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Bio-project derisking through development of systematic methodologies and frameworks for risk assessment

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Changing the World's Energy Future

Rachel M Emerson, Jordan Solomon, Marcin Lewandowski, Shyam Nair, Lorenzo J Vega Montoto, Pralhad Hanumant Burli

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Rachel Emerson
Research Scientist

Bio-Project "Derisking"

Development of Systematic Methodologies and Frameworks for Risk Assessment

FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM

U.S. DEPARTMENT OF ENERGY

Idaho National Laboratory

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Acknowledgement

FCIC
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM
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Co-Authors

Jordan Solomon	Ecostrat Inc.
Marcin Lewandowski	Ecostrat Inc.
Shyam Nair	Los Alamos National Laboratory
Lorenzo Vega-Montoto	Idaho National Laboratory
Pralhad Burli	Idaho National Laboratory

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Bio-Project Risk

Project Risk

Technical ★
- Technology
- Performance
- Product yield/quality
- Capacity

External
- Feedstock supply ★
- Market
- Customers
- Suppliers
- Environmental
- Contracts
- Regulations

Organizational & Management
- Costs
- Logistics
- Planning
- Personnel
- Financing ★

- Variability in biomass feedstock properties translates to risk for bio-project
- Success of bio-economy depends on low cost of capital which is determined by project risk

Systematic Risk Assessment

Biomass Supply Chain Risk Standards (BSCRS)

Systemized approach for quantifying supply chain risk

- Bio-project financing

Failure Mode and Effects Analysis (FMEA)

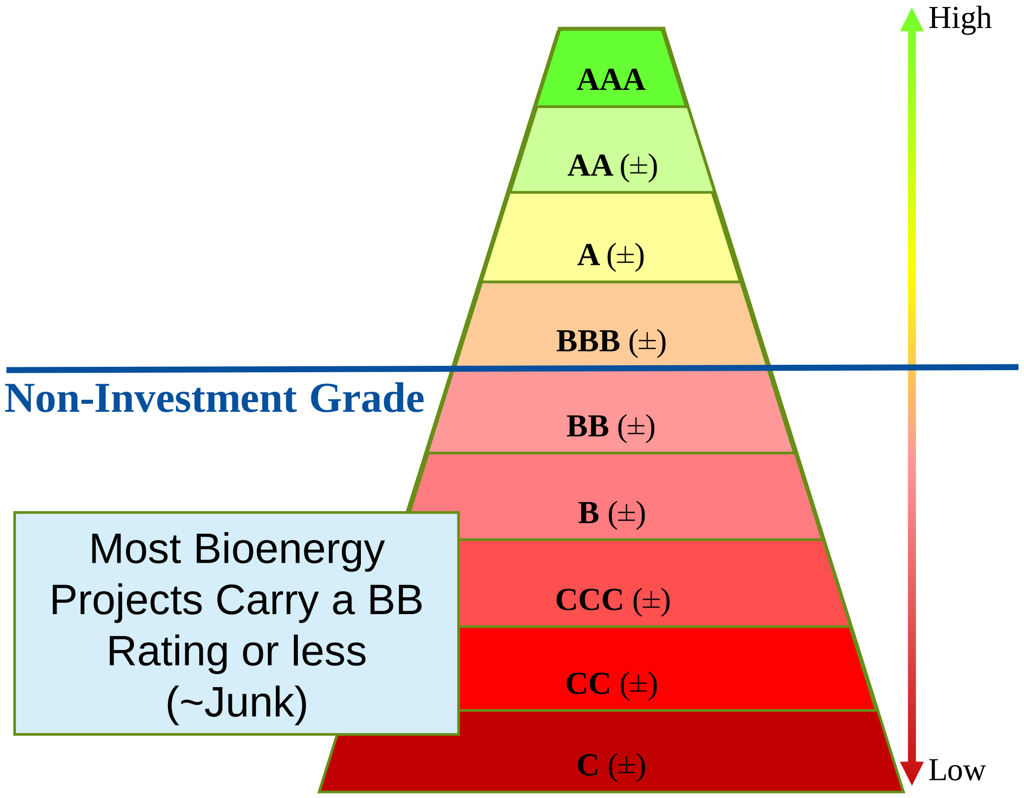
Industrial relevant risk management tool to systematically identify and assess the causes and effects of potential failures in a system

- Technology risk

Why Create Standards for Biomass Supply Chain Risk?

“Lack of BSCR Standards is a material barrier to bio-project finance.”
AGF, Stern Brothers, Raymond James, Jefferies Investment Banking

- Risks associated with biomass supply chains are not well understood.
- No established protocols, standards, or recognized industry best-practices to rely upon to empirically quantify supply chain risks.
- Developers, investors, commercial lenders, insurance companies, and rating agencies independently use inconsistent approaches and evaluation criteria.
  - Leads to unreliable assessment of project risks.
- There are many reasons for low ratings, but a key reason is confusion about the degree of long-term supply chain risk.



Generic credit rating

Industry Stakeholder Group Formation

Industry buy-in and expert input is critical to BSCRS success

Industry Stakeholder Group

- **150+** member industry stakeholder group
  - Suppliers
  - Finance agencies
  - Landowners
  - Equipment manufacturers
  - Project developers
- One-on-one interviews
- Review

BSCRS Framework Overview

Supplier

- Credit Worthiness
- Contracts
- Conflicts of interest
- Control over production and transportation
- Distance
- Experience
- Harvesting/Collection/Processing capacity
- Motivation

Feedstock Quality

- Quality Variability
- Specific Feedstock Quality Variables

Competitor

- Influence on Market
- Competitive advantage

Feedstock Scale-up

- Feedstock Scale-up

Internal Management

- Feedstock Cost Margins
- On-site Inventory
- Internal Yard Operations
- Management and Personnel

Supply Chain

- Feedstock Availability
- Historical Issues
- Non-Weather Externalities
- Production, harvest, and collection
- Transportation
- Resiliency
- Climate and Natural Risks
- Political and social
- GHG Accounting

BSCRS Framework Overview cont.

Risk Indicator 4.1.5 Geographic Location Influence on Feedstock Variability

Justification →	**Rationale**	**Feedstock from different regions may differ in quality due to variations in soil quality, topography, harvest practices, weather, fertilizer applied, etc.**
Reporting Requirements →	**Reporting**	Reporting Requirements 1. Proponent shall demonstrate understanding of geographic regions from which feedstock will be sourced, and the effect on feedstock quality.
Guidance and Resources →	**Guidance**	Guidance for Reporting Requirement 1 Because of the variability associated with supply from multiple regions, blending or pre-processing may be required to attain the desired raw material specifications. Variability in herbaceous feedstock quality parameters is typically much higher than in woody feedstocks. Blending of herbaceous materials to produce a single feedstock with a narrow range of desired quality parameters is therefore a bigger challenge than with woody feedstocks.
Source →	**Guidance Source**	Spikes (2017, interview); Swan (2018, interview)

