FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Resilience Assessment Framework for Sustainable Aviation Fuel Supply Chain

Project 001

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Motivation

Uncertain events and conditions

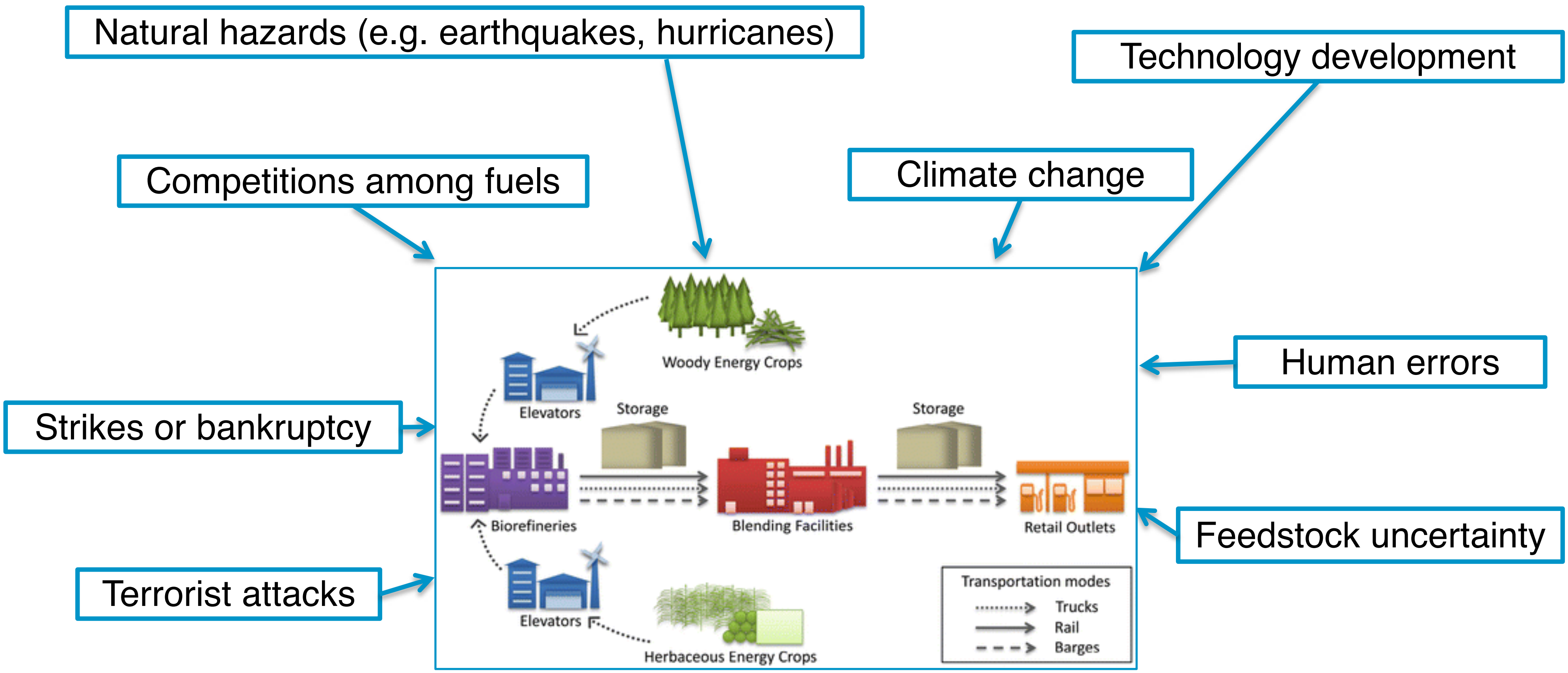


Figure adapted from Lim, M. K., & Ouyang, Y. (2016). Biofuel supply chain network design and operations. In *Environmentally Responsible Supply Chains* (pp. 143-162). Springer, Cham.

Motivation

Definition of Resilience

Broad definition: the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions

Supply chain resilience (Hosseini et al., 2019)

- Absorptive capacity of supply chain to absorb and resist the impact of perturbations
- Restorative capacity of supply chain to recover quickly and efficiently
- Adaptive capacity of supply chain to respond to uncertain conditions

