

# **Purdue Process Safety & Assurance Center - P2SAC**

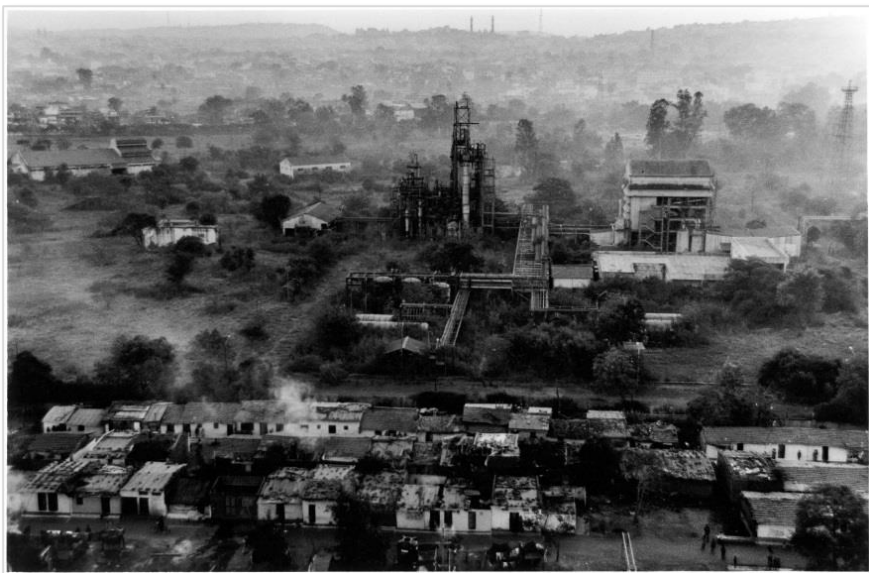
## **Highlights**

**Ray A. Mentzer**  
**Visiting Professor**  
**Executive Director, P2SAC**

Charles D. Davidson School of Chemical Engineering  
Purdue University

*December 5, 2019*

# Process Safety



Bhopal, India – 1984; +2,000 fatalities



West Pharmaceuticals – 2003; 6 fatalities



BP Texas City, 2005; 15 fatalities



Texas Tech University; Chemistry Lab – 2010

## P2SAC Formed in 2014



Process Safety a challenging quantitative / technical discipline; scope not widely recognized

Conduct process safety related research focusing on fundamental science

Teach rigorous process safety ChE core course (*+170 UG and Grad students enrolled Fall '18*)

Engage UG & Professional MS students in process safety research

Source of expertise for industry and other stakeholders regarding process safety related standards & best practices

Focus on oil & gas industry, chemicals, pharmaceuticals, agriculture, consumer products and manufacturing

Research projects solicited from industry sponsors, as well as other stakeholders such as academia & government labs

Enhance education experience of all Purdue ChE graduates

# Process Safety Conferences Held Each Semester

## *Attendees – December 5, 2019 Fall Conference*

### Sponsors

AcuTech  
AMGEN  
BP  
Chevron  
CountryMark  
Dow  
Fauske & Associates  
GSK  
Honeywell  
Kenexis  
Lilly  
Marsh Risk  
Phillips 66  
Pfizer  
SABIC  
3M

### Guests

- aeSolutions
- AMRI
- BakerRisk
- Catalent\*
- CCPS
- CDC - NIOSH
- Cook
- Corteva AgriScience
- Cummins
- DEKRA
- Endress+Hauser
- Evonik
- HEL\*
- Huntsman\*
- Jensen Hughes
- Johnson Matthey
- P&G\*
- Siemens
- Tate & Lyle
- Vertex

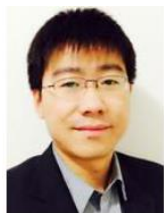
*\*denotes 1<sup>st</sup> meeting*

On-going dialog with other Depts:  
AAE, ABE, CHEM, IE, IPPH, ME & CV

# Multiple Faculty Engaged in Process Safety Related Research

– '19 / '20 program

## PhD Research



Sensing dust concentrations by imaging ...

... Safer materials and processing design for next-generation printed electronics

New directions in prevention by catalyst design ...



... Optimal placement of detectors and new directions driven by systems engineering approaches



Modeling and uncertainty analysis of dust explosions ...

... Battery safety by materials design

High throughput quantum chemical calculation of Benson group values for reliable thermodynamic calculations .....