Current BSCRS Frameworks: https://bioenergylibrary.inl.gov/BSCR/Home.aspx

BSCRS Risk Scoring

Risk Factor	**Factor X (Weighting factor)**					
Risk Indicator	**Aaa**	**A**	**Baa**	**Ba**	**B**	**C**
Reporting Requirement 1	Risk mitigated/ understood at by some quantified level >A	Risk mitigated/ understood at by some quantified level >Baa	Risk mitigated/ understood at by some quantified level >Ba	Risk mitigated/ understood at by some quantified level >B	Risk mitigated/ understood at by some quantified level >C	Risk mitigated/ understood at by some quantified level or not understood
	AND	**AND**	**AND**	**AND**	**AND**	**AND**
Reporting Requirement 2	Risk mitigated/ understood at by some quantified level >A	Risk mitigated/ understood at by some quantified level >Baa	Risk mitigated/ understood at by some quantified level >Ba	Risk mitigated/ understood at by some quantified level >B	Risk mitigated/ understood at by some quantified level >C	Risk mitigated/ understood at by some quantified level or not understood
	AND	**AND**	**AND**	**AND**	**AND**	**AND**
Reporting Requirement n	“”	“”	“”	“”	“”	“”

Raw Score Conversion Table					
Aaa	A	Baa	Ba	B	C

Low Risk ← High Risk

U.S. Patent Application No. 63/229,315 "Biomass Supply Chain Risk Quantification Methodology"

Case Study

- Existing bio-projects
- Verification of BSCRS Framework ability to quantify risk in a standard, consistent manner
- Potentially reduce perceived risk of bio-projects

Raw Score Conversion Table					
Aaa	A	Baa	Ba	B	C

Low Risk ← High Risk

	Cat. Weight	Without BSCRS	With BSCRS
1.0 Supplier Risk	100	A	A
2.0 Competitor Risk	100	B	↓ Baa
3.0 Supply Chain Rsik	95	Baa	Baa
4.0 Feedstock Quality	100	Baa	↓ Aaa
5.0 Feedstock Scale-Up	25	A	↓ Aaa
6.0 Internal Organization	75	C	↓ Ba
Overall		**Ba**	↓ **Baa**

- **Results**
- **Decreased** project risk for Case Study **27%** (**Ba** to **Baa**)
- Primarily driven by increase in available and requested data between two scenarios used to develop scoring changes.

Financial Institution Feedback

"I think this is a great tool and would be beneficial for lenders and investors as they explore opportunities in the biomass industry. I wish we had access to this on our prior projects."

Key Takeaways

- The Biomass Supply Chain Risk Standards has been demonstrated to capture the risk associated with a project’s supply chain.
- We are continuing our efforts to improve our scoring methodologies.
- Expansion of feedstocks; including waste.
- Mapping out feasible pathway for industry adoption.

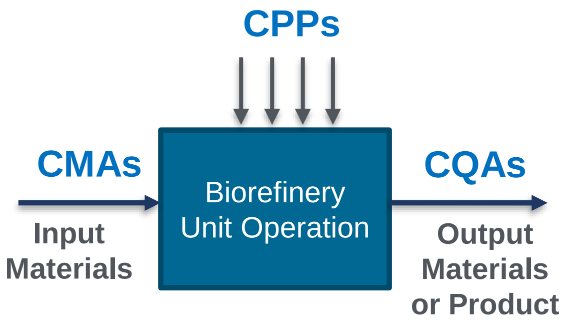
Risk: Variability in Biomass Properties

Variability in biomass feedstock properties translates to **risk** for bio-projects

- **Shutting down of existing biorefineries**
- **High capital costs for emerging bio-projects**

Understanding sources of variability
Quantifying ranges in variability → **Supply Chain and Market Risks** →
- Spatial and temporal variability in supply

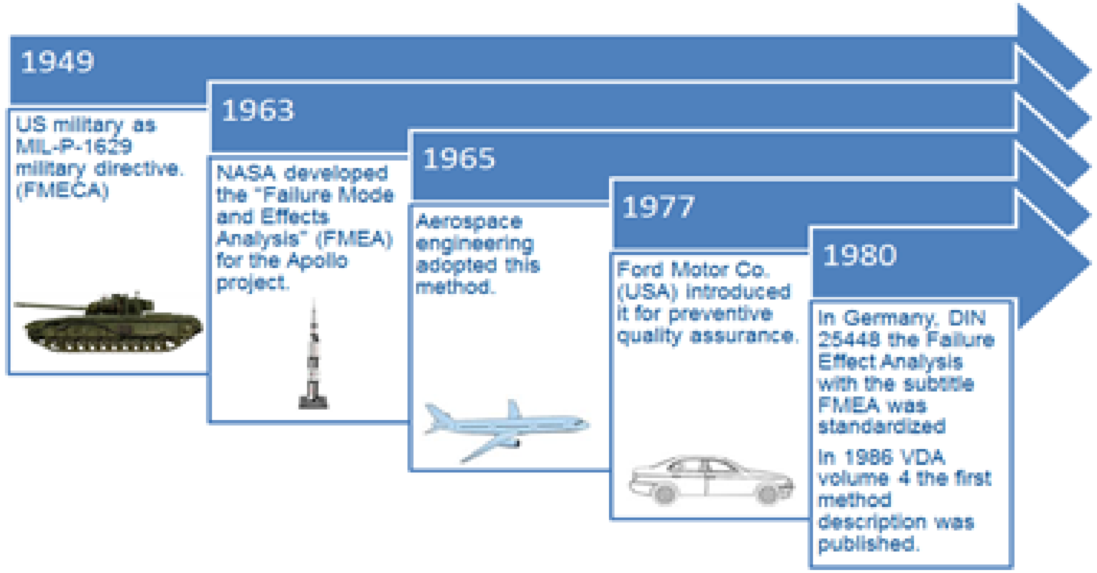
Identifying critical material attributes → **Technical Risk** →
- Equipment failure
- Inconsistent product quality



Example: Jet Fuel Production
CMA: lignin content, H_2 content
CPP: process design & operation
CQA: Aromatic content < 25%

Quality by Design Approach Can Be Analogous for Biorefinery Operations

Failure Mode and Effects Analysis



FMEA Overview

- Well-accepted risk assessment tool
- Systematic semi-quantitative analysis based on failure identification for a given operation in a process
- Ranking of **Severity** (S), **Occurrence** (O) and **Detection** (D) by Subject Matter Experts to calculate **Risk Priority Number** (RPN).

$$RPN = S \times O \times D = Risk \times D$$

- Failure defined as "not performing or producing as intended".

Benefits

- Combining qualitative and quantitative data
- Easily adaptable
- Couples well with Quality-by-Design approaches

Guidance Scale Development

- **Severity (S)**—how serious the impact of the failure mode
- **Occurrence (O)**—the likelihood or frequency of the given failure
- **Detection (D)**—how effective are the methods for detecting and/or preventing the failure.

$$RPN = S \times O \times D = Risk \times D$$

Severity Guidance Scale

Effect	Rank	Criteria
Minor	1	None to minor disruption to production line. A small portion (much <5%) of product may have to be reworked online.
Low	3	Low disruption to production line. A small portion (<15%) of product may have to be reworked online. Process up. Minor annoyance exist
Moderate	6	Moderate disruption to production line. A small portion (>20%) of product may have to be reworked online. Process up. Some inconvenience exist
High	8	High disruption to production line. A portion (>30%) of product may have to be scrapped. Process maybe stopped. Customer dissatisfied.
Very high	10	Major disruption to production line. Close to 100% of product may have to be scrapped. Process unreliable. Failure occurs without warning. Customer very dissatisfied. May endanger operator and/or equipment.