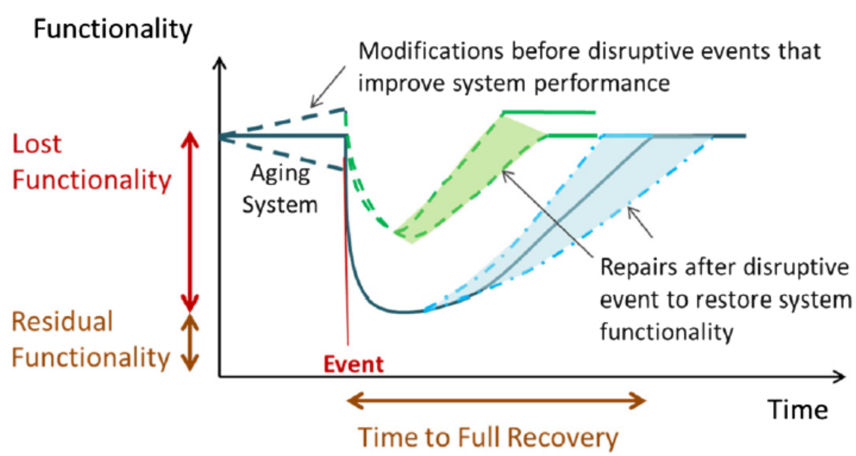


Figure adapted from Lounis, Z., & McAllister, T. P. (2016). Risk-based decision making for sustainable and resilient infrastructure systems. *Journal of Structural Engineering*, *142*(9), F4016005.
Hosseini et al., 2019, Review of quantitative methods for supply chain resilience analysis, Transportation research Part E 125: 285-307.

Goal and Objectives

Goal

- Develop a resilience assessment framework for SAF supply chain

Objectives

- Quantify the effect of multiple uncertain events/conditions on the performance of a supply chain
  - mitigate the negative impacts while capitalizing on opportunities
- Develop a new resilience index
  - that considers the long-term performance of a supply chain
  - that considers the quantitative effects of multiple uncertain events/conditions
  - that quantifies all dimensions of resilience

The Scope of the Work

Theoretical framework development

What has been done

Step 1. Identify possible uncertain events and conditions

Step 2. Assess their quantitative effects on the supply chain

Step 3. Compute the resilience index of the supply chain

Step 4. Apply the framework to the regional supply chain

Case study

What will been done

Step 1. Risk Identification

Uncertain events and conditions classified into eight categories

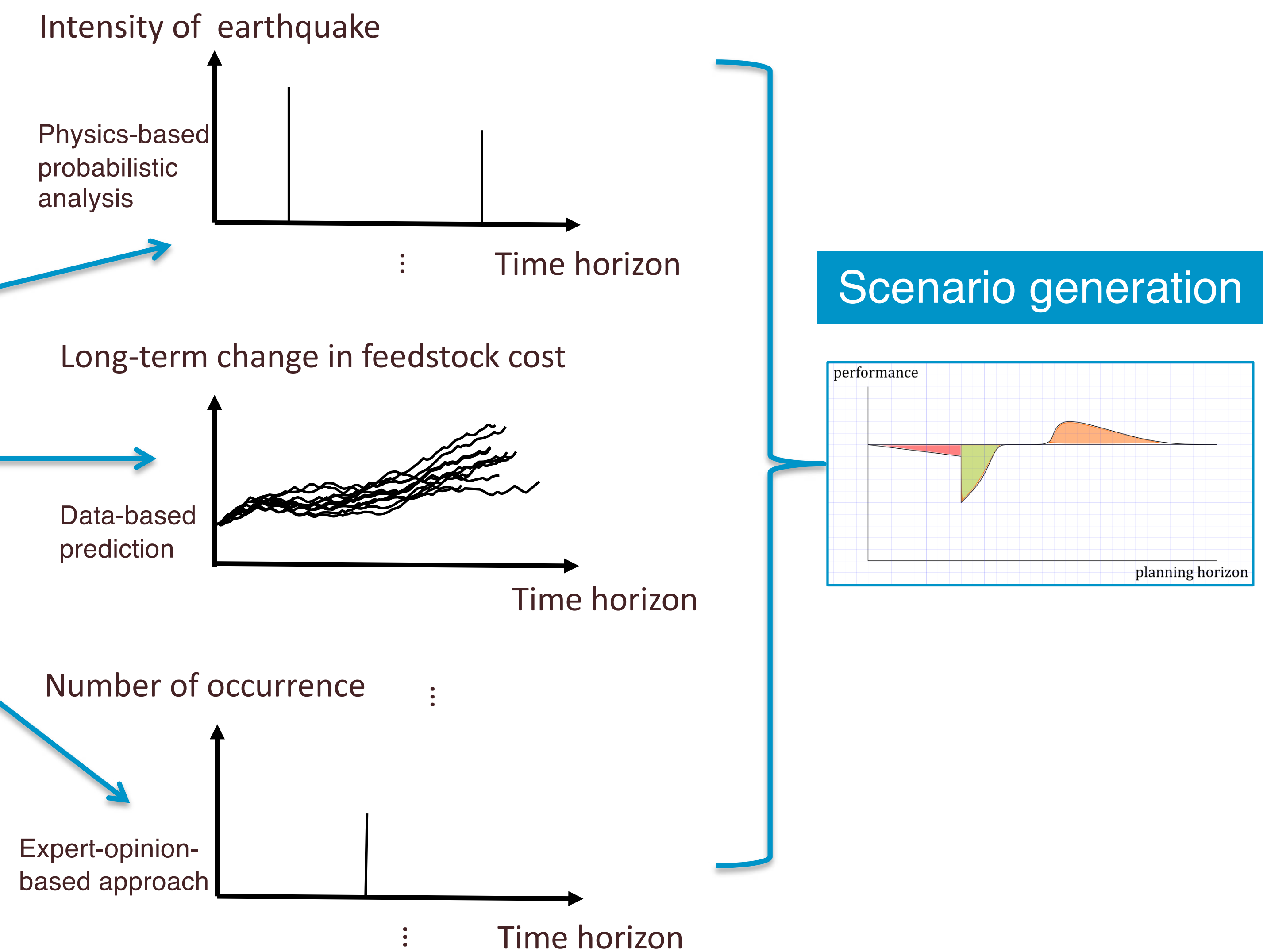
Category	Events/Conditions	Threat/Opportunity
Natural hazards	Earthquake	Threat
Natural hazards	Hurricane	Threat
Climate change	Dry climate	Threat
Climate change	Increasing intensity and frequency	Threat
Man-made hazards	Intelligent attacks	Threat
Market	Competition among fuels	Threat
Market	Customer preferences	Threat or Opportunity
Supply	Feedstock amount	Threat or Opportunity
Technology	Conversion rate	Opportunity
Finance	Backruptcy in one of the nodes	Threat
Human/Organizational behavior	Human errors	Threat
Human/Organizational behavior	Strike in one of the nodes	Threat

