## Simulating Energy Resilience in District Energy Systems

Energy Master Planning for Resilient Public Communities Virtual Training

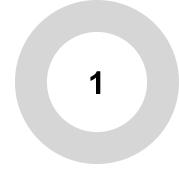
Michael O'Keefe

*Big Ladder Software* October 14, 2020



### Agenda

- Energy Resilience Calculation
  - Concepts
  - Simulator
  - Load Profiles, Data as a Great Decoupling Mechanism
- MS Excel User Interface
- Using IEA Annex 73 Resources in Concert
- Summary



# Overview of Energy Resilience Calculation

### Concepts

- Resilience, Design Basis Threat, and Resilience Metrics
- Components and Networks
- Scenarios: Blue-Sky and Threats
  - Duration
  - Load Profiles
  - Probability of Occurrence
  - Damage Intensities and Fragility Curves
  - Reliability: Failure and Repair Distributions

### **Resilience and Design Basis Threats**

- Resilience: ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions.
- Resilience is contextual defined in relation to a threat
  - Example, system resilient to hurricanes may not be resilient to earthquakes
- Threats to plan against are called Design Basis Threats (DBTs)
  - Natural disasters, accidents, and man-made threats
  - Planners must select the threats that are most applicable
  - Important to include low frequency / potentially high consequence threats

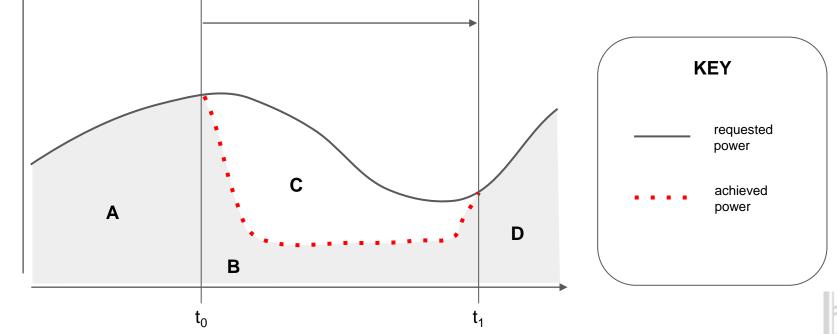
Watson, J.P., R. Guttromson, C. Silva-Monroy, R. Jeffers, K. Jones, J. Ellison, C. Rath, J. Gearhart, D. Jones, T. Corbet, C. Hanley, and L. Walker. 2014. Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States. Sandia National Laboratories Report. SAND

Jeffers, B., Wachtel, A., Zhivov, A., Thompson, C., Srivastava, A., and Daniels, P. 2020. Integration of Resilience Goals into Energy Master Planning Framework for Communities. ASHRAE 2020 Winter Conference. Transactions 2020. Vol 126, pt1.

### **Resilience Metrics**

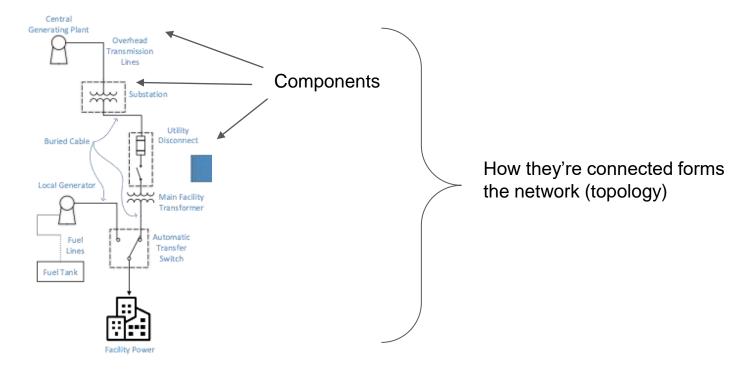
(calculated **by load**)

Energy Availability (%) =  $[(A+B+D) \times 100\%] / (A+B+C+D)$ Max Downtime (hours) =  $t_1 - t_0$ Load Not Served (kWh) = C



Power (kW)

#### **Components and Network**



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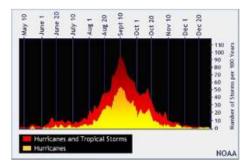
#### **Example Scenario: Category 3 Hurricane**

#### Intensities:



inundation (flooding): X feet (from GIS flood plane analysis)

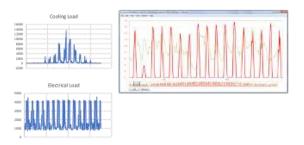
#### Probability of Occurrence:





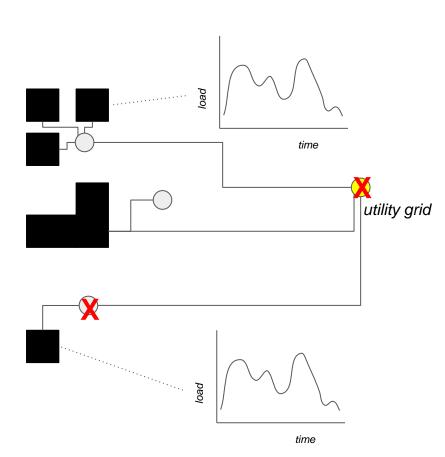
wind speed: 125 mph (from category 3 classification)