Guidance Scale Development Cont.

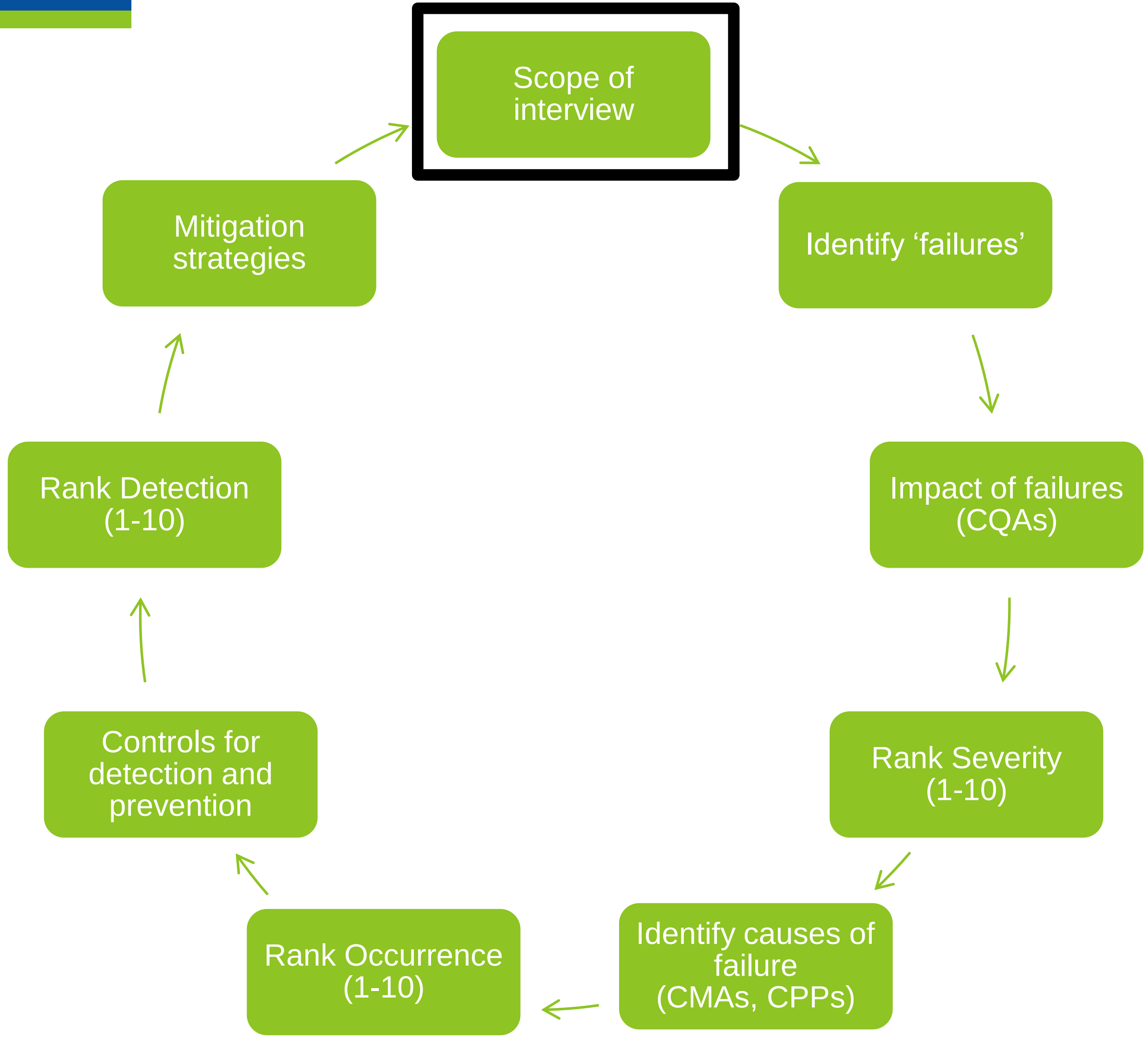
Occurrence Guidance Scale

Occurrence	Rank	Criteria
Remote	1	Failure is very unlikely. No failures associated with similar processes.
Low	3	Few failures. Isolated failures associated with similar processes.
Moderate	6	Occasional failures associated with similar processes.
High	8	Repeated failures. Similar processes have often failed
Very high	10	Process failure is almost inevitable.

Detection Guidance Scale

Detection	Rank	Criteria
Almost certain	1	Process control will almost certainly detect or prevent the potential cause of subsequent failure mode.
High	3	High chance the process control will detect or prevent the potential cause of subsequent failure mode.
Moderate	6	Moderate chance the process control will detect or prevent the potential cause of subsequent failure mode.
Remote	8	Remote chance the process control will detect or prevent the potential cause of subsequent failure mode.
Very uncertain	10	There is no process control. Control will not or cannot detect the potential cause of subsequent failure mode.