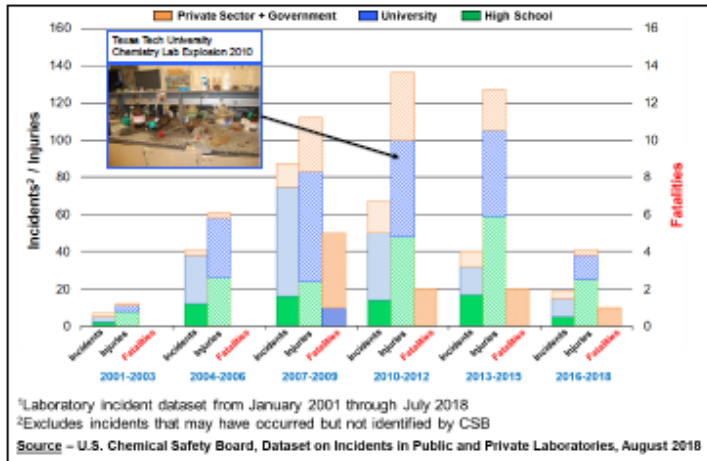
... Catalyst design and reactor runaway: selective oxidation of alcohols

The role of chemical agents (surfactants) and electrostatics in coalescence ...



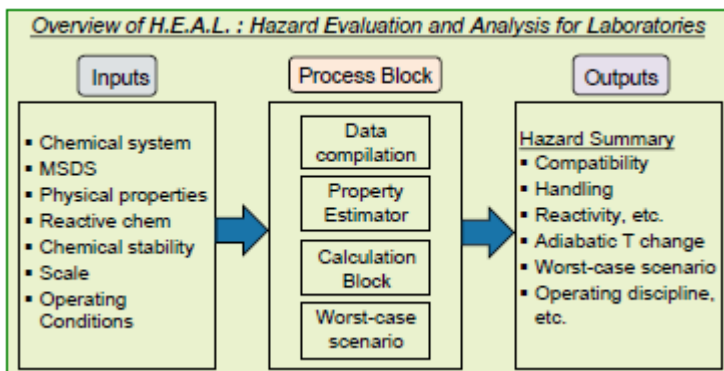
# Joint P2SAC / CISTAR projects funded by NSF

## Lab Safety – Academic & Industrial



Focused on:

1. Surveys and establishing / sharing best practices
2. Develop software tool for hazard analysis, toxicity, flammability, etc



## Cybersecurity Best Practices

Problem: Cybersecurity implications of proposed CISTAR facilities: remote sites, unmanned well-site facilities or regional/centralized processing facilities

300% increase in energy sector cyber-attacks since '12  
 Survey questions in three subject areas: demographics, cybersecurity & physical security

**80%** of companies employ 4+ cyber professionals

**93%** of companies use a layered cyber defense

- **100%** use firewall
- **93%** use multi-factor authentication
- **80%** use demilitarized zones
- **73%** use virtual machines

## Best Practices

- Password requirements
- Password changes
- Credential audits
- Scheduled software patch cycles
- Antivirus software
- Two-factor authentication
- Demilitarized zones
- Cloud-based services

# ChE Professional Masters Program

Grown from 9 students in '15 / '16 academic year to 70 in Fall 2019

2019 Cohort: 34% female; 79% int'l; \$84k avg starting salary 2019, 100% placement within 6 mos

Six areas of concentration:

- + Energy Systems Fundamentals & Processes
- + Kinetics, Catalysis, and Reaction Engineering
- + Biochemical Engineering,
- + Polymer Science and Engineering
- + Pharmaceutical Engineering
- + Gas and Petroleum Engineering

Program scheduled for one year

- + Students take 2 core courses; 3 in area of concentration; 3 in Management; followed by summer research project
- + Additional semester required for those without BS in chemical engineering

Summer research projects are typically suggested and led / mentored by industry

- + Students remain on campus with ~30 minute weekly call with industry mentor
- + Two-Three students per projects noted above; +800 hrs of 'free' research
- + Summer '19: Nine process safety related projects being pursued; ~50% of pgm
- + Companies participating: Air Liquide, **AMGEN**, Catalent, **Chevron**, Cook, **CountryMark**, Dow, **Dow AgroScience**, ExxonMobil, **Fauske**, Fresenius, **Kenexis**, Pioneer Oil, SP2, **3M**

# **P2SAC Research Program – Prof MS**

## **AMGEN**

- Thermal Hazards in the Pharmaceutical Industry – ‘19

## **Chevron / DowAgro**

- Leveraging Data Science for Oil & Gas Asset Integrity Management – ‘19
- Dimensional analysis and similitude for multiphase flows in pipe reactors – ‘19