#### Weather and Loads:



#### A scenario has a:

- duration
- load profiles
- probability of occurrence
- maximum occurrences
- damage intensities
- a network to simulate
- whether to calculate reliability

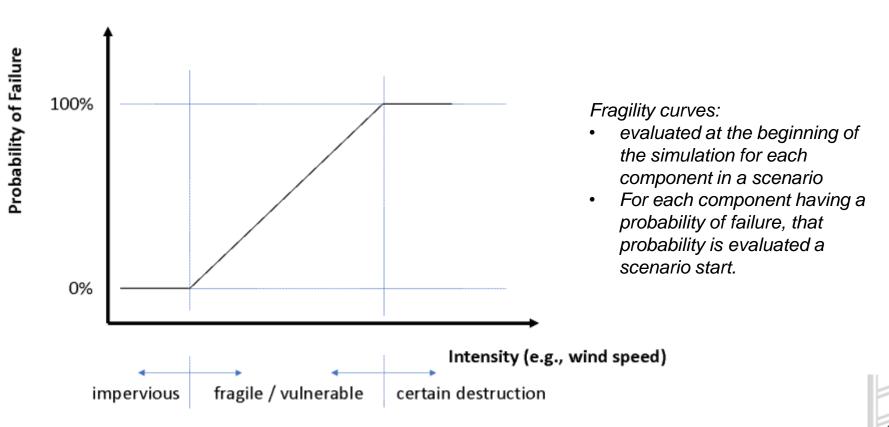


### Components and Networks are Simulated over Scenarios that May Involve Failure

### Two Types of Failures Considered

- Design Basis Threat based failures:
  - failure due to extreme event
  - $\circ$  "fragility"  $\rightarrow$  "Fragility Curve"
  - Component is "failed" for the entire scenario
  - Assessment made at scenario start
- Reliability:
  - failure due to routine wear and tear
  - o "reliability"→ "Failure Mode"
  - Component is "failed" until repaired
  - Assessment is made throughout simulated time
  - Reliability statistics are probably not accurate for extreme event stresses

#### Fragility Curve in Concept: Maps Failure Probability to Various Damage Intensities From the Scenario...



### Reliability: Statistical Models of Failure Modes

Failure Mode	Failure Distribution	Repair Distribution					
Starter battery dies	NormalDistribution( mean=1000 hours, stdev=100 hours)	FixedDistribution(4hours)					

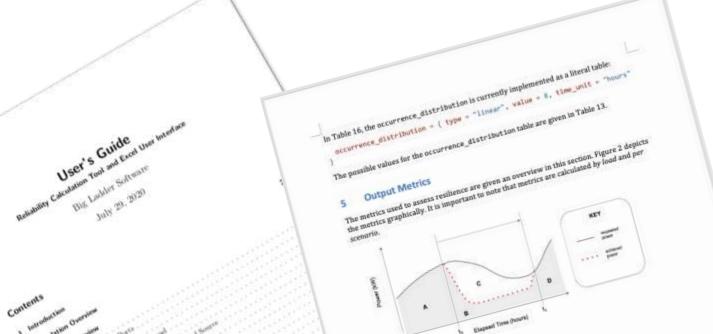
Reliability is only calculated if requested during a scenario and if at least one component has failure mode data.

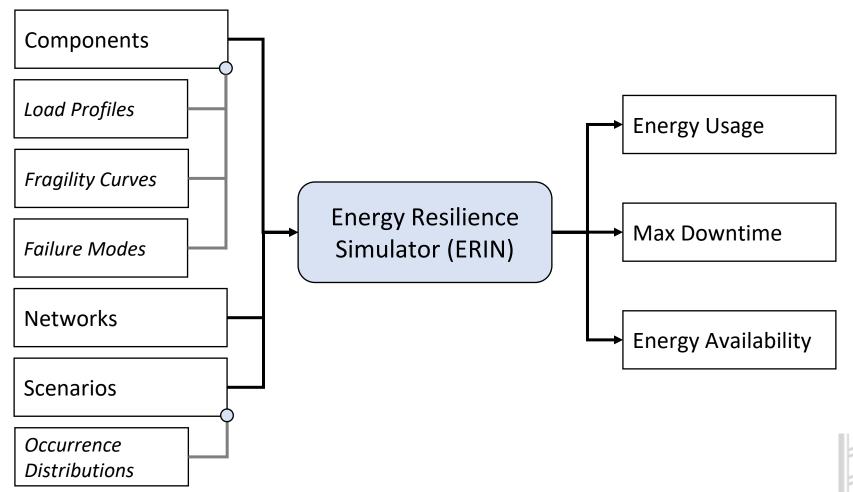
### Simulation Engine Inputs and Outputs

- Introduction to the Simulation Engine
  - ERIN: Energy Resilience of Interacting Networks
  - Command Line program written in C++
  - To be free and open-source when released
  - Takes a text input file written in TOML format
  - Writes out two output files in CSV format (readable by MS Excel)
  - The simulation is a "discrete event simulator"
    - Change in the simulator happens at discrete events
      - e.g., the occurrence of a scenario
      - e.g., the change of a load's requested power
      - e.g., failure of a component due to reliability
    - Energy usage and resilience statistics are calculated for output
- Powerflow Model that accounts for failures and keeps statistics
- Simulates unlikely threats repeatedly to get a statistical feel for resilience

