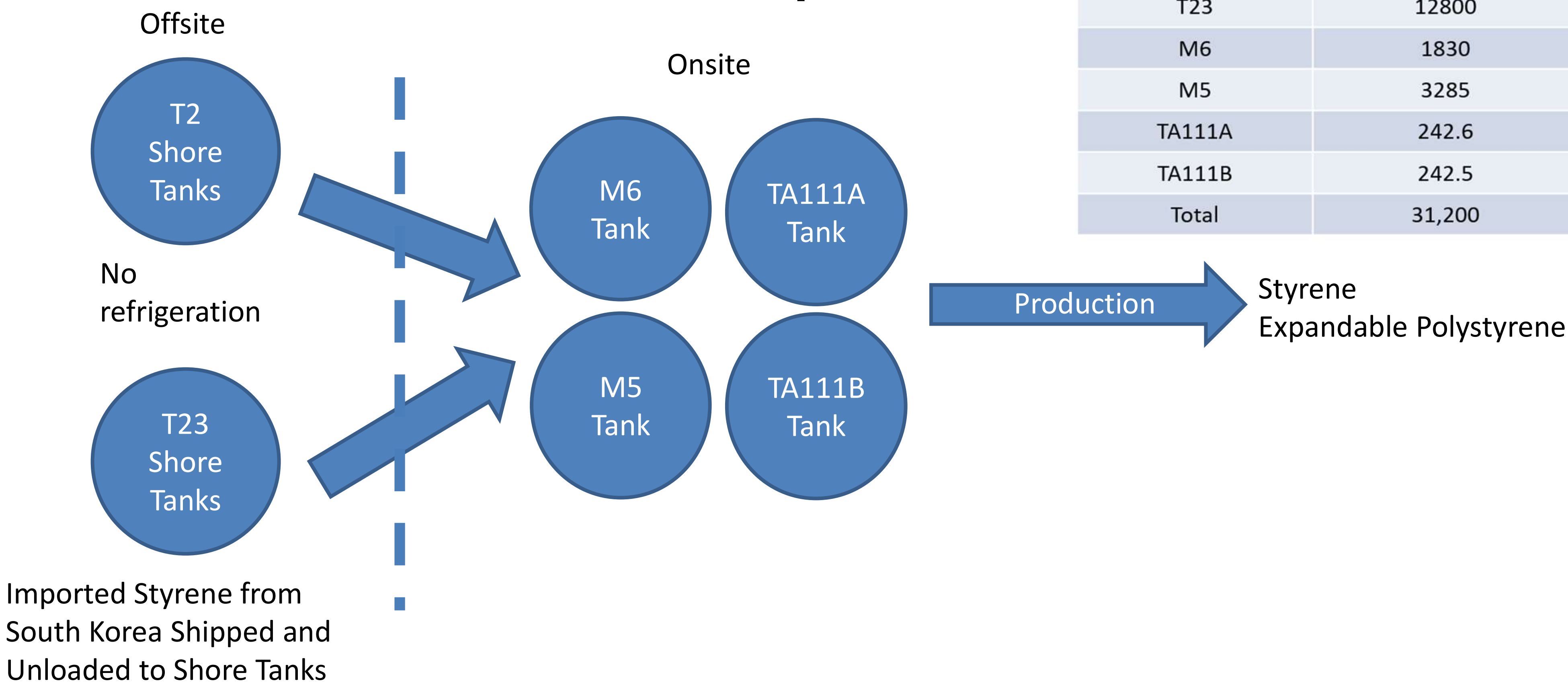
RAST Documentation ("Reports") include:

- Assumptions and limits based on industry guidance (*default values*)
- Assumptions and limits based on company-specific guidance (*overrides defaults*)
- Scenarios used to establish tolerable risk (*provides list of possible scenarios*)
- Barriers required to sustain tolerable risk (*uses LOPA*)

Downloadable at no cost from our CCPS Website:
https://www.aiche.org/ccps/resources/risk-analysis-screening-tool-rast-and-chemical-hazard-engineering-fundamentals-chef

Case Study – LG Polymers
Process Description

Tanks	Styrene Quantity tons
T2	12800
T23	12800
M6	1830
M5	3285
TA111A	242.6
TA111B	242.5
Total	31,200



Source: Report of the Joint Monitoring Committee in the O. A. No. 73 of 2020

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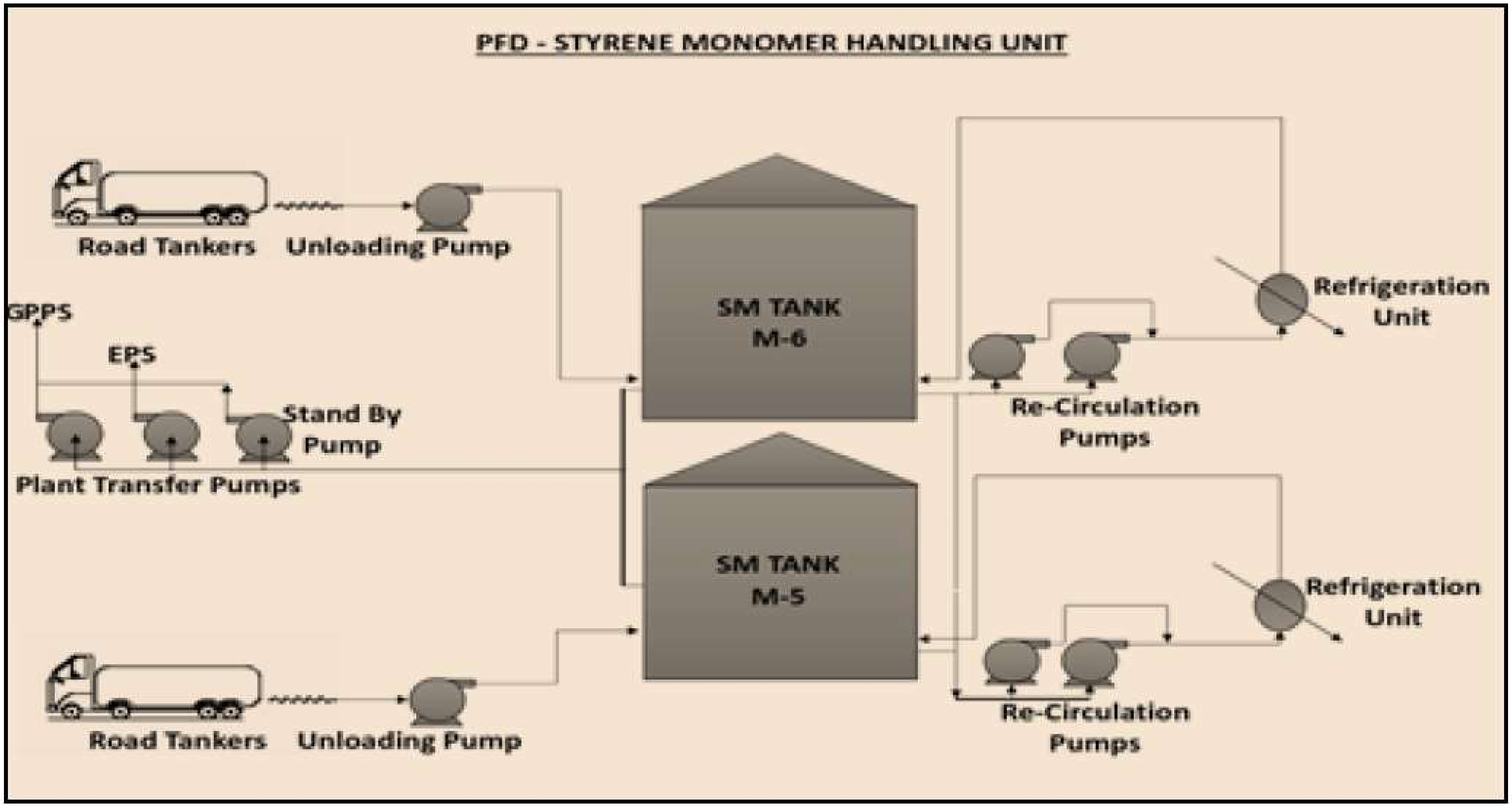
Case Study – LG Polymers