FMEA Interview Flowchart

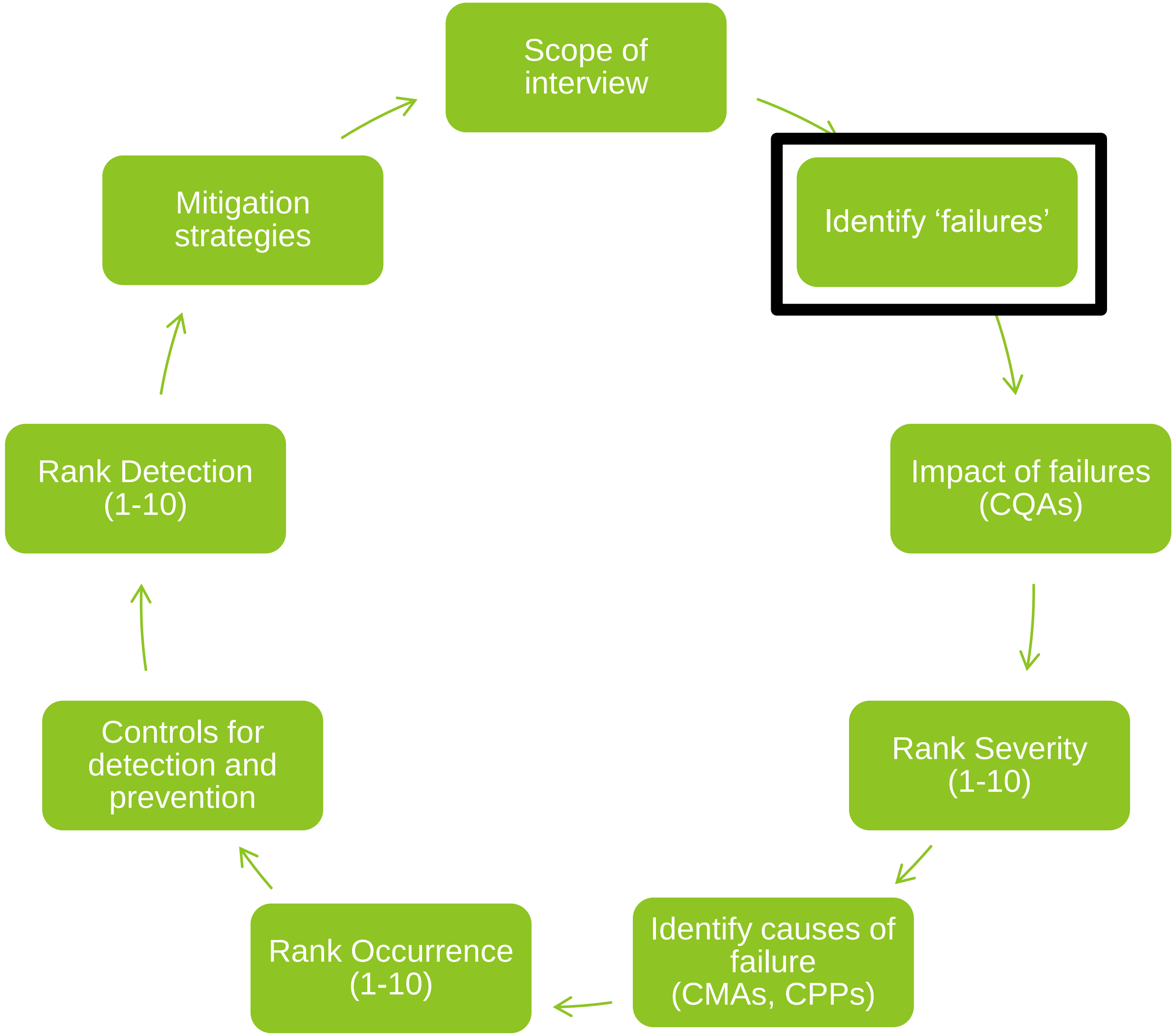


Scope of Interview:

- Specific equipment configuration
- Operational mode
- Feedstock focus
- Establish TRL

Preprocessing Interview Scope	
Unit Operation	Hammer mill
TRL	A (7-9)
System Configuration	*Upstream:* Bale grinder and conveyor; *Downstream:* screw conveyor (Biochemical Conversion)
Feedstock	Corn stover (square bales)
Input/Output Format	≥3 inch / ≥1 inch
Equipment Scale	5 tons/hr

FMEA Interview Flowchart



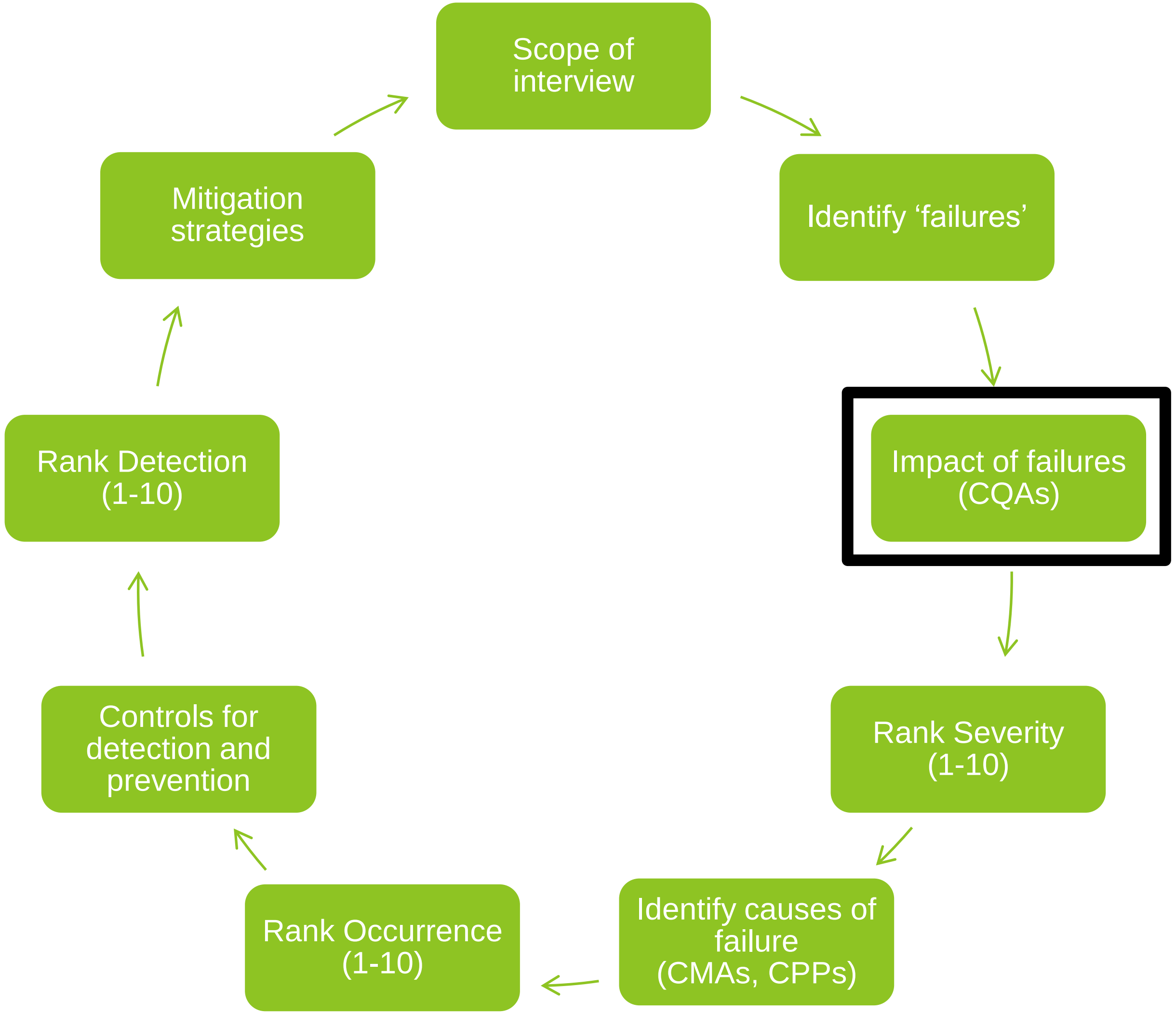
Identify 'Failures':

- Not performing or producing as intended
- Deviations from CQAs

Hammer Mill Primary Failures:

- **Plugging of the screen**
- Process slowdown
- Deviation from target particle size (excessive overs)
- Deviation from target particle size (excessive fines)