### User Guide For the Simulation Engine

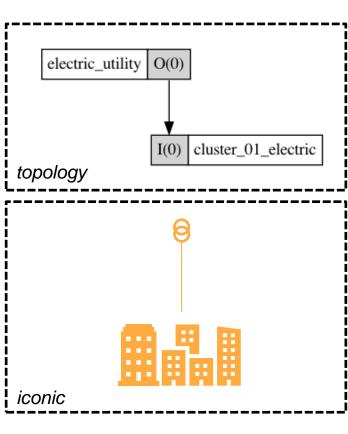
- A User's Guide comes with the simulation to assist in using the tool
- Continuing to update as needed as questions and comments arise





#### **The Input File**

A Picture is Worth a 1,000 Words... or 36 lines...



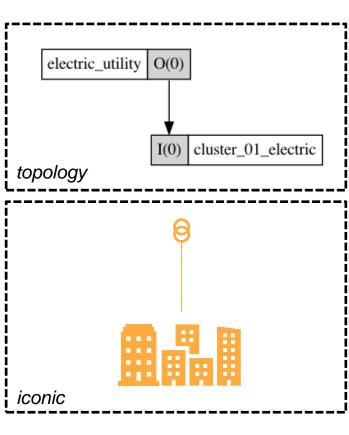
[simulation info] rate unit = "kW" quantity\_unit = "kJ" OML time\_unit = "hours" Stainal Lenguage max time = 4 [loads.building electrical] time unit = "hours" rate\_unit = "kW" time\_rate\_pairs = [[0.0, 1.0], [4.0]][components.electric\_utility] type = "source" # Point of Common Coupling for Electric Utility output\_stream = "electricity" [components.cluster\_01\_electric] type = "load" input\_stream = "electricity" loads\_by\_scenario.blue\_sky = "building\_electrical" [networks.normal\_operations] # Specify network as an array of 3-tuples. # The interpretation is as follows: # 3-tuples: [COMPONENT\_AND\_PORT, COMPONENT\_AND\_PORT, STREAM\_ID] # COMPONENT AND PORT := COMPONENT ID ":" ("IN" | "OUT") "(" \d+ ")"; # COMPONENT\_ID := STRING\_IDENTIFIER ; # STREAM\_ID := STRING\_IDENTIFIER ; # STRING IDENTIFIER := [a-zA-Z ] [a-zA-Z 0-9]\*; connections = [["electric\_utility:OUT(0)", "cluster\_01\_electric:IN(0)", "electricity"]] [scenarios.blue\_sky] time\_unit = "hours" occurrence\_distribution = {type = "fixed", value = 0} duration = 4 $max_occurrences = 1$ 

network = "normal\_operations"

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#### **The Input File**

A Picture is Worth a 1,000 Words... or 36 lines...



[loads.building\_electrical] time\_rate\_pairs = [[0.0,1.0],[4.0]] [components.electric\_utility] [components.cluster\_01\_electric] loads\_by\_scenario.blue\_sky = "building\_electrical" [networks.normal\_operations] [scenarios.blue\_sky] duration = 4

simulation

information

load profiles (loads)

components

networks

scenarios

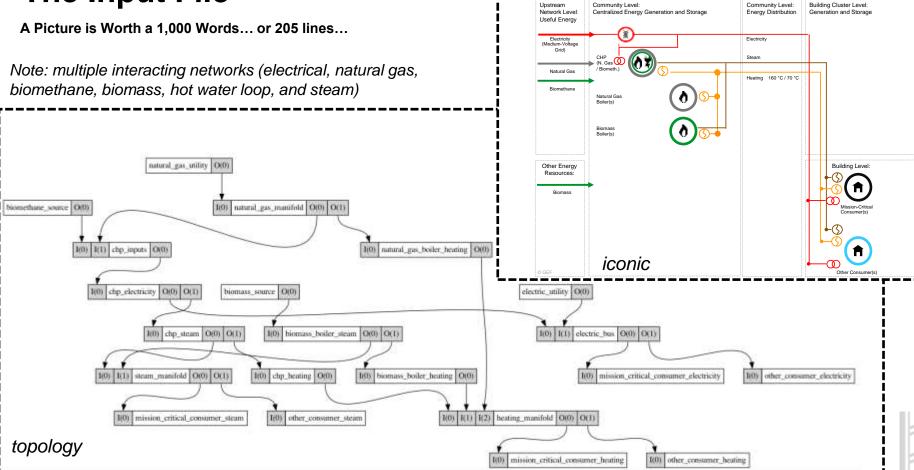
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#### **The Input File**