Process Description



Source: The High Power Committee Report on the Styrene Vapor Release Incident at LG Polymers India Pvt Ltd Shri Neerabh Kumar Prasad, Chief Secretary, Government of Andhra Pradesh

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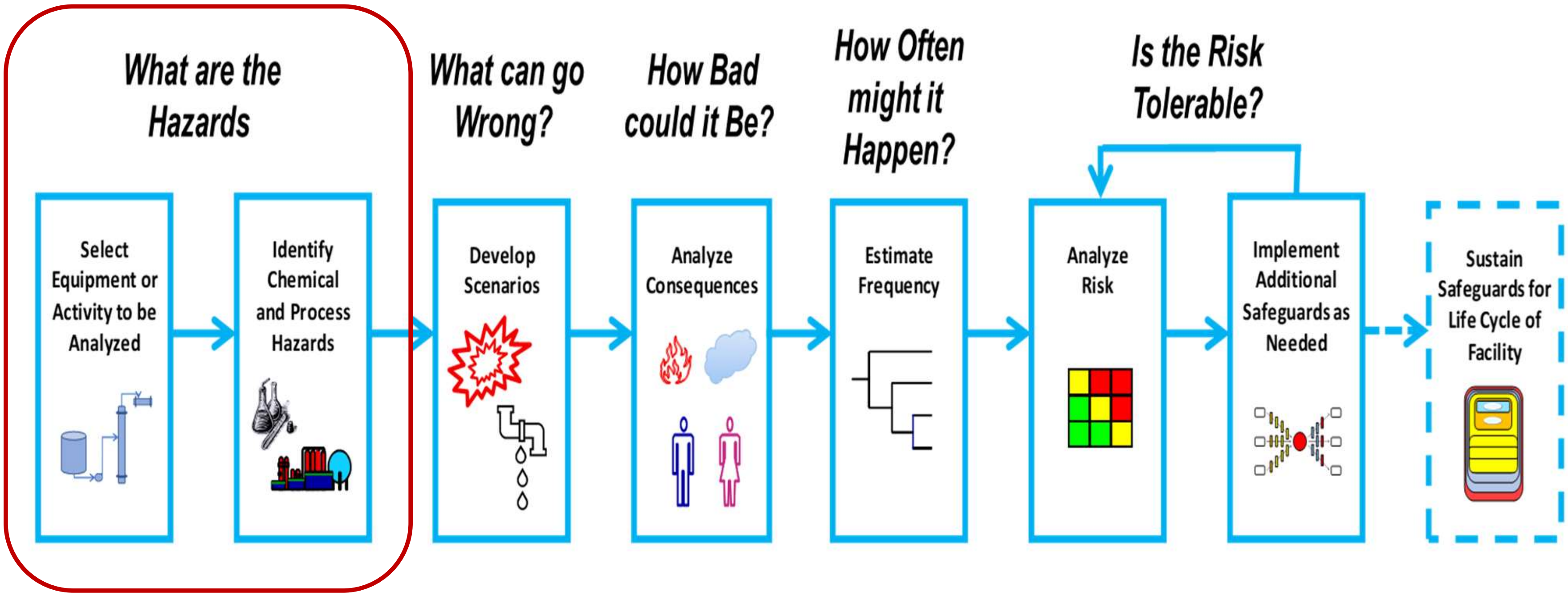
Case Study – LG Polymers

Hazard Identification and Risk Analysis (HIRA) Study



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Case Study – LG Polymers

Hazard Identification

Styrene

NFPA 704

Diamond	Hazard	Value	Description
	Health	2	Can cause temporary incapacitation or residual injury.
	Flammability	3	Can be ignited under almost all ambient temperature conditions.
	Instability	2	Readily undergoes violent chemical changes at elevated temperatures and pressures.
	Special		

Flash Point: 31°C (NTP, 1992)
Lower Explosive Limit (LEL): 1.1 % (NTP, 1992)
Upper Explosive Limit (UEL): 6.1 % (NTP, 1992)
Autoignition Temperature: 490°C (USCG, 1999)
Melting Point: -31.1 to -30.5°C (NTP, 1992)
Vapor Pressure: 4.3 mm Hg at -9.44°C;
9.5 mm Hg at 30°C; 10 mm Hg at 35°C (NTP, 1992)
Specific Gravity: 0.906 at 20°C (USCG, 1999)
Boiling Point: 145 to 146.°C at 760 mm Hg (NTP, 1992)
Molecular Weight: 104.16 (NTP, 1992)
IDLH: 700 ppm (NIOSH, 2016)

Interim AEGLs for Styrene (100-42-5)

Exposure Period	AEGL-1	AEGL-2	AEGL-3
10 minutes	20 ppm	230 ppm	1900 ppm
30 minutes	20 ppm	160 ppm	1900 ppm
60 minutes	20 ppm	130 ppm	1100 ppm
4 hours	20 ppm	130 ppm	340 ppm
8 hours	20 ppm	130 ppm	340 ppm

Lower Explosive Limit (LEL) = 9000 ppm
indicates value is 10-49% of LEL. Safety consideration against explosions must be taken into account.
Level of Distinct Odor Awareness = 0.54 ppm
(NAC/NRC, 2017)

ERPGs (Emergency Response Planning Guidelines)

Chemical	ERPG-1	ERPG-2	ERPG-3
Styrene (100-42-5)	50 ppm	250 ppm	1000 ppm

indicates that odor should be detectable near ERPG-1.
(AIHA, 2016)

PACs (Protective Action Criteria)

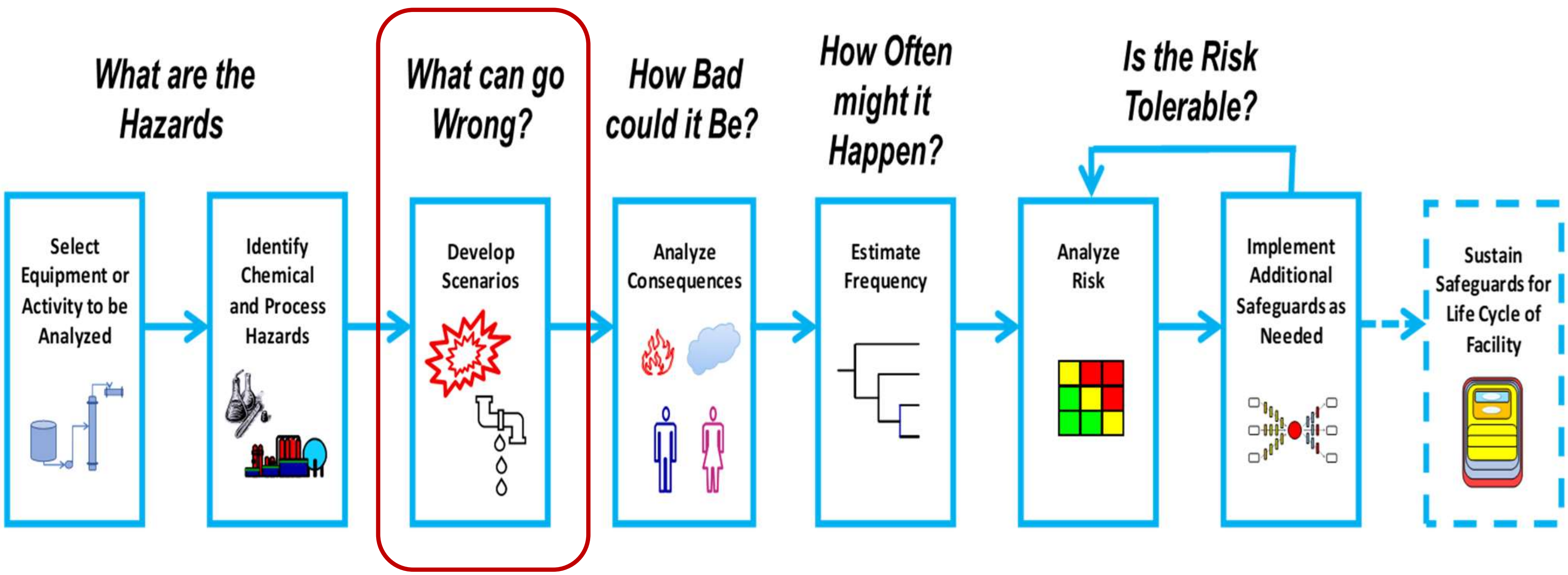
Chemical	PAC-1	PAC-2	PAC-3	
Styrene (100-42-5)	20 ppm	130 ppm	1100 ppm	LEL = 9000 ppm

indicates value is 10-49% of LEL.