## **CountryMark**

- Co-Processing Renewable Feedstock in a Distillate Hydrotreater – ‘19
- Optimization of Gasoline & Diesel Product Blending – ‘19

## **Dow Agro**

- A systems engineering approach for managing changes in chemical process R&D labs – ‘18

## **ExxonMobil**

- Oil field development approach in a high regulation environment – ‘19
- Acoustically-induced vibration of piping systems – ‘18

## **Fauske**

- Design and construct a prototype of a benchtop tool to be used to screen chemicals for reactivity – ‘19

## **Kenexis**

- Determination of Minimum Sufficient Dispersion Model Scenarios for Gas Detection Optimization - ‘19
- Improving Understanding of Hazards of Process Plants through PHA Gamification – ‘19
- Develop a scheme for conducting process hazard analyses and develop guidance for automating – ‘18
- Validate large scale consequence modeling with Middle East propane release – ‘17

## **Lilly**

- Compilation of thermal hazard safety data for amide coupling reagents – ‘17

## **Shell**

- Quantification of toxicity effects of H<sub>2</sub>S ingress into buildings / temporary refuge – ‘18

## **3M**

- Understanding Ignition Properties of Flammable Gas / Particulate Mixtures & Mitigation Through Inerting – ‘19



# Industry Suggested Research - per Dec '18 Conference; input from 19 cos

## PHAs

Thoroughly analyze PHA shortcomings that led to incidents & develop targeted training

Software to mine PHA / HAZOP data; make the data more useful to communicate to front-line

## Risk

High consequence scenarios; critical risks; alternate approaches to identify and prevent major incidents

Safety pyramid; recognition that only a small fraction of less severe incidents can lead to Tier 1 significant incidents; which ones?

## Reaction engineering

Management of exothermic reactions – hydrogenation, etc

Reactive chemistry calorimetric measurements

## Other

Effectively reducing human errors, which are often the cause of incidents

Computational tools for predicting properties

Best practices for inerting of vapor space above tanks

*Challenged with start / initiation / progression of process safety journey*

*Challenged to effectively articulate breadth / desirability of process safety positions; & fill positions*

# P2SAC Research Program – UG

## 2019

Role of human error in process safety incidents & prevention - *ongoing*

Identification of specific deficiencies in PHAs that led to major incidents - *ongoing*

Examination of incidents involving fired heaters and consequence modeling tools (PMP) – *ongoing*

Best practices for prevention of tank overflow incidents - *ongoing*

Analysis of process safety incidents across 14 industries & comparison of root causes - continuing

Analysis of process safety incidents in the pharmaceutical industry (PMP) - continuing

Calorimetric study of pharmaceutical reagents by ARSST (PMP) – continuing

## 2018

Extend Benson group data base for thermodynamic property prediction – evolved to PhD

Determine and predict temperature at which time to max rate of reaction is 24 hr (PMP) - complete

Develop guidance on energy released during testing vs. volume of sample for pharma industry (PMP) - complete

Risk and reliability of aged natural gas pipelines - *published*

Compilation of process safety related software commercially available - complete

Develop database of MIEs of dusts with focus on pharma / mixtures – evolved to PhD

## 2017

Comparison of global process safety regulations - *published*

Experience with corrosion under insulation; detection & mitigation

Experience with LNG metallurgy failures

## 2016

Analysis of process safety incidents in the pharmaceutical & agriculture industries

Study of incidents involving reactive chemical hazards

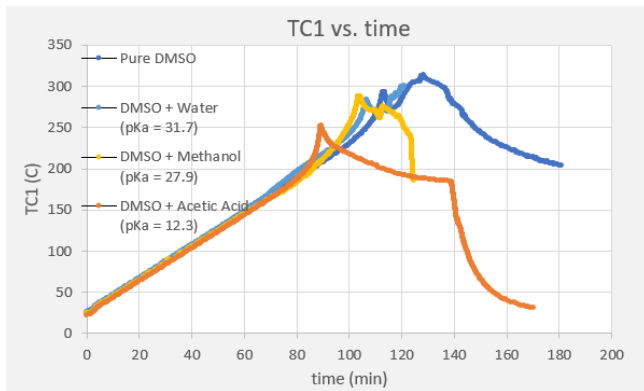
Process safety incidents involving nanomaterials