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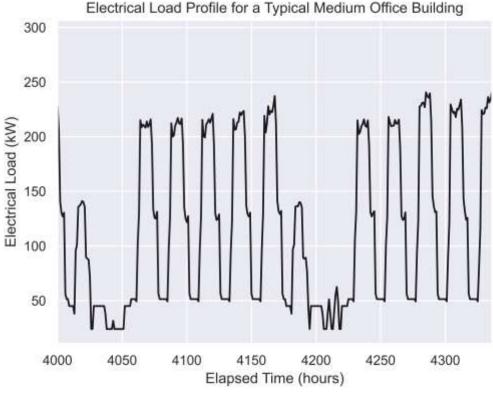
Note: multiple interacting networks (electrical, natural gas, biomethane, biomass, hot water loop, and steam)

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#### Load Profiles

- Specify the load versus time for a given building (or other load asset)
  - Any flow of energy: electrical, district hot water, heating lines, cooling load, steam, etc.
- Data is a great decoupling mechanism!
  - Loads can be generated by any building energy simulation tool
  - Or provided as measured data (if available)
- Load profiles can represent a single building or cluster of building
  - the choice is up to the modeler / analyst



data source: https://reopt.nrel.gov/tool

#### Sources of Simulated Load Profiles:

- U.S. DoE Commercial Reference Buildings
- University of Applied Sciences, Stuttgart (Germany), SimStadt
- U.S. Army Corps of Engineers, SMPL (EnergyPlus)
- EMD International A/S, energyPRO, <u>https://www.emd.dk/energypro/</u>
- CSIRO, (Australia) house energy rating tool AccuRate
- REOpt Lite Website

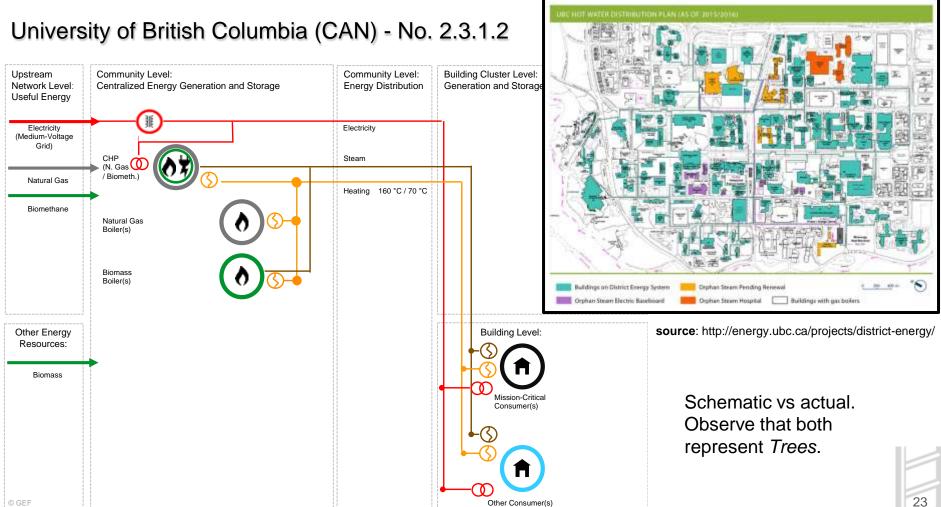
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7		6	72.332				
8		7	72.463				
9	1	8	42.304				

### User Interface to the Calculation Engine in MS Excel

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4	mc	blue_sky	heating	mc-heating-blue-sky.csv						
5	mc	class_4_hurricane	heating	mc-heating-class-4-hurricane.csv						
6	mc	blue_sky	cooling	mc-cooling-blue-sky.csv						
7	mc	class_4_hurricane	cooling	mc-cooling-class-4-hurricane.csv						
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9	other	class_4_hurricane	electrical	other-electrical-class-4-hurricane.csv						
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### Overview of Capabilities and Workflow

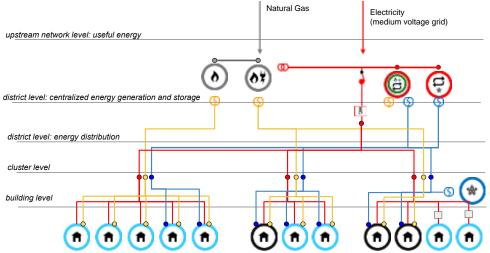
- Objective:
  - Allow access to the calculation engine without having to create an input file by hand
  - Constrain the problem to fixed levels of connectivity to reduce complexity

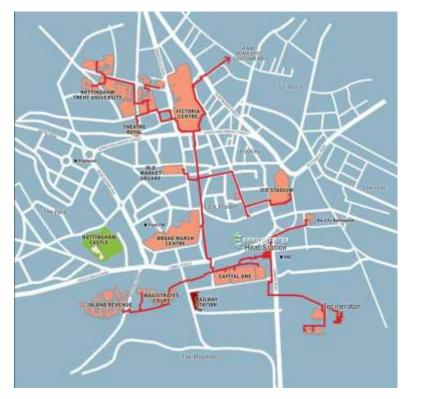


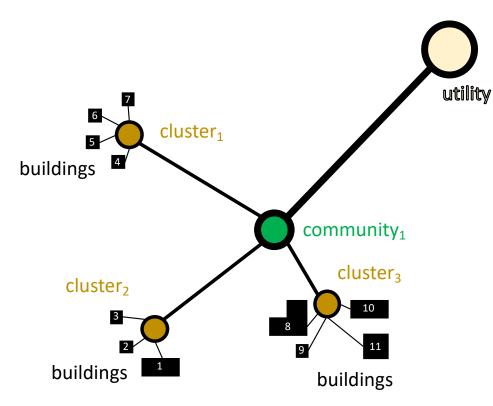


source: https://informedinfrastructure.com/399/researchers-map-the-city-of-sheffieds-heat/