Reference: Cameo Chemicals

Case Study – LG Polymers

Hazard Identification and Risk Analysis (HIRA) Study



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Case Study – LG Polymers
Potential Scenarios

Go to Top

Example Listing of scenario groups for Common Chemical Process Equipment

Scenario or Hazard Category	Parameter/ Deviation	Applicable Equipment	Initiating Events *(Partial List)*	Loss Event*	Incident Outcome
Excessive Heat Input - Pool Fire Exposure	Temperature-High Pressure-High Heat Input-High	All	Scenarios involving spill plus ignition in nearby liquid-containing equipment	Relief Venting Equipment Rupture Equipment Damage	Flammable Release Toxic Release Flash Fire or Fireball Physical Explosion Business Loss
Ignitable Headspace	Composition-Wrong Concentration Electrostatic Charge-High Electrical Conductivity-Low	All but Liquid-Full Equipment	Flow Control Failure Failure of Bonding or Grounding Particle Size Control Failure (Solids) Wrong Type or Damaged Bag, Pak or Drum (Solids) Improper Changing Dust Collector Bag or Screen (Solids)	Gasket Leak Equipment Rupture Equipment Damage	Flammable Release Toxic Release Flash Fire or Fireball Physical Explosion Business Loss
Overfill, Overflow, or Backflow	Level-High Flow-Backflow	All Liquid Containing Equipment	Level Control Failure Procedure Failure (Human Error)	Overflow Release Equipment Damage Equipment Rupture	Flammable Release Toxic Release Physical Explosion Business Loss
Uncontrolled Reaction	Reaction-High Rate Temperature-High Composition-Wrong	All	Flow Control Failure Temperature Control Failure	Relief Venting Equipment Rupture	Flammable Release Toxic Release Flash Fire or Fireball Physical Explosion Business Loss
Uncontrolled Reaction - Incompatible Materials	Reaction-Wrong Reaction	All	Addition of Wrong Recipe (Human Error) Addition of Wrong Material (Human Error)	Equipment Rupture	Flammable Release Toxic Release Flash Fire or Fireball Physical Explosion Business Loss
Vacuum Damage	Pressure-Low	All	Pressure Control Failure Mechanical Failure	Full-Bore Leak Equipment Damage	Flammable Release Toxic Release Business Loss

Center for Chemical Process Safety
An AIChE Technology Alliance

Case Study – LG Polymers
Runaway Exothermic Reaction

Table 1

Effect of Inhibitor and Oxygen on the Shelf Life of Styrene at Various Temperatures

Monomer Temperature	12 ppm TBC		50 ppm TBC
	Saturated with Air	Less than 3 ppm O_2	Saturated with Air
60 °F (15.6 °C)	6 months	10 to 15 days	1 year
85 °F (29.4 °C)	3 months	4 to 5 days	6 months
110 °F (43.3 °C)	8 to 12 days	Less than 24 hours	Less than 30 days

Reference: Americas Styrenics LLC, "*Safe Handling and Storage of Styrene Monomer*" (2016)

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Case Study – LG Polymers
Time to Maximum Rate

$T_{MR} = R\,T_i^2 / (q_i\,\Delta E)$ *where T_i is the initial temperature, q_i the initial reaction heat rate, R the gas law constant, and ΔE is the Activation Energy.*

$T_{MR} = R\,T_i^2 / (q_i\,\Delta E)$ = 1.987 (293 K)^2 / (19200 cal/mol 0.00020 C/min) = **44420 min or 30.8 days**
which excludes the induction time for depletion of the inhibitor

Note that: T_{MR} from 30 C (303 K) is only 15810 minutes or 11.0 days
T_{MR} from 40 C (313 K) is only 6110 minutes or 4.2 days

Case Study – LG Polymers
Detailed Evaluation of the Incident

The various screening techniques described in RAST have been utilized to this point for evaluation of the LF Polymers incident. There are many unanswered questions remaining:

- How long might it take for the inhibitor to become depleted?
- How effective was the tank cooling system?
- Is it feasible to reach runaway reaction conditions to occur within the time frame of the plant shutdown?
- Other questions?

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Case Study – LG Polymers

Process Description – Inhibitor Depletion Model

$L = A * \exp\left(\frac{E}{RT}\right) * C^N$ is an inhibitor depletion model originally proposed by Fisher. H at the DiERS User Group meeting.

Where, L is Induction Period (days),

A is pre-exponential factor (days/ppm-inhibitor) = 3.176e-18

R is Gas Constant (cal/gm-mole K) = 1.9872

E is Activation Energy (cal/gm-mole) = 25070

N is concentration exponent (dimensionless) = 1.308

Source: DiERS User Group, H Fisher (1991). A Runaway Styrene Polymerization Incident with Inhibitor Effectiveness Study. Pittsburgh, PA.

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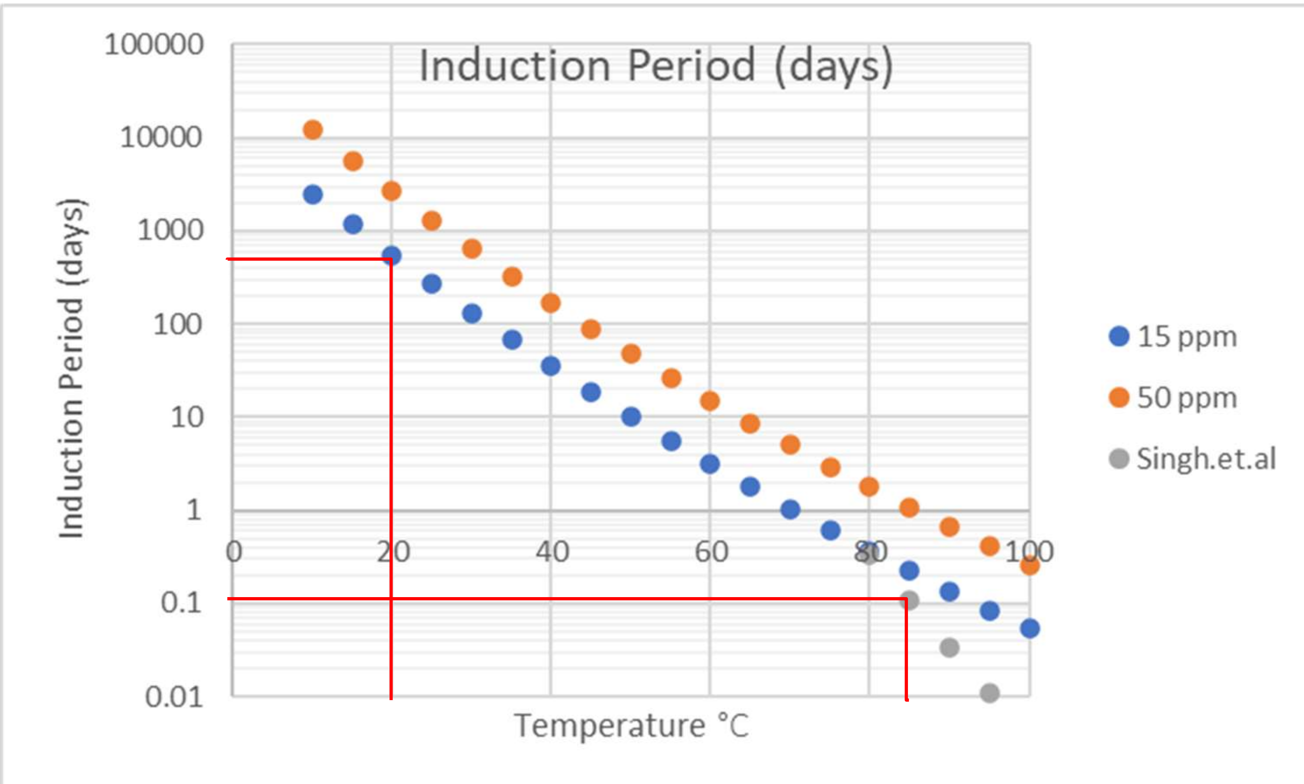
Case Study – LG Polymers