FMEA Interview Flowchart

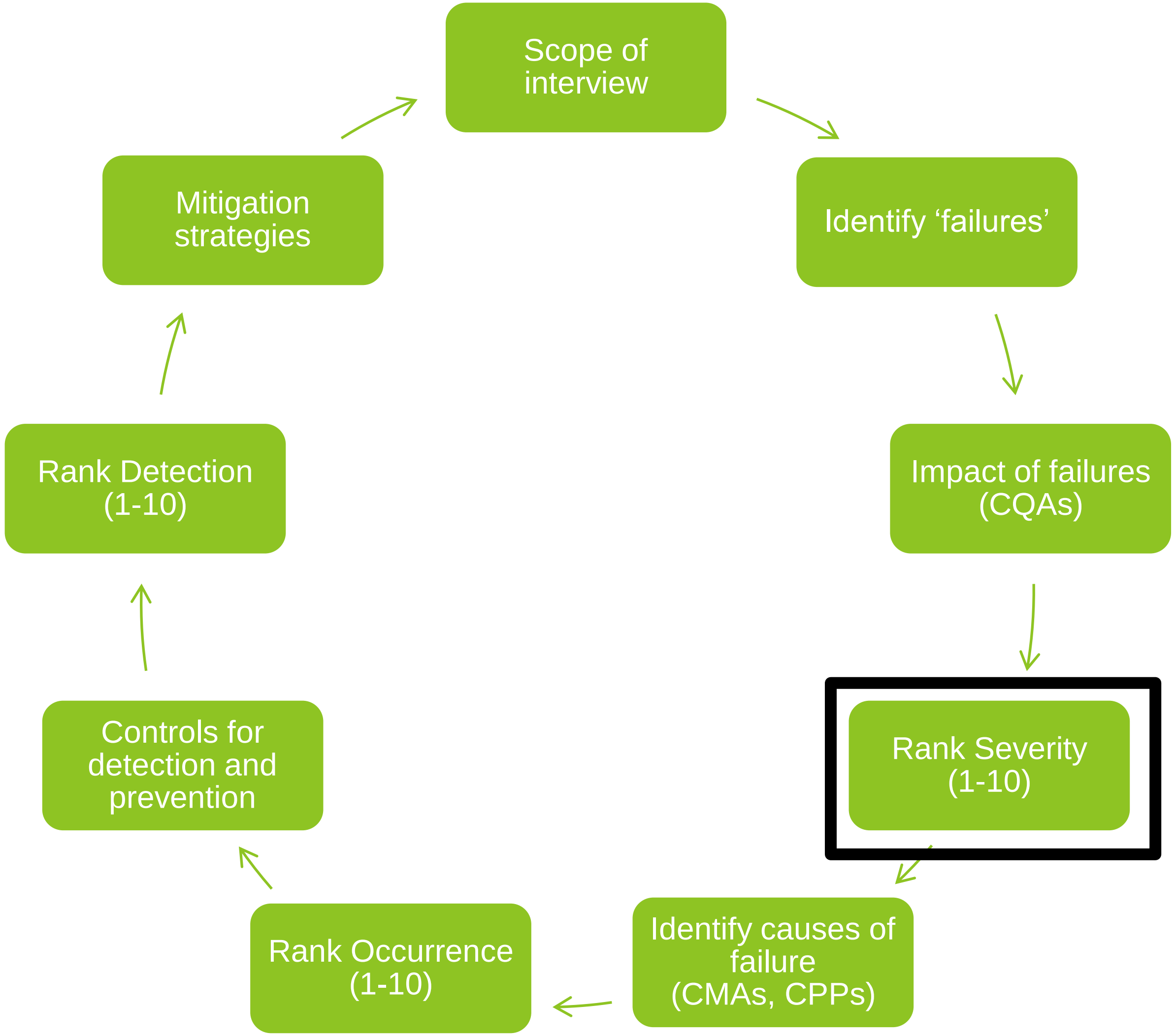


Impact of failures:

- What is the impact if this failure is not prevented or corrected?
- What are the direct or indirect CQAs associated with the failure
- How would the impacts and/or CQAs be categorized:
    - Process Efficiency (Proc)
    - Product Quality (Prod)
    - Economics (Eco)
    - Sustainability (LCA)

Failure		Impacts		CQA		Layer
Plugged screen	❯	Downtime	❯	Throughput	❯	Proc

FMEA Interview Flowchart



Rank Severity:

- Semi-quantitative translation guidance scales (TRL dependent)
- Considering the impacts

Effect	Rank	Criteria
Minor	1	None to minor disruption to production line. A small portion (much <5%) of product may have to be reworked online.
Low	3	Low disruption to production line. A small portion (<15%) of product may have to be reworked online. Process up. Minor annoyance exist
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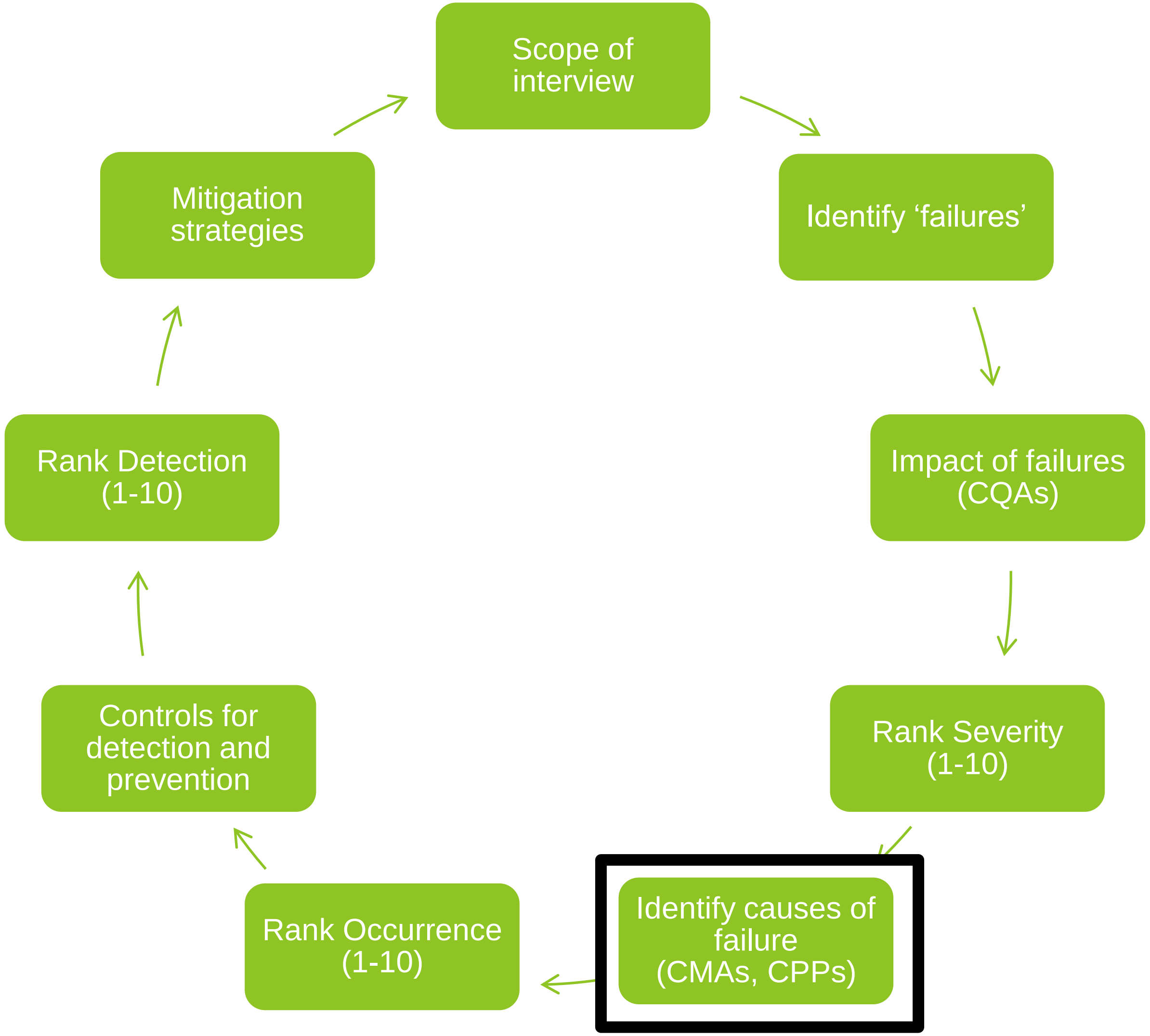
Plugged Screen