#### Conceptually...

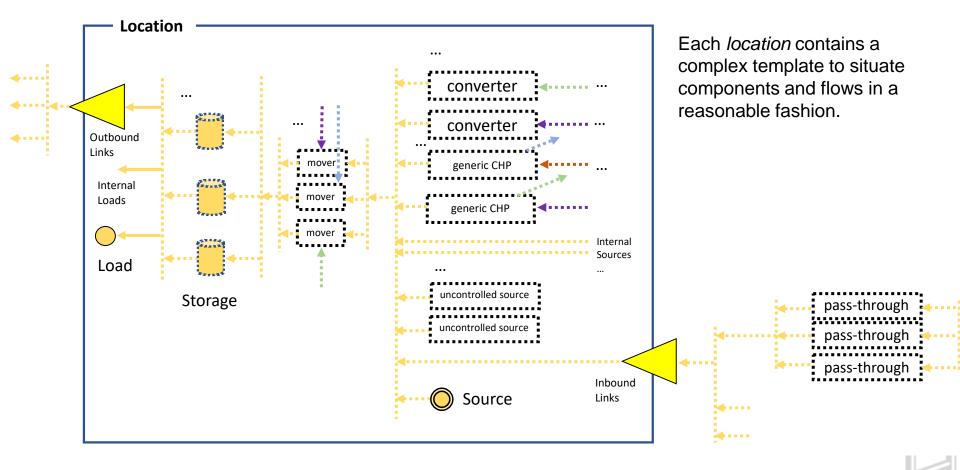


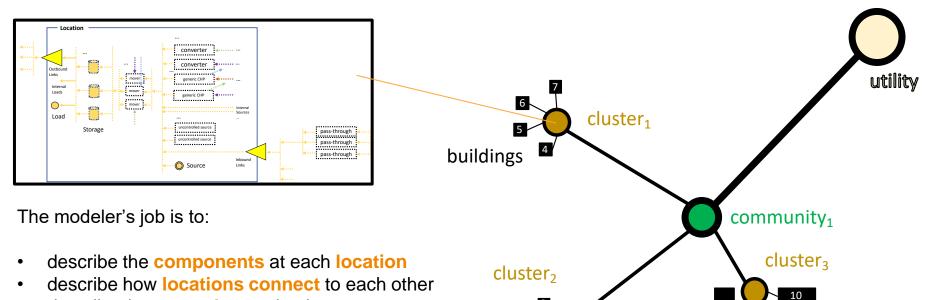




We use the concept of "location" to easily map between nodes in the above graph.

source: https://informedinfrastructure.com/399/researchers-map-the-city-of-sheffieds-heat/



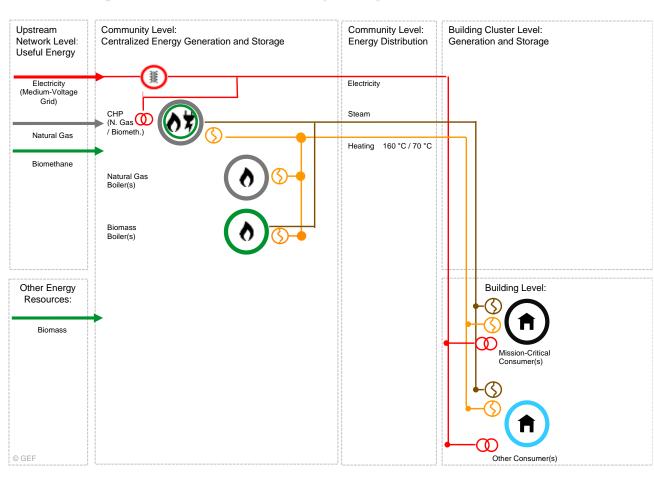


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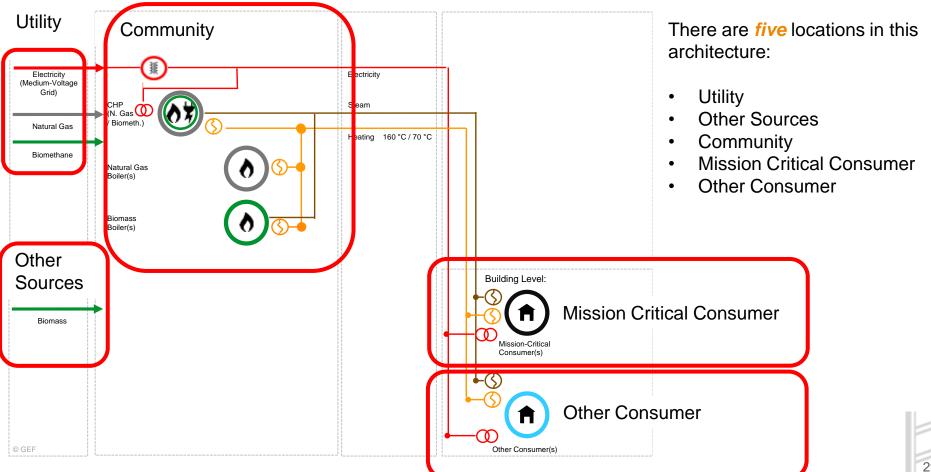
• describe the scenarios to simulate