Process Description – Inhibitor Depletion Model

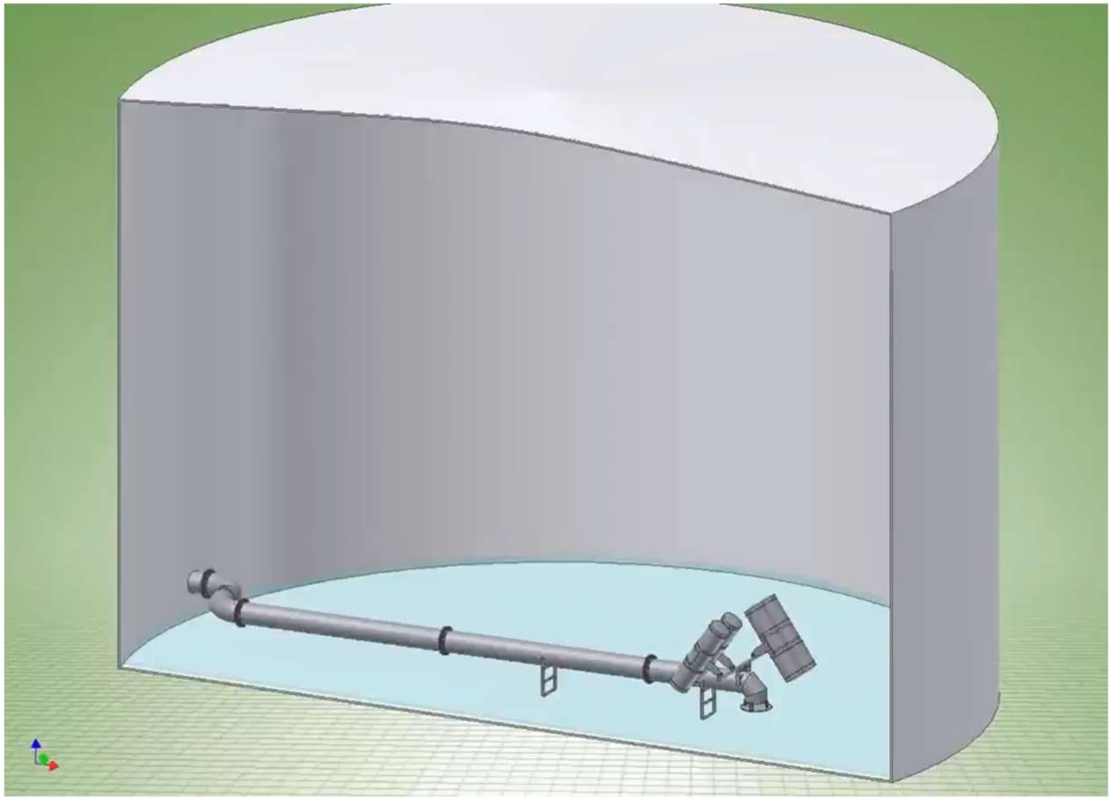


Source: DiERS User Group, H Fisher (1991). A Runaway Styrene Polymerization Incident with Inhibitor Effectiveness Study. Pittsburgh, PA.

Source: DiERS User Group Singh.et.al. (Fall 2012). Determination of Self Accelerating Decomposition Temperature (SADT) of Styrene using Accelerating Rate Calorimeter. Concord, MA