# Two On-going PMP Research Projects

## ARSST Calorimeter - Advanced Reactive System Screening Tool

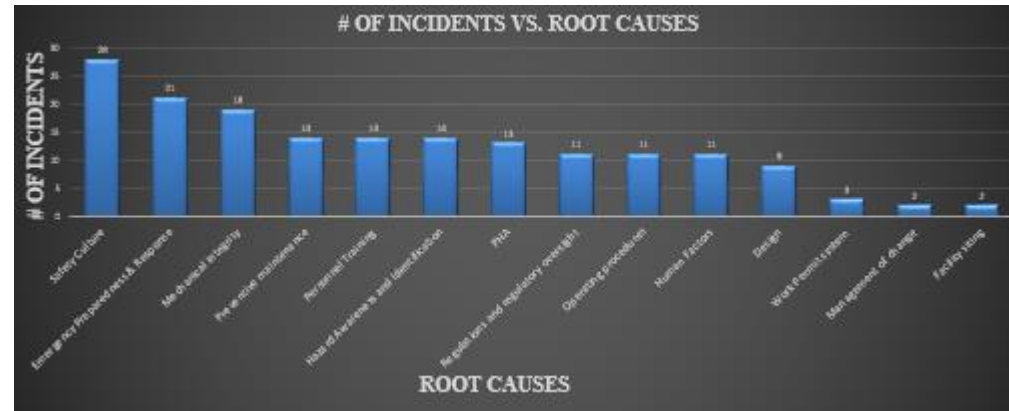
- Used to study the decomposition of DMSO
- Records temperature & pressure data over time
- Calculated the  $\Delta H_R$ ,  $E_a$ , and the Pre-Exponential Factor from the DMSO Decomposition reaction
- Compared the thermochemical properties of the DMSO decomposition under acidic conditions by mixing DMSO with acids of varying pKa's
- Obtained a Linear Free Energy Relationship between the onset T of the DMSO decomposition reaction and the pKa of acid added to the system
- Analyzed the change in this Linear Free Energy Relationship under different concentrations of acid with DMSO

Plots illustrating the change in  $T_{onset}$  with different acid strengths



## Analysis of Root Causes of Incidents across 14 Industries

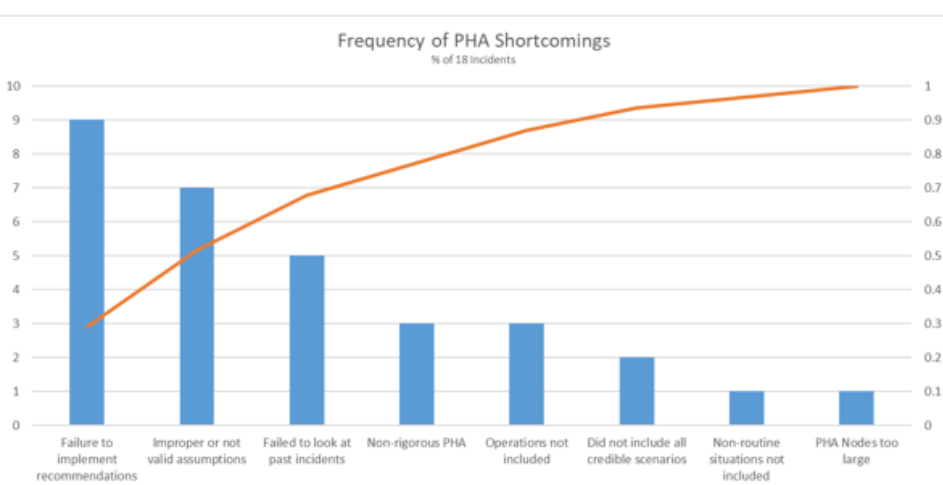
- Studied: Refining, Chemicals, Oil & Gas, Storage, Pipeline, Fertilizer, Pharmaceutical, Agriculture, Food, ... *3 primary incidents per industry*
- Identified 14 primary root causes; several per incident
- Analyzing significant data set in terms of root causes, fatalities, monetary damage, impact beyond plant fence, state of operation, and developed / developing country



# Two On-going Undergraduate Research Projects

## PHA Shortcomings Leading to Incidents

- Identified ~20 serious incidents with inadequate PHA as a root cause
- Categorizing the shortcomings
- Plan to locate or develop guidance materials to address shortcomings



## Incidents Resulting from Human Error

### Categories of error

Commission: Intentional & Un-intentional  
 Omission: Intentional & Un-intentional  
 Competency

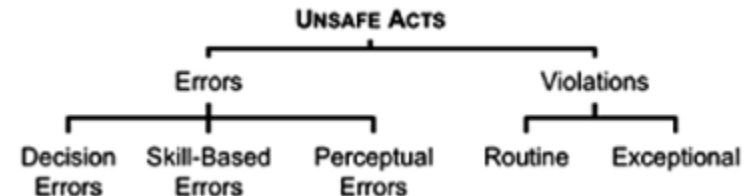
Causes of error: Stress (Time issues, Work environment), Task Difficulty/ Complexity, Fitness of Duty, Supervision, Communication, Lack of qualification