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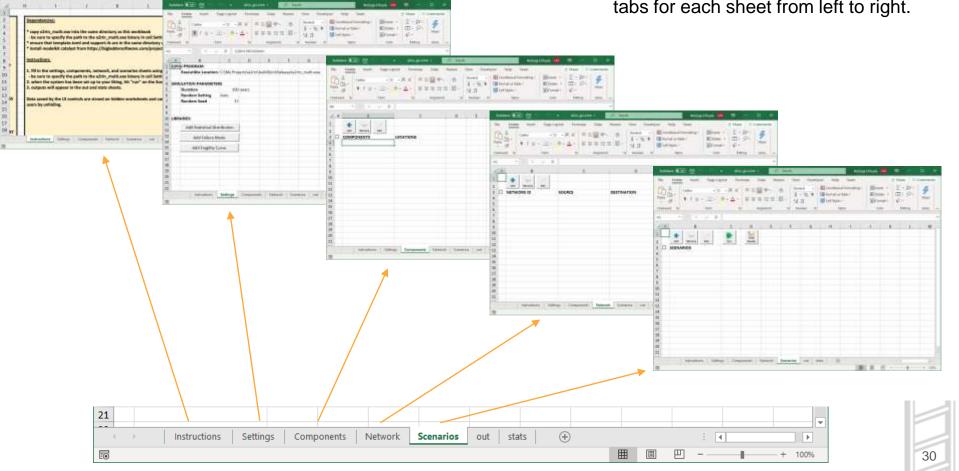


Let's take an architecture and describe it in the tool!