Case Study – LG Polymers

Process Description – Best Practice



Source: YouTube
https://www.youtube.com/watch?v=-rVRTM_7JVc

Protego®

Case Study – LG Polymers

Process Description – Best Practice

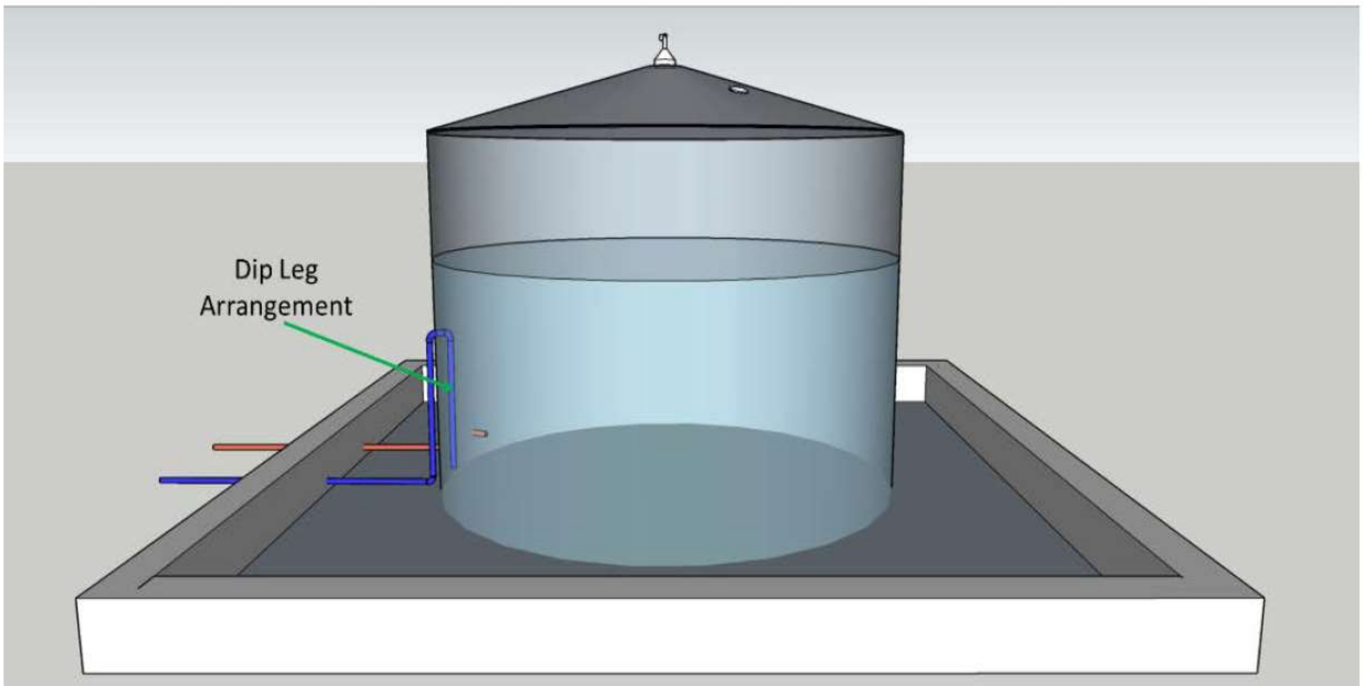


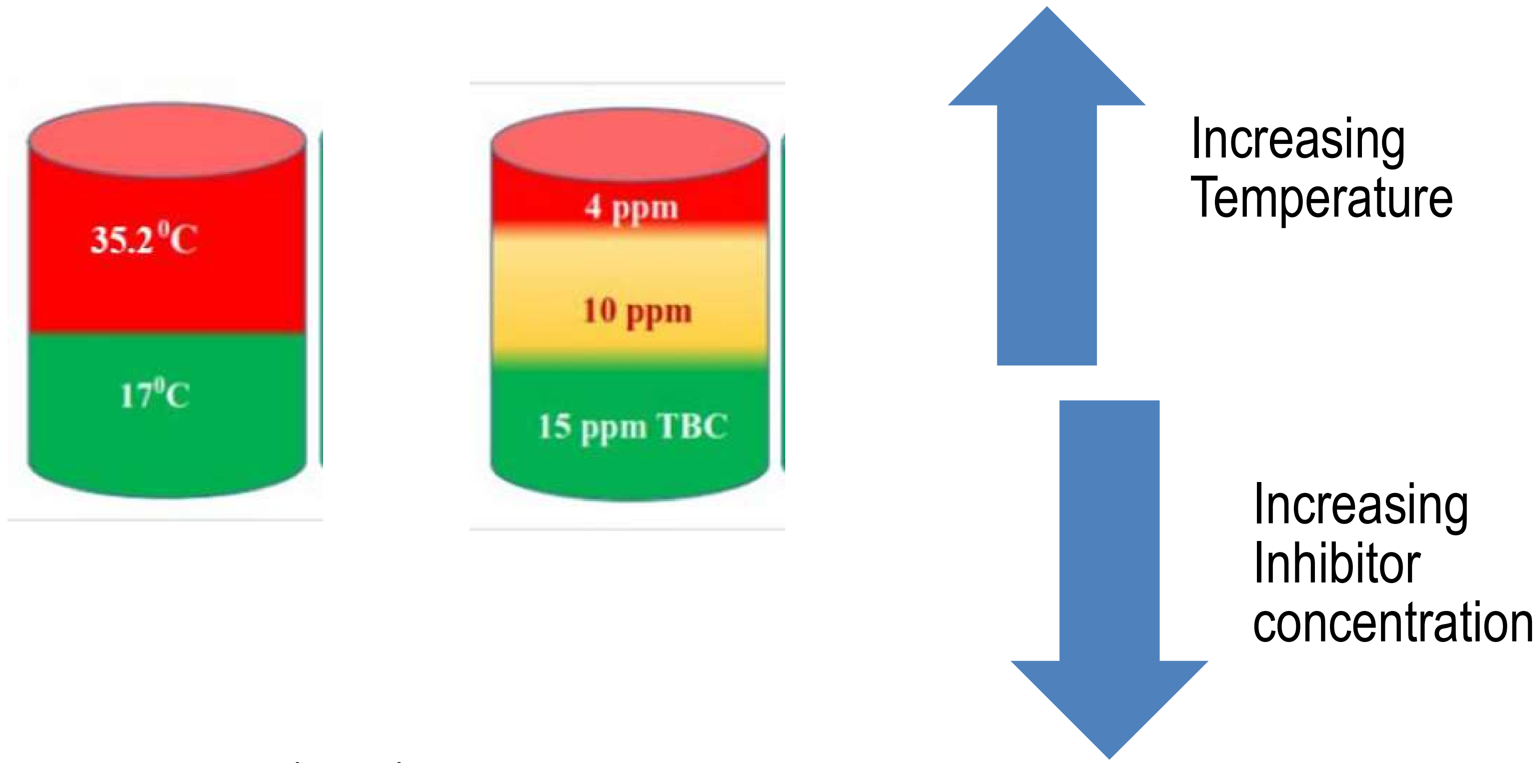
Figure 2.13: After the Modification in Styrene M6 Tank

Source: The High Power Committee Report, GoAP

CCPS — An AIChE Technology Alliance — Center for Chemical Process Safety

Case Study – LG Polymers

Temperature & Inhibitor Stratification



Source: The High Power Committee Report, GoAP

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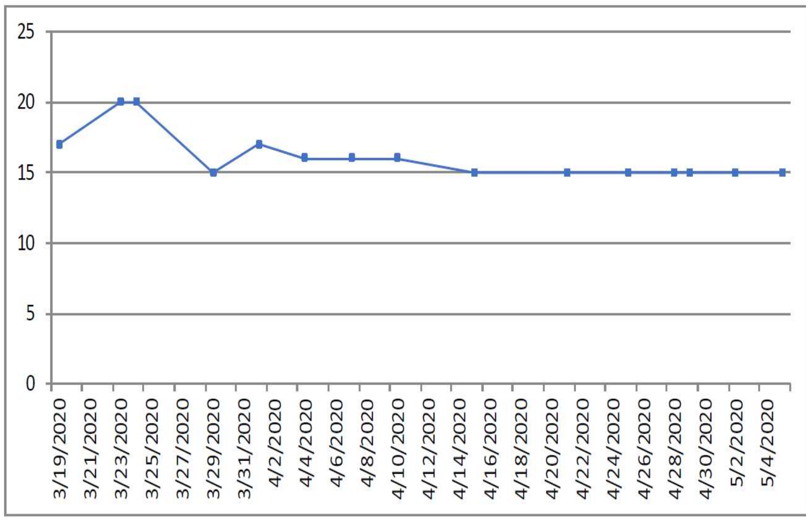
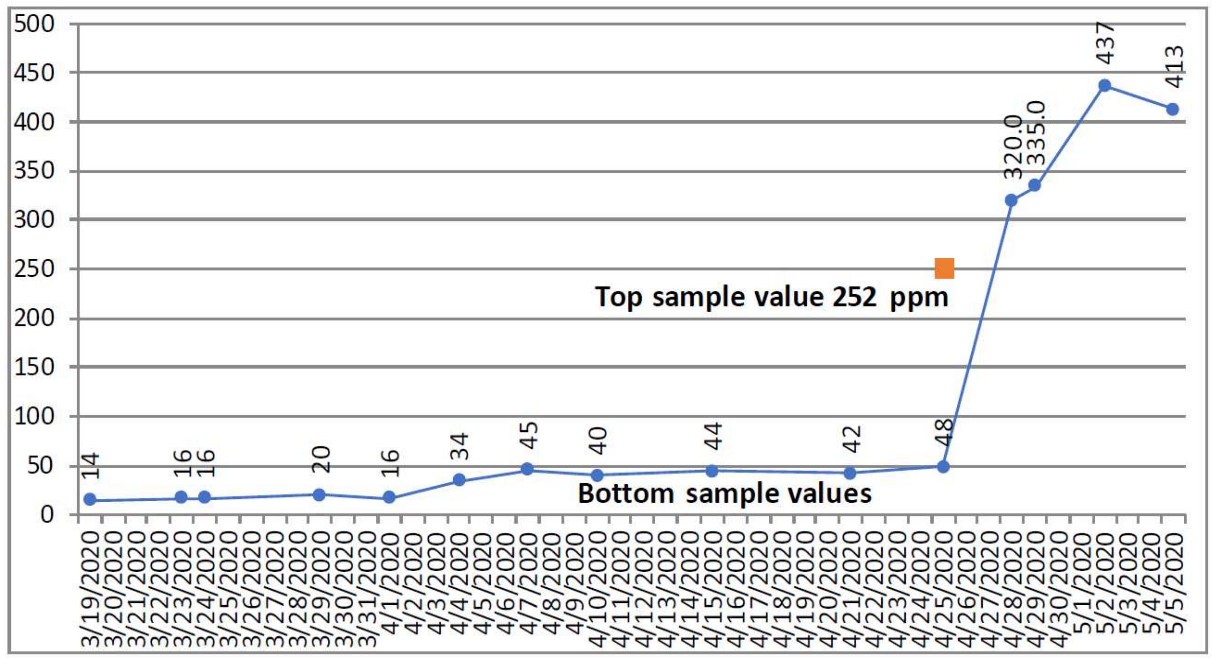
Temperature & Inhibitor Stratification