FMEA Interview Flowchart



Identify causes of failure:

- Why or how does failure occur
- Material properties (CMAs)
- Process parameters (CPPs)

Causes

- Material buildup and particle agglomeration

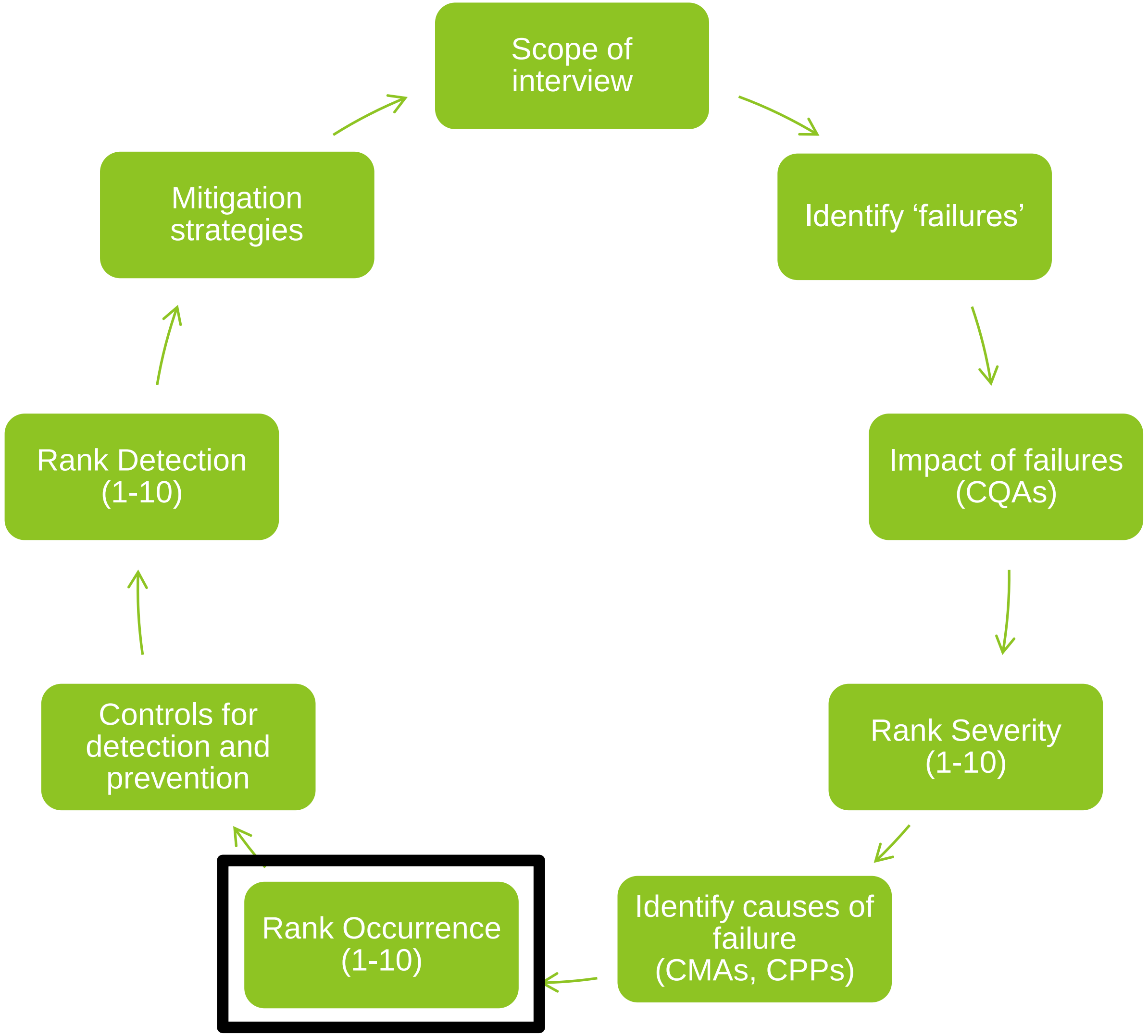
CMAs

- High moisture (40%)
- Excessive fines (self-heated)