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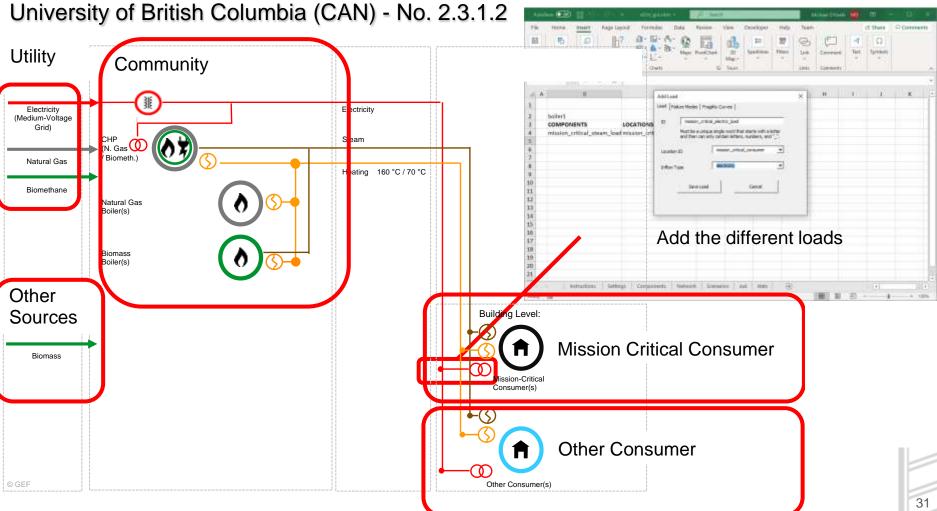
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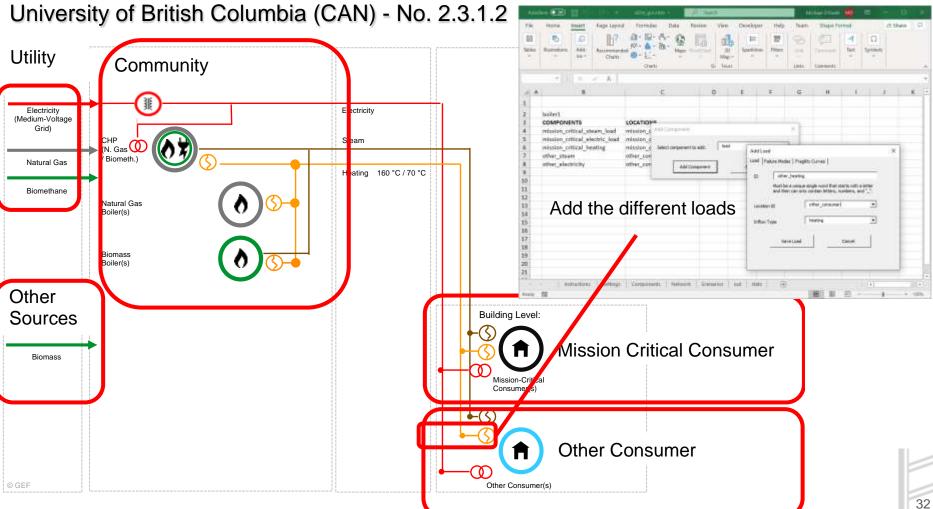
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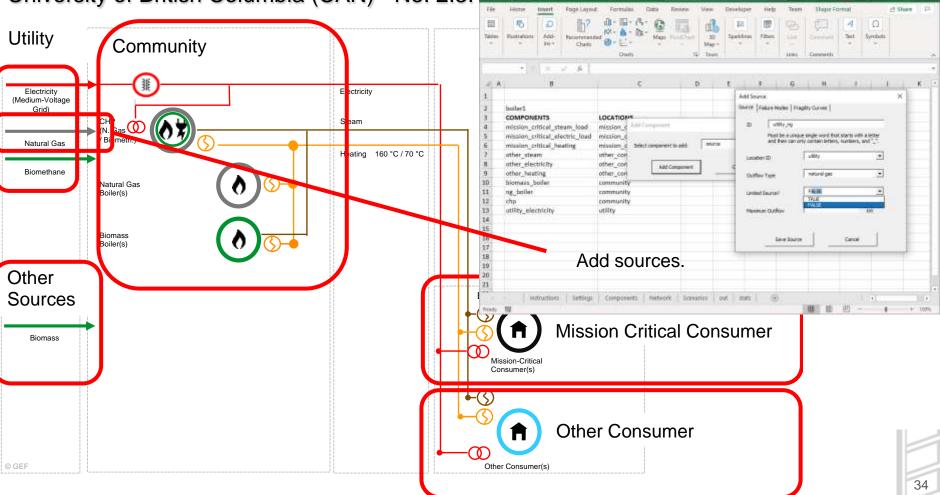
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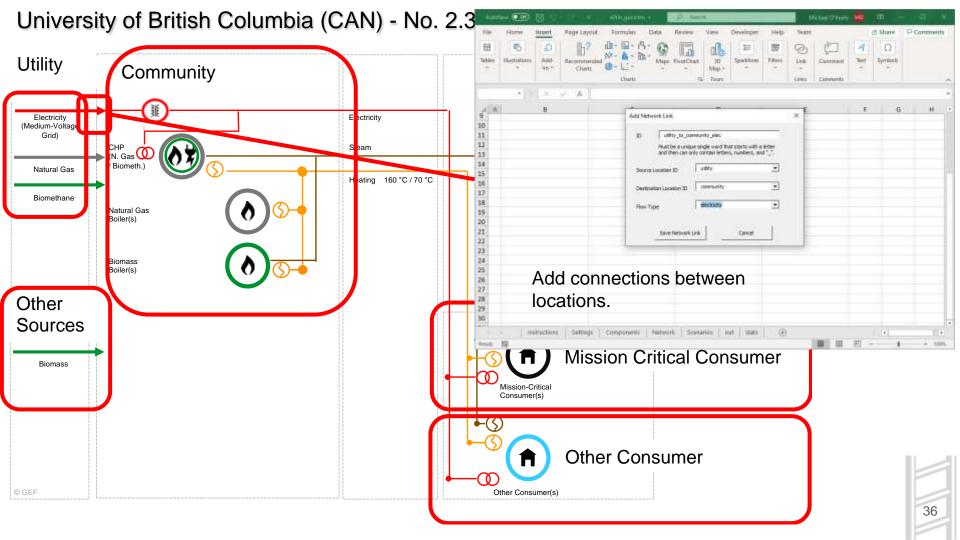
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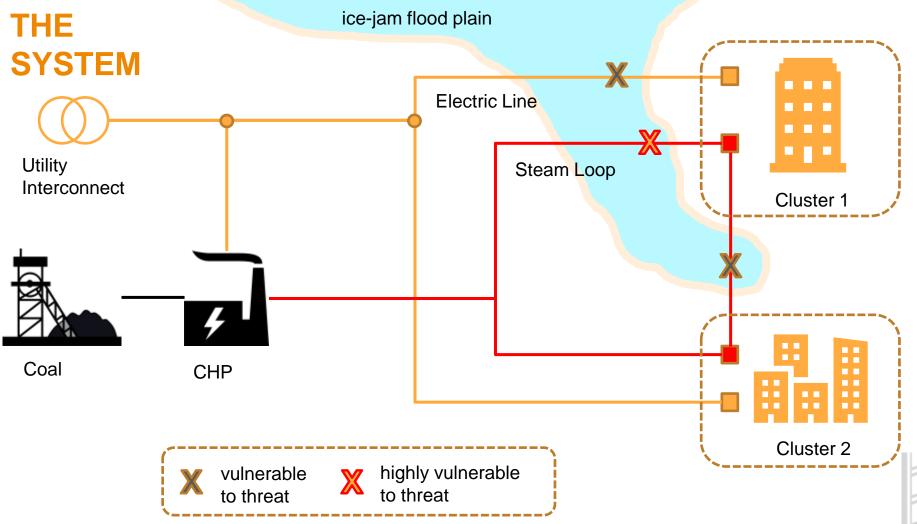
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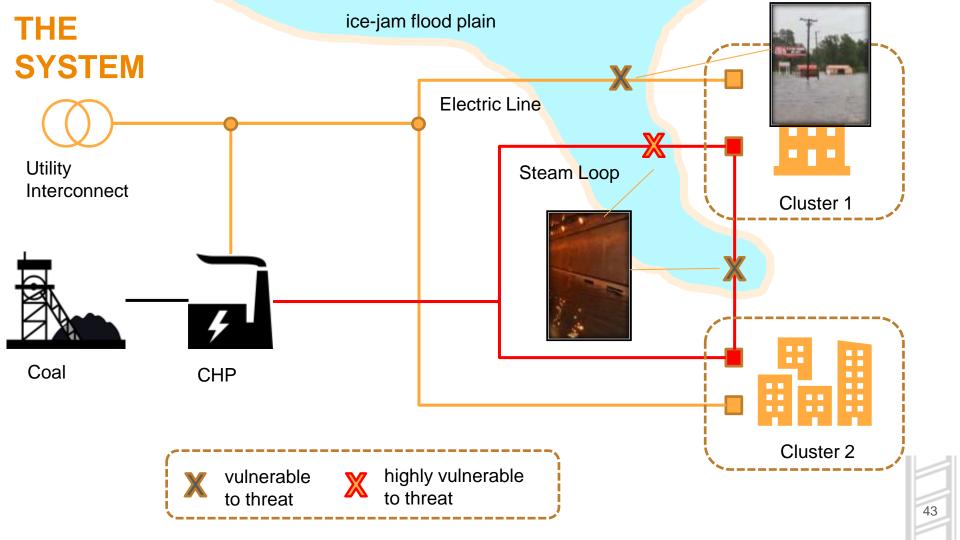
Outputs show all of the events over a scenario by component