Graph below shows 15 ppm inhibitor concentration 3 days prior to incident



Graph 2.4: M6 Tank TBC (Inhibitor) Values in PPM

400 ppm polymer noticed 2 days before incident



Graph 2.5: M6 Tank Polymer (bottom sample) values in PPM

Source: The High Power Committee Report, GoAP

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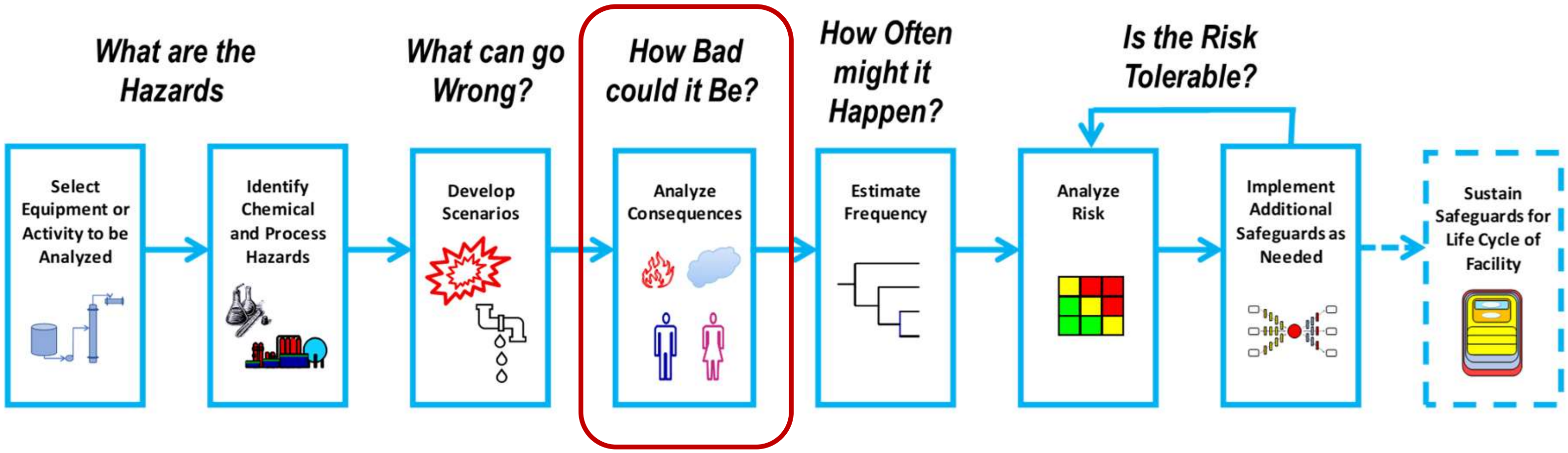
Hazard Identification and Risk Analysis (HIRA) Study



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Runaway Exothermic Reaction – Source Model

From the calorimetry data for uninhibited styrene at ϕ = 1.56:

ΔE = 19.2 kcal/mol $\quad T_{Detected}$ = 80 C (or 353 K) $\quad R$ = 1.98 cal/mol

Observed r_0 = 0.035 C/min $\quad$ *Adiabatic* r_0 = 0.035 (1.56) = 0.055 C/min

Observed overall ΔT = 210 C $\quad$ *Adiabatic overall* ΔT = 210 (1.56) = 328 C

Heat Rate = $(1-\chi)^1 \, r_0 \, e^{(\Delta E/R)\,(1/T_{Detected} - 1/T)}$

at 148 C (or 421 K) from an initial 20 C:

conversion, χ = (148 C – 20 C) / 328 C = 0.39

Heat Rate = $(1-0.39)\ 0.055\ \text{C/min}\ e^{(19200/1.987)(1/353 - 1/421)} = 0.61\ (0.055\ \text{C/min})\ e^{(4.421)} = 2.8\ \text{C/min}$

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Runaway Exothermic Reaction – Source Model

- The heat of vaporization for styrene is approximately 83 kcal / kg At 148 C,
- The liquid heat capacity is approximately 0.51 kcal / kg C.
- The quantity vaporized to balance the reaction heat is:
  2.8 C / min (0.51 kcal / kg C) / 83 kcal / kg = **0.017 kg / min vapor per kg styrene**
- The storage tank contained 1830 metric ton such that the vent rate to balance the reaction heat is 1830000 (0.017) = 31480 kg/min = **525 kg/sec**.

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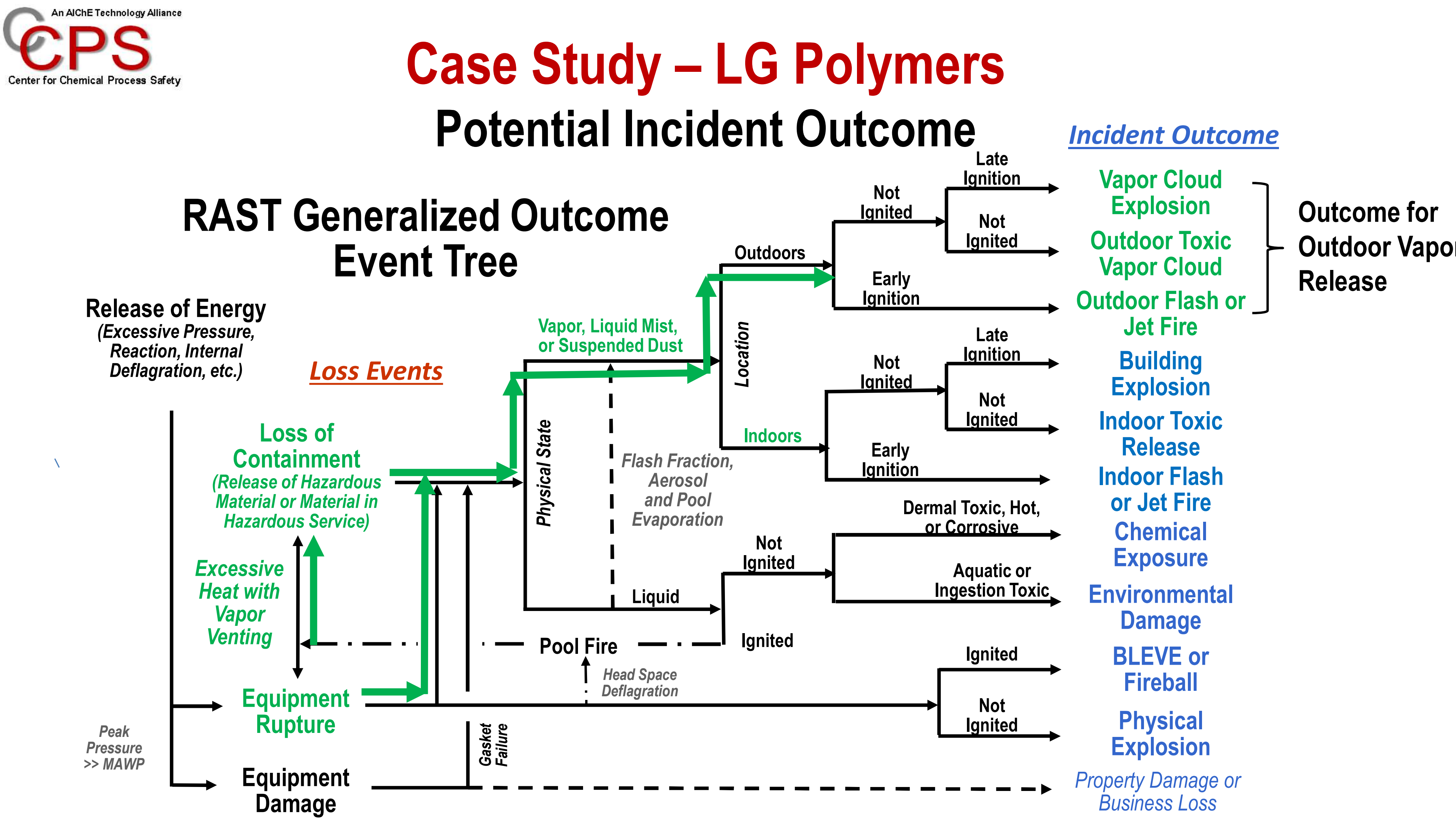
Potential Incident Outcome