CPPs

- Feedrate

FMEA Interview Flowchart



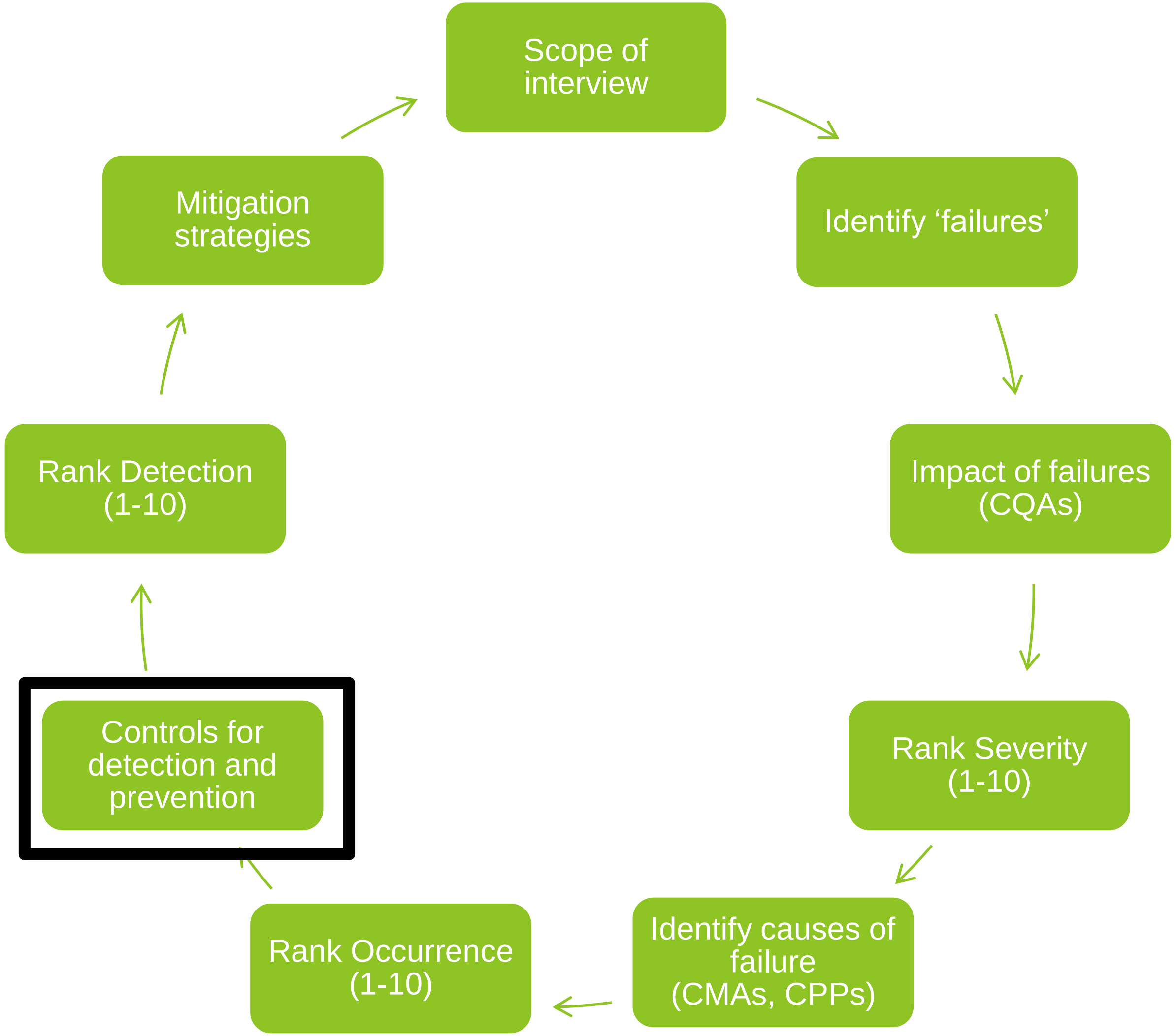
Rank Occurrence:

- Likelihood of the failure occurring
- Guidance scales

Occurrence	Rank	Criteria
Remote	1	Failure is very unlikely. No failures associated with similar processes.
Low	3	Few failures. Isolated failures associated with similar processes.
Moderate	6	Occasional failures associated with similar processes.
High	8	Repeated failures. Similar processes have often failed
Very high	10	Process failure is almost inevitable.

Plugged Screen

FMEA Interview Flowchart



Controls for detection and prevention:

- What controls exists to detect or prevent a failure before it occurs?

Sensors:

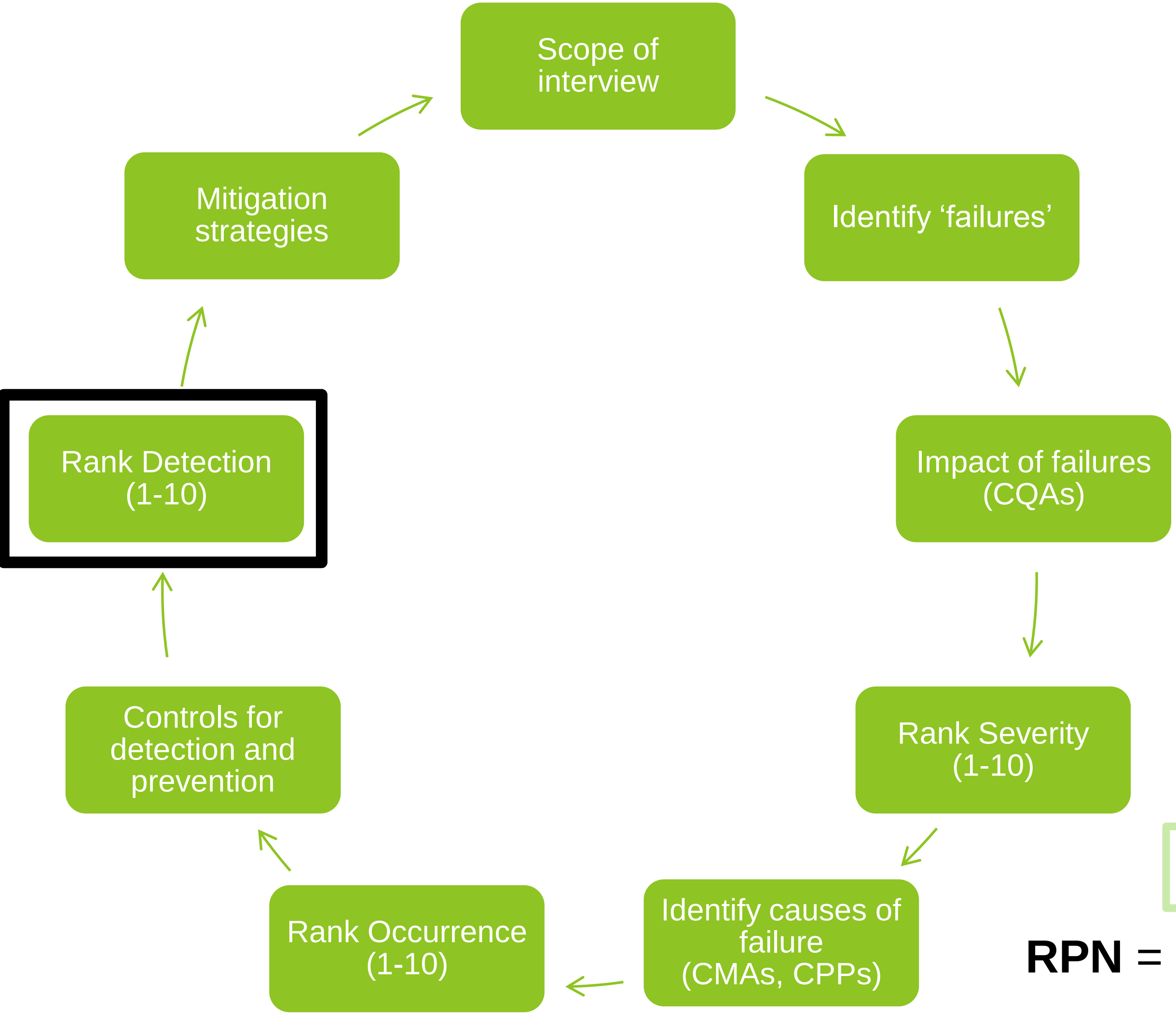
- Current/amperage readings
- Inline moisture sensor and probe based
- Visual observations

Controls:

- Feedrate

*Address high moisture driven situations

FMEA Interview Flowchart



Rank Detection:

- Likelihood of available controls to detect and/or prevent a given failure

Effect	Rank	Criteria
Almost certain	1	Process control will almost centainly detect or prevent the potential cause of subsequent failure mode.
High	3	High chance the process control will detect or prevent the potential cause of subsequent failure mode.
Moderate	6	Moderate chance the process control will detect or prevent the potential cause of subsequent failure mode.
Remote	8	Remote chance the process control will detect or prevent the potential cause of subsequent failure mode.
Very uncertain	10	There is no process control. Control will not or cannot detect the potential cause of subsequent failure mode.