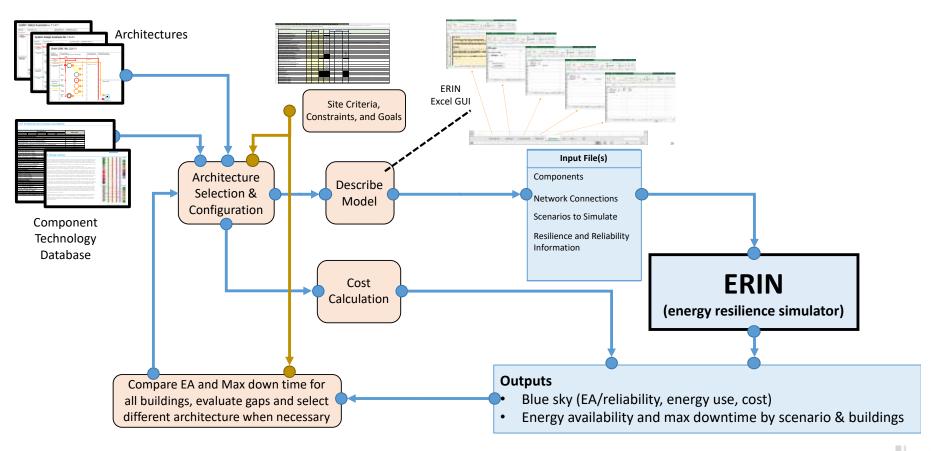
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## Using IEA Annex 73 Resources in Concert

A Hypothetical Example Analysis

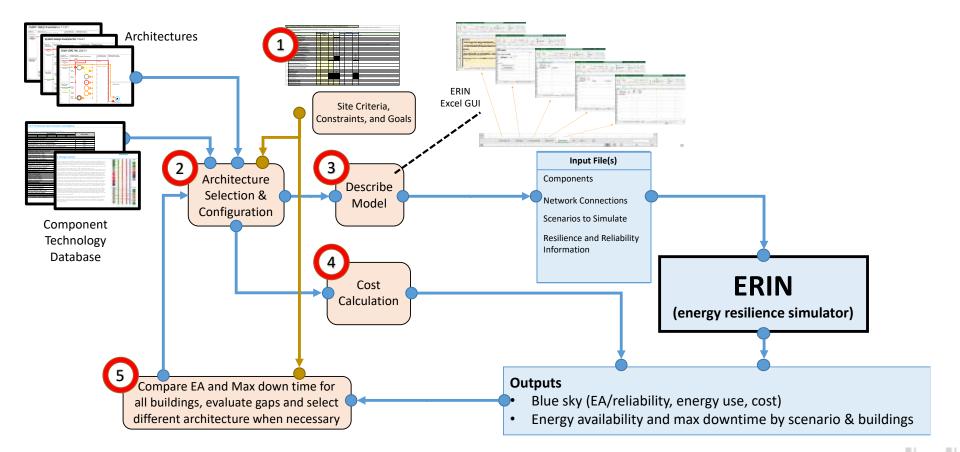






#### KEY

**Modeler Activity** 



## Summary

### Conclusions

- Free and open-source resilience calculation tool
  - Command line executable
  - MS Excel Minimal User Interface
- Part of a larger energy master planning process
  - Describing a model from an architecture template
  - Discussed how data products from IEA Annex 73 could be used in concert

Thank you!