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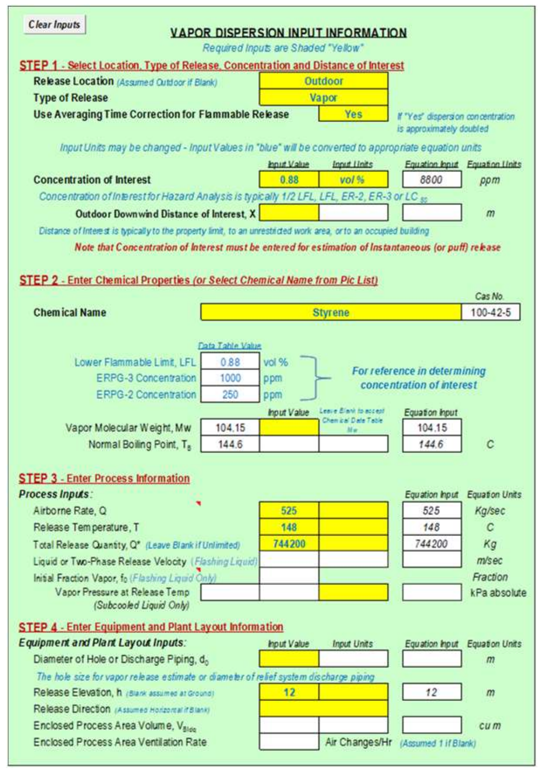
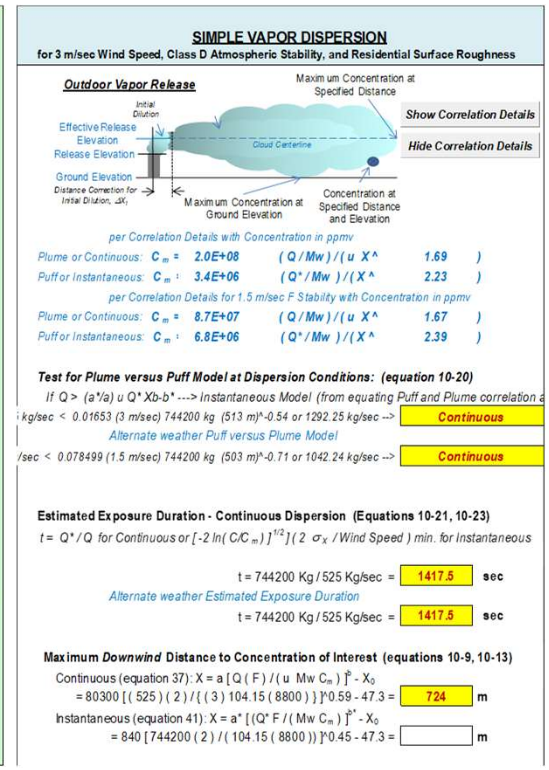
Dispersion Model

Using the RAST Calculation Aid, a 525 kg/sec styrene release would reach the following distances for specific concentrations at a wind speed of 3 m/sec and residential surface roughness..

Concentration (ppm)	Distance (m)
LFL of 8800 ppm*	724*
½ LFL of 4400 ppm*	1114*
1000	1818
2000	1197
5000	684

*based on flammable averaging time of 18 sec





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Explosion Model

Using the RAST Calculation Aid, a 525 kg/sec styrene release and distance to LFL concentration of 724 m, a Vapor Cloud Explosion would yield:

Distance to 1 psi blast overpressure of 679 m from the release location.

Distance to 2.5 psi blast overpressure of 495 m from the release location

Clear Inputs

EXPLOSION INPUT INFORMATION

Required Inputs are Shaded "Yellow"

STEP 1 - Select Type of Explosion and Distance of Interest

Type of Explosion: Vapor Cloud Explosion

Input Units may be changed - Input Values in "blue" will be converted to appropriate equation units

	Input Value	Input Units	Equation Input	Equation Units
Distance of Interest, X	495		495	m

~~STEP 2 - Enter Equipment Burst Pressure and Volume for Physical Explosion~~ *Skip Step*

Physical Explosion Inputs:	Input Value	Input Units	Equation Input	
Burst Pressure (gauge), $P_B - P_0$				kPa gauge
Equipment Volume, V_{Equip}				cu m
Burst Temperature, T_{Burst}				C
Fraction Liquid Level (if Superheated), F_F				
Flash Fract during Depressurization, F_V				

~~STEP 3 - Enter Quantity and Heat of Reaction for Condensed Phase Explosion~~ *Skip Step*

Condensed Phase Detonable Inputs:	Input Value	Input Units	Equation Input	
Mass of Material, M				Kg
Heat of Reaction per Mass, ΔH_R				Kjoule/Kg

STEP 4 - Enter Chemical Properties (or Select Chemical Name from Pic List)

Chemical Name: Styrene — Cas No. 100-42-5

	Data Table Value	User Value	Equation Input	
Vapor Molecular Weight, Mw	104.15		104.15	
Liquid Density, ρ_L (at Burst Temperature)	924		924	kg/m^3
Lower Flammable Limit, LFL	0.88		0.88	vol %
Fuel Reactivity based on Fundamental Burning Velocity	Medium		Medium	

(Leave User Value Blank to accept Data Table Value)

Ideal Gas Vapor Density, ρ_V (at Burst Temperature): 4.63 kg/m^3

~~STEP 5 - Enter Information for Building or Head Space Explosion~~ *Skip Step*

Building or Head Space Explosion Inputs:	Input Value	Input Units	Equation Input	
Building or Head Space Volume, V_B				cu m
Degree of Internal Congestion		Assumed "Medium" if Blank		
1 D Confinement? (such as Fire Tube Boiler)		Assumed "No" if Blank		

STEP 6 - Enter Information for Vapor Cloud Explosion

Vapor Cloud Explosion Inputs:	Input Value	Input Units	Equation Input	
Distance to LFL from Dispersion Model, X_{LFL}	724		724	m
Vapor Rate	525		525	Kg/sec
Degree of Outdoor Congestion		Assumed "Medium" if Blank		

BAKER-STREHLOW-TANG MODEL

Vapor Cloud Explosion (based on 3 m/sec wind speed)

Fuel Reactivity	Obstacle Density or Congestion: Low	Medium	High
High	0.5	>1	>1
Low-Medium	0.35	0.5	1

Use Mach 0.5 for Low-Medium Fuel Reactivity and Medium Confinement

Flammable Cloud Volume (equation 11-4), $V_C = 407\ Q\ X_{LFL} / (Mw\ C_{LFL})$ =

407 (525) (724) / [(104.15) (0.88)] = **30000** m^3

Distance to Explosion Epicenter, $X_{EE} = 0.5\ X_{LFL}$ = 0.5 (724) = **362** m

Potential Explosion Site Volume limited to 30000 cu m

Explosion Energy (equation 11-3), $Q_E = 3500\ V_{PES}$ =

3500 (30000) = **105000000** KJoules

Scaled Overpressure at 1 psi = 0.068

Scaled Distance, $R = X / (2\ Q_E / P_0)^{1/3}$ = **2.5**

Distance to 1 psi = $R\,(2\ Q_E / P_0)^{1/3} + X_{EE}$ =

2.5 [2 (105000000) / 101.3]^1/3 + 362 = **679.2 m**

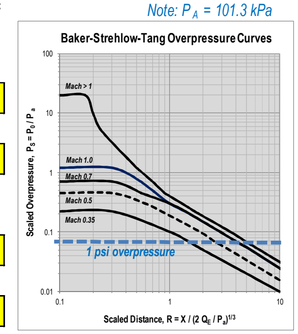
From Graph, Scaled Distance, $R = (X - X_{EE}) / (2\ Q_E / P_0)^{1/3}$ =