Step 2. Risk Assessment

Computational scenario-based performance assessment

Risk identification & categorization

- Natural hazards
- Climate change
- Man-made hazards
- Uncertainty in market
- Uncertainty in supply
- Technology development
- Uncertainty in finance
- Human/organizational behavior



Step 2. Risk Assessment

Supply chain performance measure: Unmet Demand Ratio (UDR)

- Unmet demand ratio in demand node d at time t during scenario n

: $U_{d,n}(t) = \dfrac{DM_{d,n}(t) - \sum_{r=1}^{R} x_{r,d,n}(t) \cdot FS_{r,d,n}(t)}{DM_{d,n}(t)}$

- Unmet demand ratio of the supply chain at time t during scenario n

: $UDR_n\,(t) = \dfrac{\sum_{d=1}^{D} U_{d,n}(t)}{D}$

where

$DM_{d,n}$: demand in demand node d during scenario n

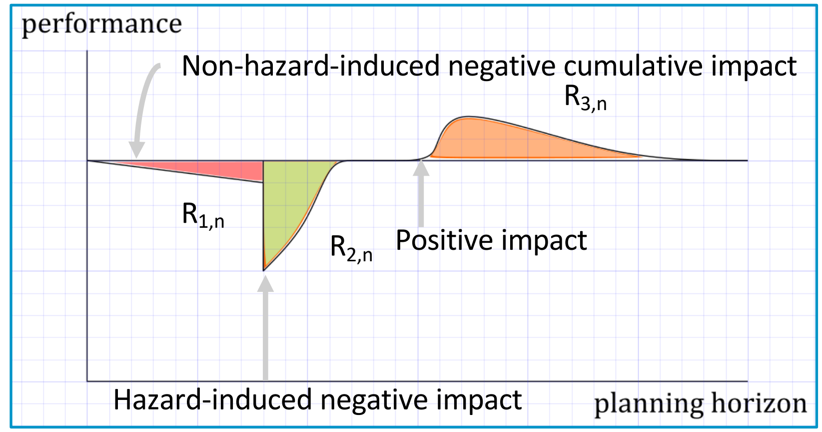
R: a set of refinery nodes

$x_{r,d,n}$: flow of SAF on arc (r,d) during scenario n

$FS_{r,d,n}$: normalized capacity of arc (r,d) during scenario n

D: number of demand nodes

Step 3. Resilience Index Calculation



Three dimensions of resilience index

- **Non-hazard-event resilience: robustness**

  : $R_{1,n} = \int_{t_c} UDR_n(t_c)dt_c$

  where t_c = the periods during which +UDR is induced by cumulative negative impact caused by non-hazard events/conditions