### Incident Investigation & Analysis – Examples

| Incident                 | Description   | Category               |
|--------------------------|---|------------------------|
| BP Amoco (2001)          | Workers open vessel containing accumulated, pressurized polymer         | Commission, accidental |
| Three Mile island (1979) | Lapse in attention resulting in failure to open valve after maintenance | Omission, accidental   |

### Possible Error Mitigation techniques

- Task Analysis
- Human Error Identification:
  - Hfacs



- SHERPA (Systematic Human Error Reduction and Prediction Approach)

+ Classify incident using error possibilities e.g action, checking, retrieval, transmission or diagnostic errors.

# CHEN 420 / 597- Chemical Process Safety – core UG course

## Personnel vs. Process Safety & Metrics

Applicable regulations: OSHA PSM, EPA RMP, etc

Source Term Modeling

Toxicants & Industrial Hygiene

Toxic/Flammable Gas Release

Dispersion Modeling

Fire & Explosion Protection

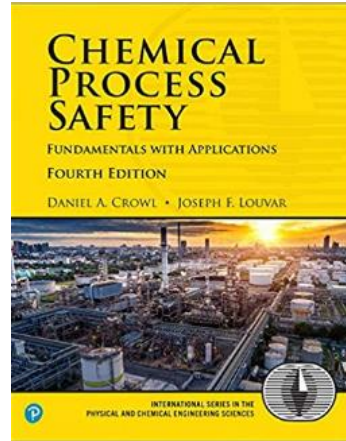
Chemical Reactivity

Relief System Design

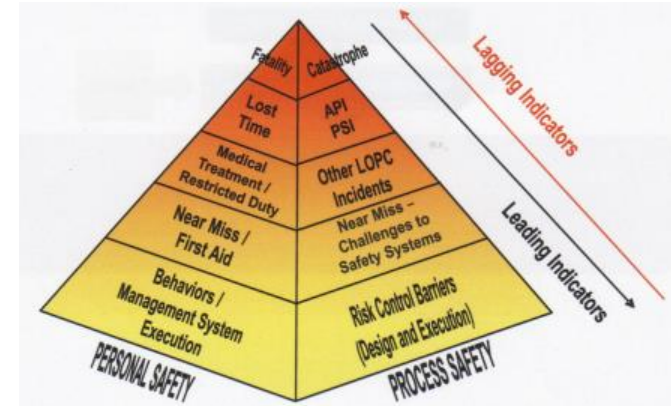
Hazards Identification (HAZOP, ..)

Risk Assessment (Matrix, QRA, ..)

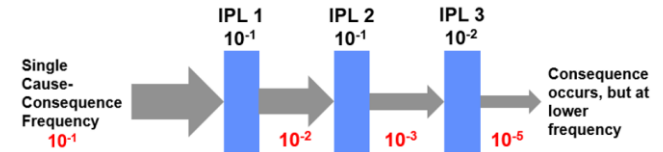
Accident Investigations



## Process Safety Metrics



## LOPA Frequencies



## Typical 4x4 Risk Matrix

|          |            | Likelihood |           |          |          |
|----------|------------|------------|-----------|----------|----------|
|          |            | Frequent   | Possible  | Rare     | Remote   |
| Severity | Major      | Very High  | Very High | High     | Moderate |
|          | Serious    | Very High  | High      | Moderate | Low      |
|          | Minor      | High       | Moderate  | Low      | Low      |
|          | Incidental | Moderate   | Low       | Low      | Low      |

## HAZOP

Node # \_:  
Design Intent:

| Parameter | Guide Word | Deviation | Causes | Consequences | Recommendations |
|-----------|------------|-----------|--------|--------------|-----------------|
|           |            |           |        |              |                 |

# 2019 P2SAC Highlights

- Four new company Sponsors
- Progressed 10 PhD / 9 PMP / 8 UG research projects
- 19 P2SAC related PMP projects suggested for summer '19; 9 chosen
- Installation & initial testing with Fauske donated ARSST calorimeter
- Active engagement of multiple companies in student research via Skype, teleconference, etc
- Department effort seeking to name / endow P2SAC, as well as process safety chair / professorship

# P2SAC Sponsors



*Typical Sponsor agreement is \$25k / year for 3 years*