High Moisture

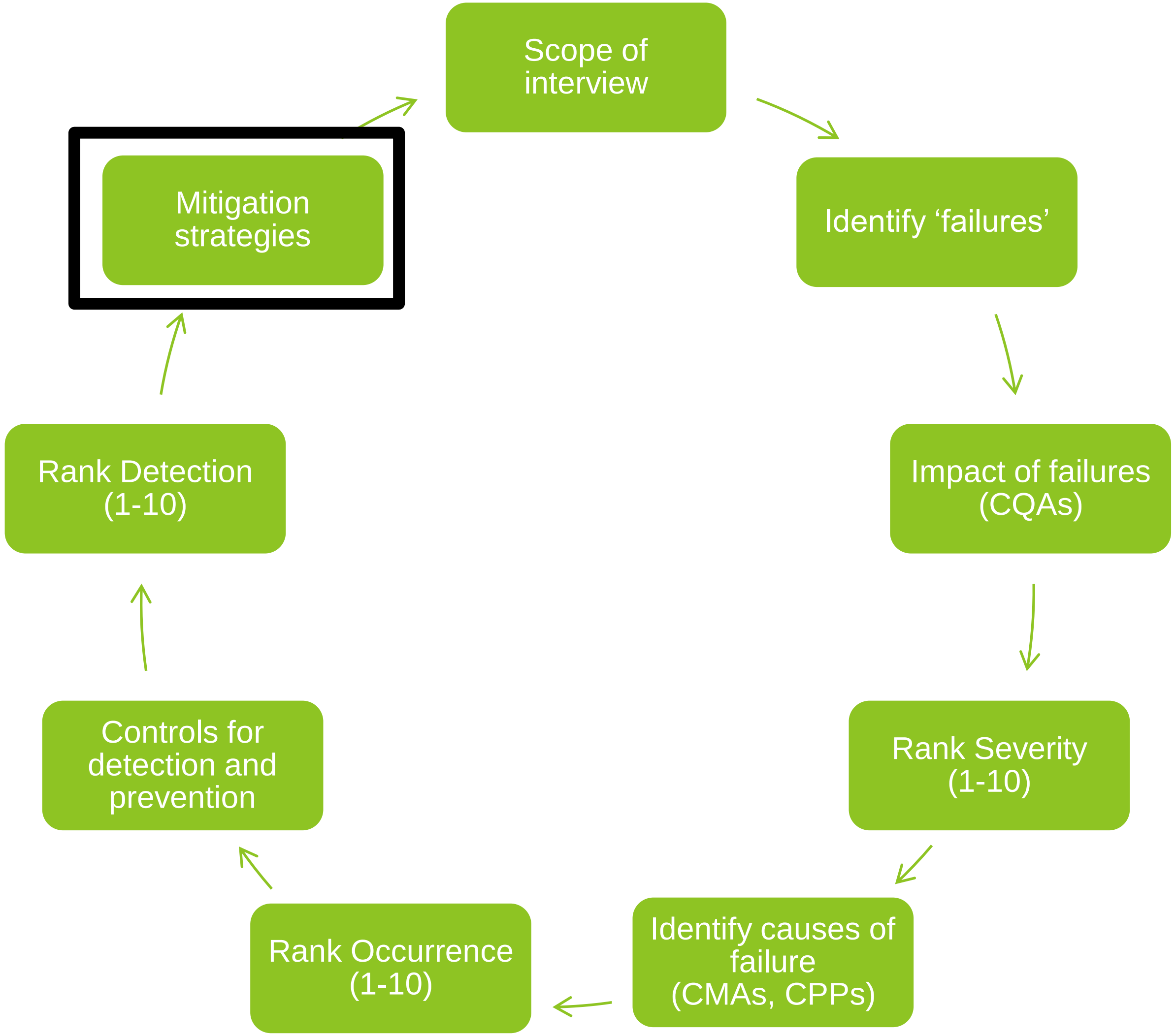
RPN = S(10) x O(6) x D**(1)** = **60**

Fines (self-heating)

RPN = S(10) x O(6) x D**(8)** = **480**

Plugged screen

FMEA Interview Flowchart



Mitigation Strategies:

- What actions can be taken with respect to severity, occurrence, and **detection**?
- New sensors (e.g., spectral), additional equipment (e.g., fractionation)
- Re-evaluate Severity, Occurrence, and Detection (if data available)
- Recalculate RPN

Theoretical Sensor Improvements:

- Machine learning to detect self-heating and soil contamination through image analysis
- Detection: 8 (remote) ⟩ 3 (high)
- RPN: 480 ⟩ 180

FMEA Simplified Example

Potential Failure Mode	Potential Failure Effects	CQA	SEVERITY	Potential Causes	CMA	CPP	OCCURRENCE	DETECTION	RPN
In what ways could the step, change or feature go wrong?	Impact on the customer if this failure is not prevented or corrected	CQAs impacted by this failure		What causes the step, change or feature to go wrong?	Identified CMA associated with failure and cause	CPP associated with failure			
Plugged Screen	Complete shutdown	Throughput	10	Screen plugging due to high moisture.	Moisture content (>40% Fresh and stored)	Feedrate Screen size	6	1	**60**
		Throughput	10	Screen plugging due to fines production.	Fines generated from self-heating (storage)	Feedrate Screen size	6	8	**480**
Process slowdown	>50% decrease in throughput	Throughput	10	Decrease in feedrate because of partial screen plugging	Moisture content >25% (Fresh and stored)	Feedrate	8	3	**240**
	50% decrease in throughput	Throughput	8	Moisture content 25-35% (Fresh or "Gooey" from storage)	Moisture content 25-35% (Fresh and stored)	Feedrate	8	3	**192**
	25% decrease in throughput	Throughput	6	Moisture content 15-25% (Fresh or "Gooey" from storage)	Moisture content 15-25% (Fresh and stored)	Feedrate	8	3	**144**
	Decrease in throughput	Throughput	1	Overs from 1st stage bale grinder.	Particle size (overs)	Feedrate	6	10	**60**
Overs production	Missed particle size specification	Particle size	8	Moisture >15% (Fresh and "Gooey" from storage)	Moisture >15% (Fresh and stored)		6	3	**144**
		Particle size	8	Early hammer wear	Inorganic species		6	8	**384**
Fines production	Missed particle size specification	Particle size	6	Self-heated material (storage)	Fines		6	8	**288**

Key Takeaways

- Standardized framework to represent and semi-quantitatively rank CMAs, CPPs, and CQAs in the context of a ‘Failure’ across multiple unit operations.

- Criticality evidence.

- Help in prioritization of experimental needs.

- Ability to quantify impacts of research driven improvements.

Summary

Biomass Supply Chain Risk Standards (BSCRS)

Systemized approach for quantifying supply chain risk

- **Bio-project financing**

Failure Mode and Effects Analysis (FMEA)

Industrial relevant risk management tool to systematically identify and assess the causes and effects of potential failures in a system

- **Technology risk**

Questions

Contact Information:

Rachel Emerson
rachel.emerson@inl.gov
208-526-1931