- **Hazard-event resilience: rapidity and resourcefulness**

  : $R_{2,n} = \int_{t_{h,i}} UDR_n\left(t_{h,i}\right)dt_{h,i}$

  where $t_{h,i}$ = the periods during which +UDR is induced by the i^{th} hazard

  i = the number of hazard events over T during scenario n

- **Redundancy**

  : $R_{3,n} = \int_{t_{p,j}} UDR_n\left(t_{p,j}\right)dt_{p,j}$

  where $t_{p,j}$ = the periods during which -UDR is induced by the j^{th} event

  j = the number of positive events over T during scenario n

Step 3. Resilience Index Calculation

Resilience index

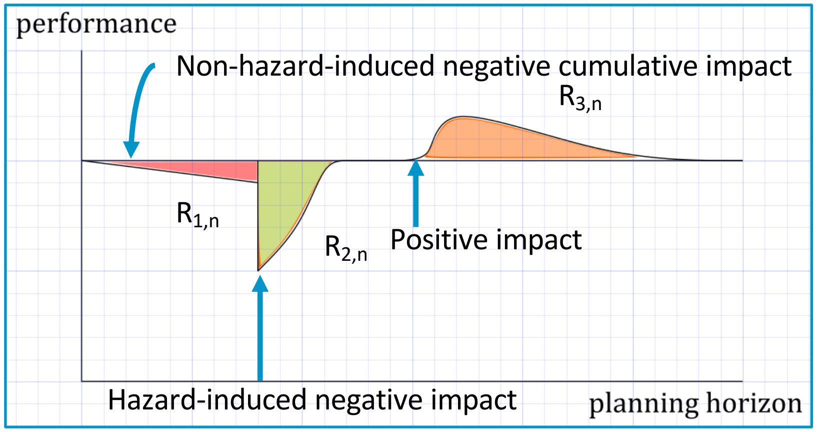
: combines three dimensions of resilience

$$R = -w_1 R_1 - w_2 R_2 + w_3 R_3$$

where $R_1 = E_n[R_{1,n}]$, $R_2 = E_n[\sum_i R_{2,n}]$, $and\ R_3 = E_n[\sum_j R_{3,n}]$

Combine all the scenarios

Scenario i



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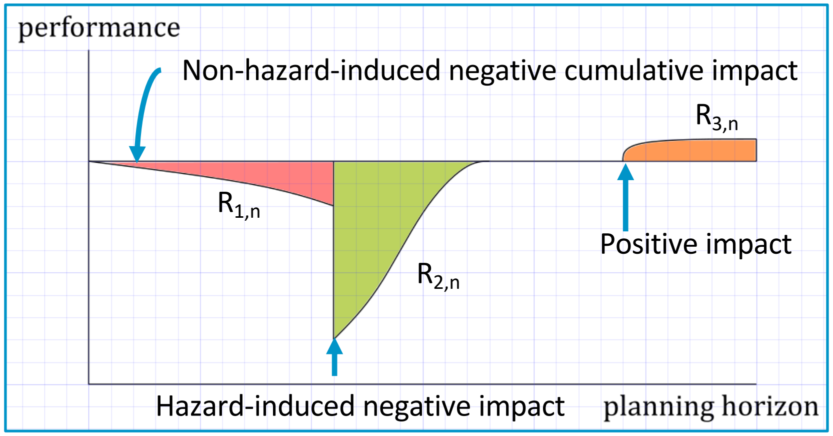
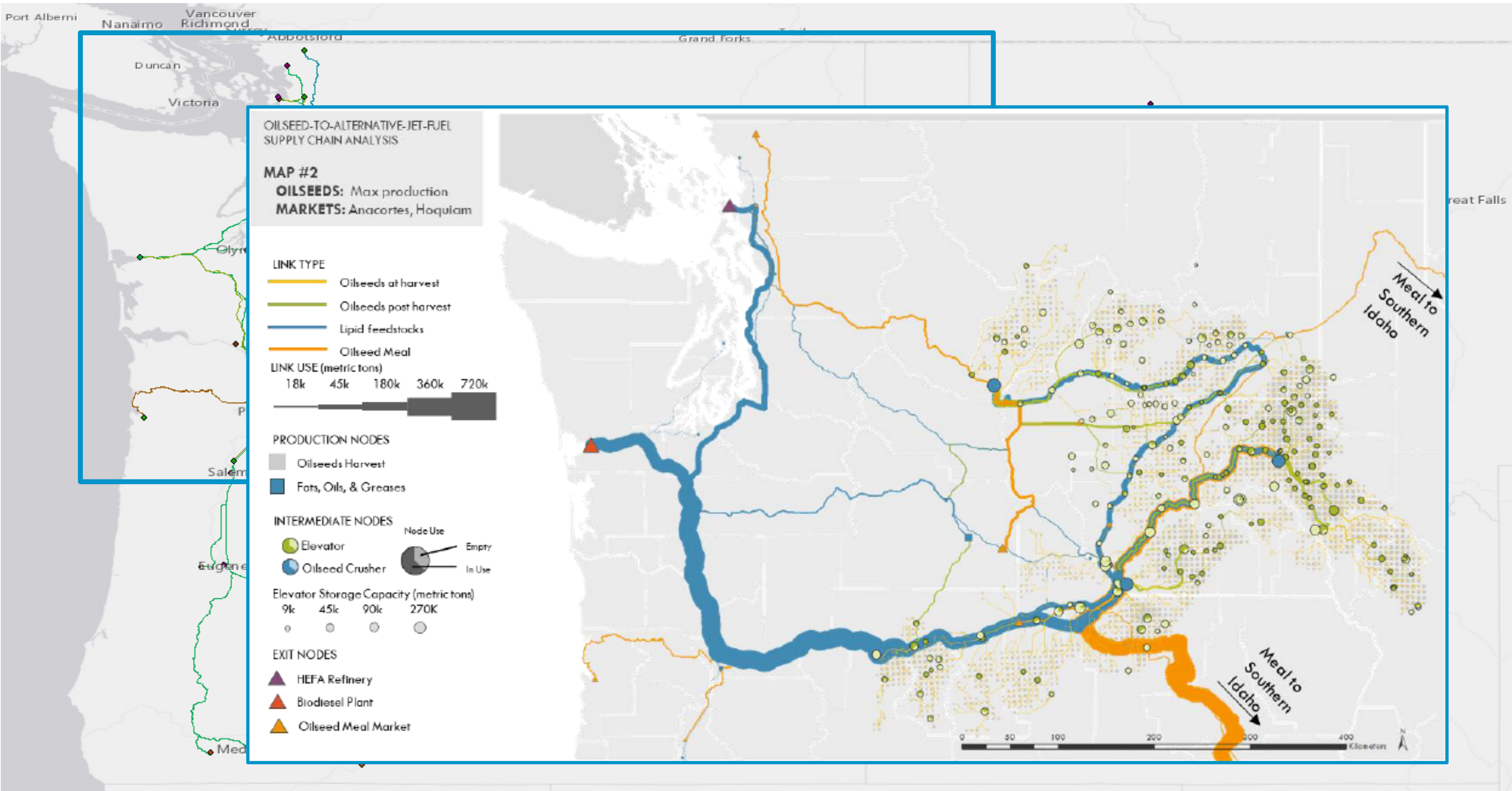
Scenario n