(495 - 362) / [2 (105000000) / 101.3]^1/3 = **1.048**

Scaled Overpressure = **0.171**

Overpressure at 495 m = **2.5 psi**

Note: P_A = 101.3 kPa



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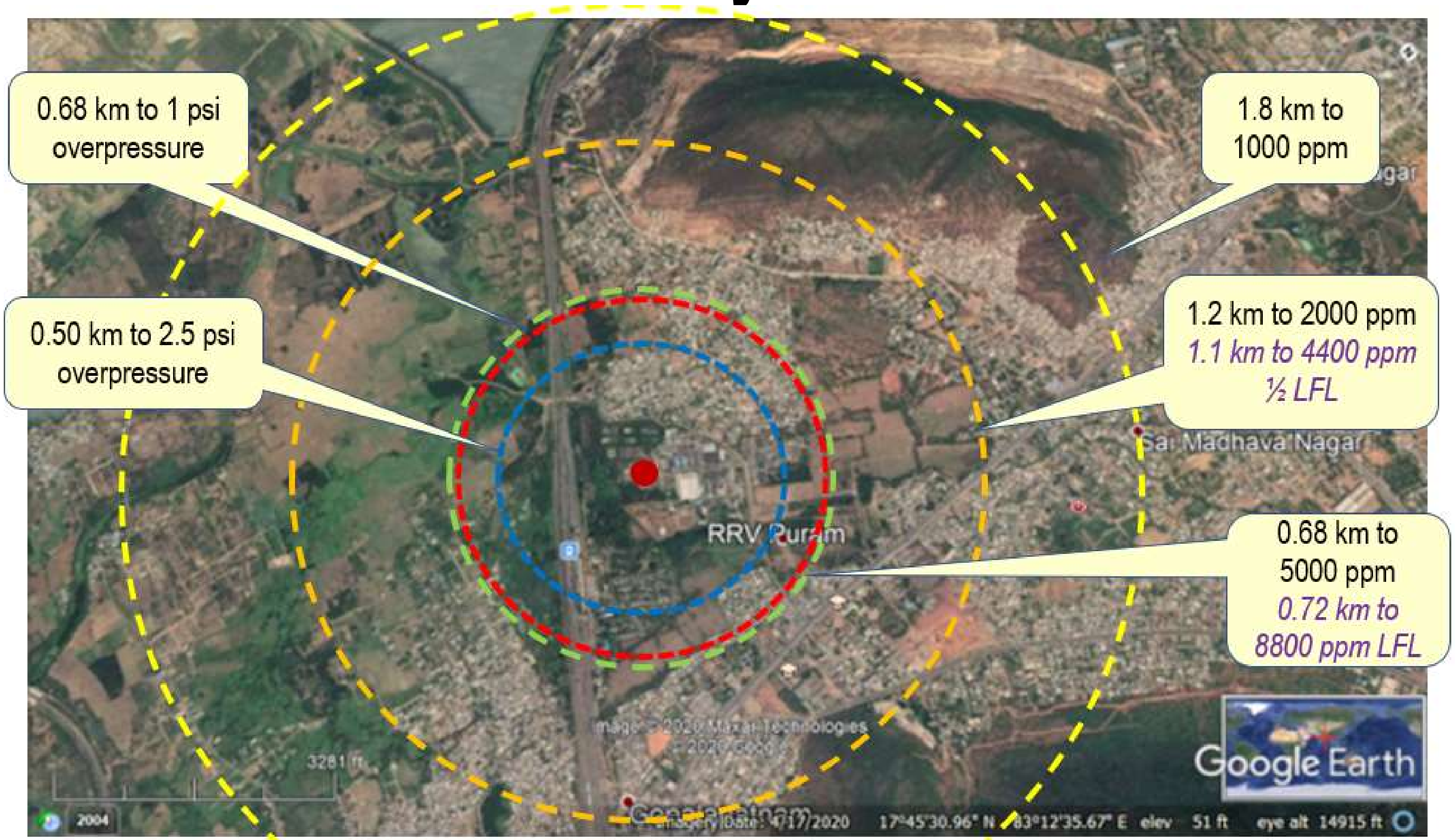
Site Layout



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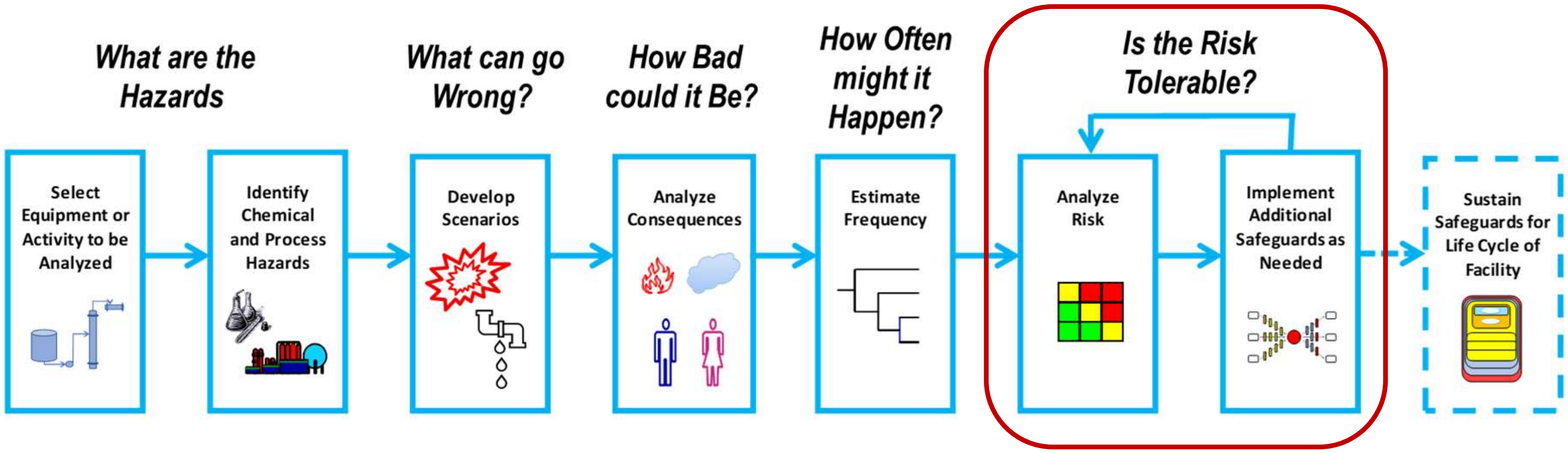
Hazard Identification and Risk Analysis (HIRA) Study



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Consequence Analysis / Frequency Evaluation

With the high population density near the facility, flash fire, toxic impacts or vapor cloud explosion would all likely yield multiple potential fatalities. Depending on the specific risk matrix, this would be a **very-high consequence severity** requiring several protective layers.

There may be other scenarios associated with Styrene Storage Tank (m6) that may ultimately need to be addressed through risk analysis to ensure hazard are managed to within a reasonable tolerable frequency.

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Summary of Root Cause Analysis per High Power Committee Report

- **Ineffective Design of Styrene Monomer Storage Tank by removing suction float.**
- **Inability to understand Process Safety Information and Failure to rectify Standard Operating Procedures.**
- **Improper Hazard Identification.**
- **Management of Change (Removing suction float)**
- **Emergency Planning and response**
- **Process Safety Competency related issues**
- **Deficient Mechanical / Asset Integrity**

Questions?

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DNV

Thank you for joining us