Step 4. Case Study

Oilseed-to-alternative-jet-fuel supply chain



CAMENZIND, D. A. (2018). *Supply Chain Analysis for Sustainable Alternative Jet Fuel Production from Lipid Feedstocks in the US Pacific Northwest* (Doctoral dissertation, Washington State University).

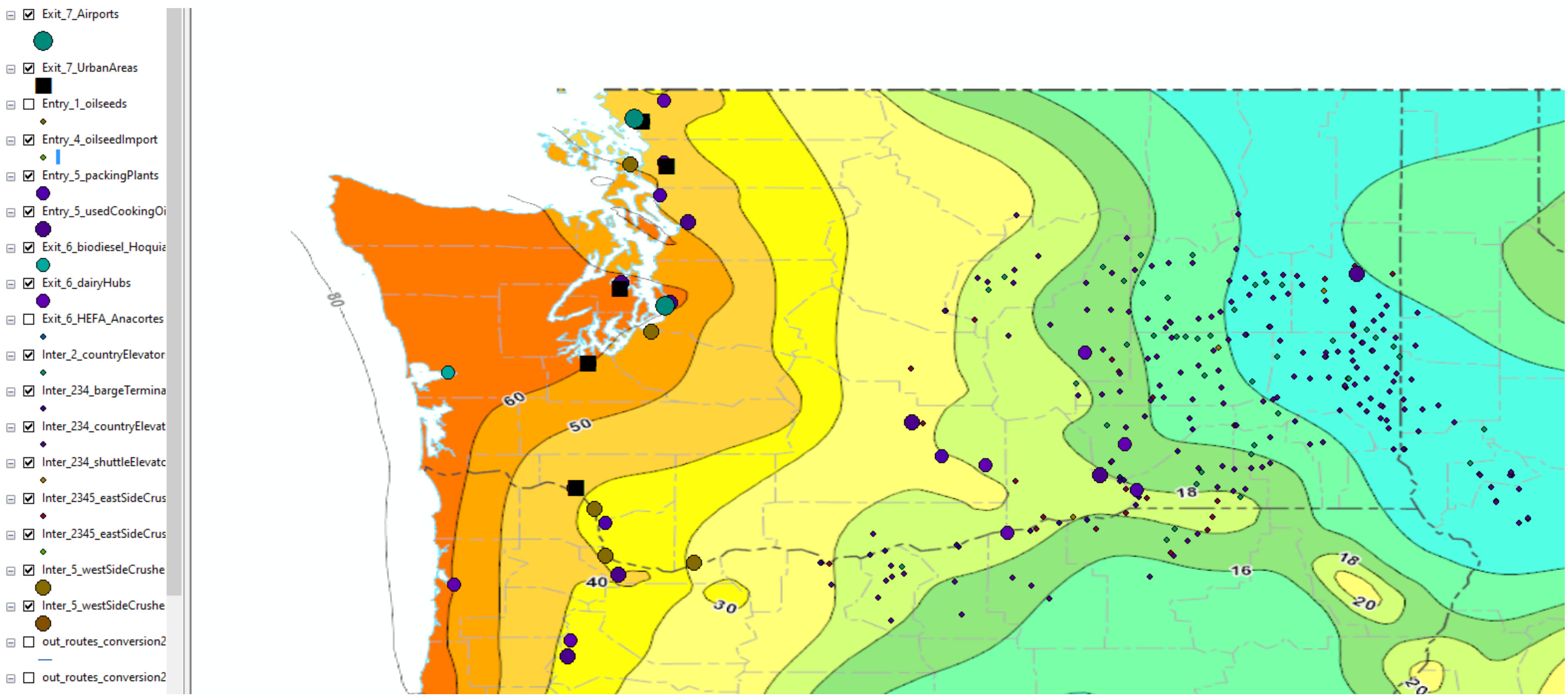
Step 4. Case Study

Risk identification

Category	Risk	Threat/Opportunity	Assessment
Natural hazard	Earthquake	Threat	SPHA
Climate change	Dry climate	Threat	Scenario-based analysis
Technology development	Conversion rate	Opportunity	Retrospective analysis
Man-made hazard	Intelligent attack	Threat	Expert opinion

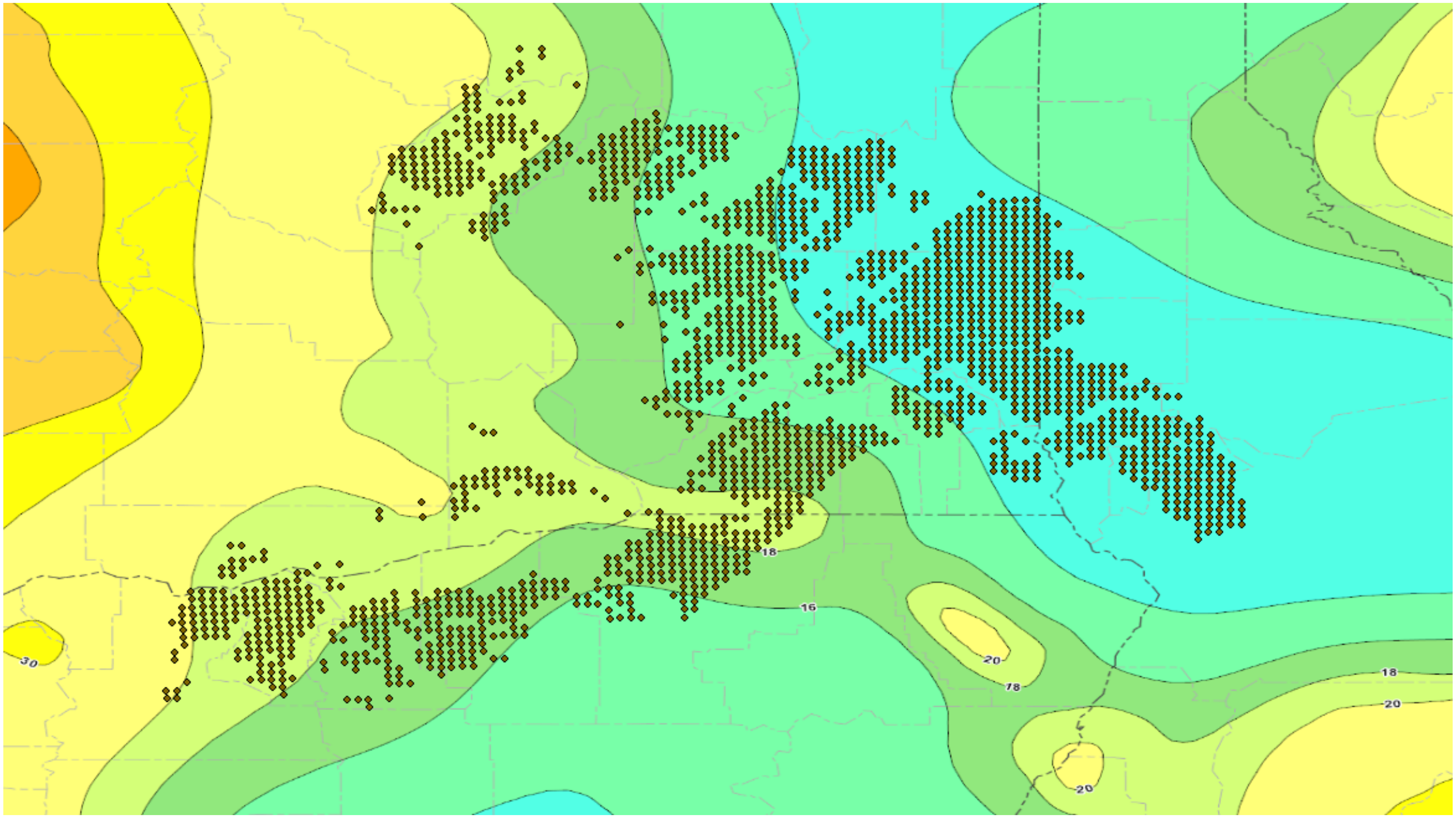
Step 4. Case Study

Seismic hazard map: all the nodes except feedstock production nodes



Step 4. Case Study

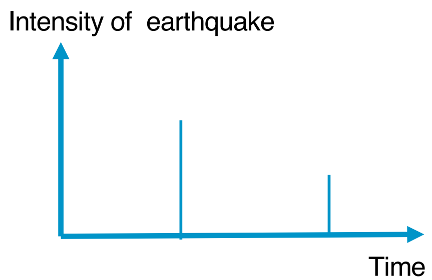
Seismic hazard map: oilseed production nodes



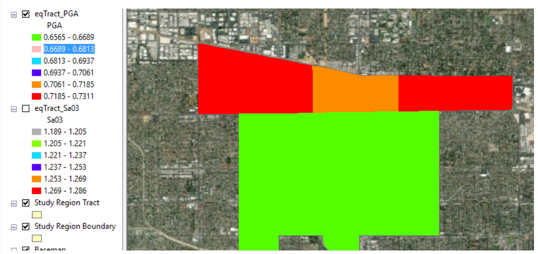
Step 4. Case Study

Probabilistic seismic hazard analysis and damage state estimation

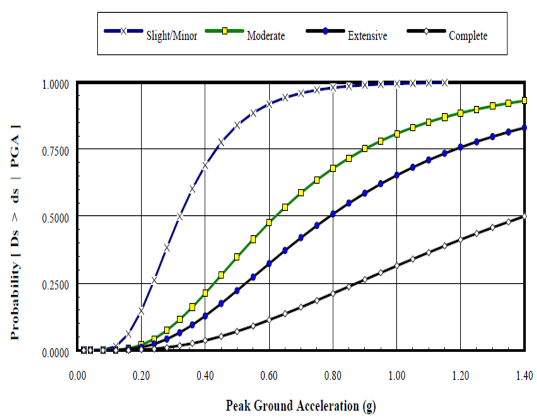
Earthquake occurrence



Ground motion at each site using PSHA



Fragility curve for each node and link: $P(DS_i|PGA)$



Damage state for each node and link using MCS

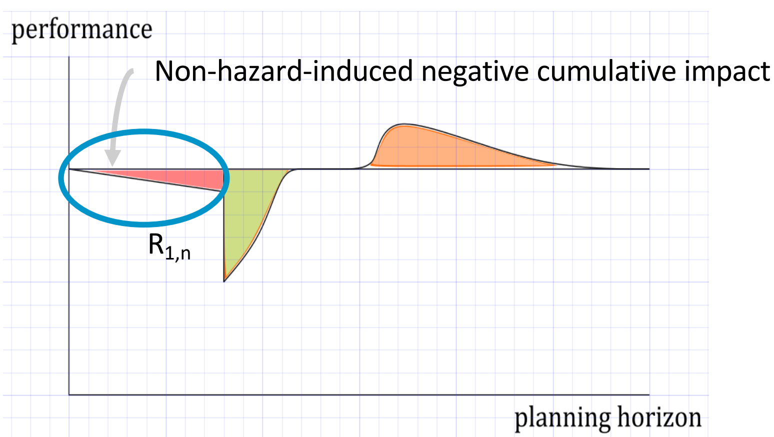
Capacity reduction at each node and link using MCS

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Buried Pipes	leak	0.10	0.05 to 0.20
	break	0.75	0.5 to 1.0
Refineries	slight	0.09	0.01 to 0.15
	moderate	0.23	0.15 to 0.4
	extensive	0.78	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Pumping Plants	slight	0.08	0.01 to 0.15
	moderate	0.4	0.15 to 0.4
	extensive	0.8	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Tank Farms	slight	0.13	0.01 to 0.15
	moderate	0.4	0.15 to 0.4
	extensive	0.8	0.4 to 0.8
	complete	1.00	0.8 to 1.0

Step 4. Case Study

Dry climate scenarios induced by climate change

: long-term change in feedstock amount due to dry climate



Dry climate scenarios (IPCC 2013)

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Annual precipitation projection for each scenario

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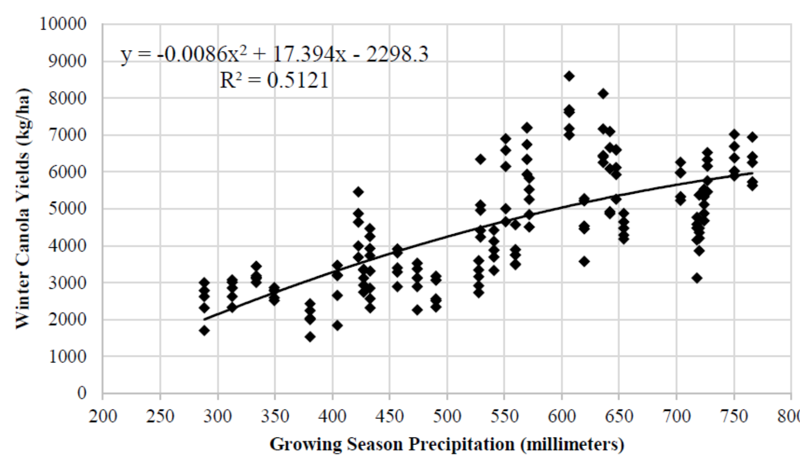
Long-term change in feedstock amount for each scenario

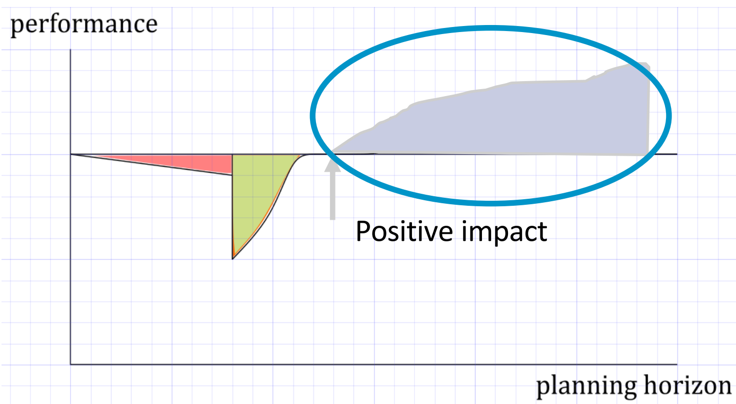


(This is for oilseed amount)

Step 4. Case Study

Technology development

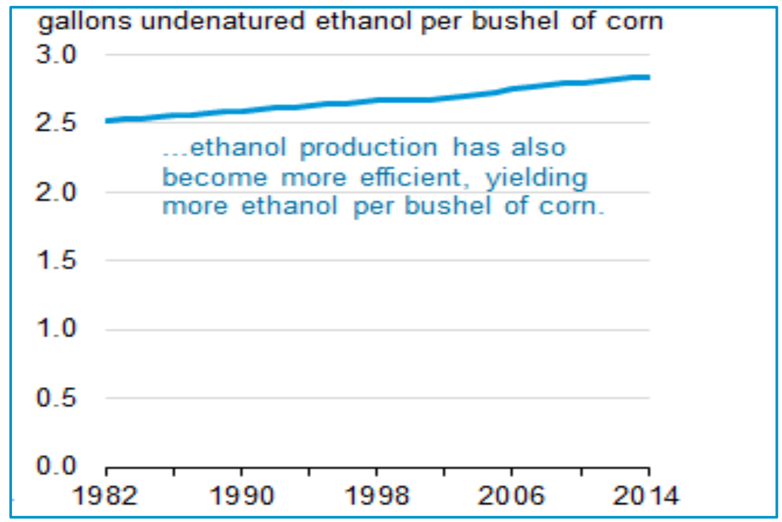
: long-term change in conversion rate in HEFA



2 scenarios

No technology development

Increase in conversion rate



0.375%/year increasing rate for the conversion rate in HEFA, with maximum theoretical yield to be 89.9% (Pearlson, 2011)

Pearlson M N. A techno-economic and environmental assessment of hydroprocessed renewable distillate fuels[D]. Massachusetts Institute of Technology, 2011.

Summary

- Summary of accomplishments during the past year (October 2018 – October 2019)
  - Develop a resilience assessment framework for SAF supply chain
    - Quantify the effect of multiple uncertain events/conditions on the performance of a supply chain → help identify appropriate risk mitigation measure
    - Develop a new resilience index → used in risk-informed decision-making for resilient supply chain

- Next steps
  - Apply the framework to the oilseed-to-alternative-jet-fuel supply chain in Washington State
    - Assess the combined effects of earthquake, dry climate, intelligent attack and technology development on the long-term performance of the supply chain
    - Assess the expected resilience index of the supply chain

THANK YOU