SAND2008-7923C

Chemical and Natural Gas Network Interdependencies

Chemical Supply Chain Industry Workshop
November 18 – 19, 2008

Walt Beyeler
Team Member
Sandia National Laboratories
psdowne@sandia.gov
(505) 284-2719

Los Alamos NATIONAL LABORATORY

Sandia National Laboratories

Many natural and engineered systems can be Described and analyzed as networks

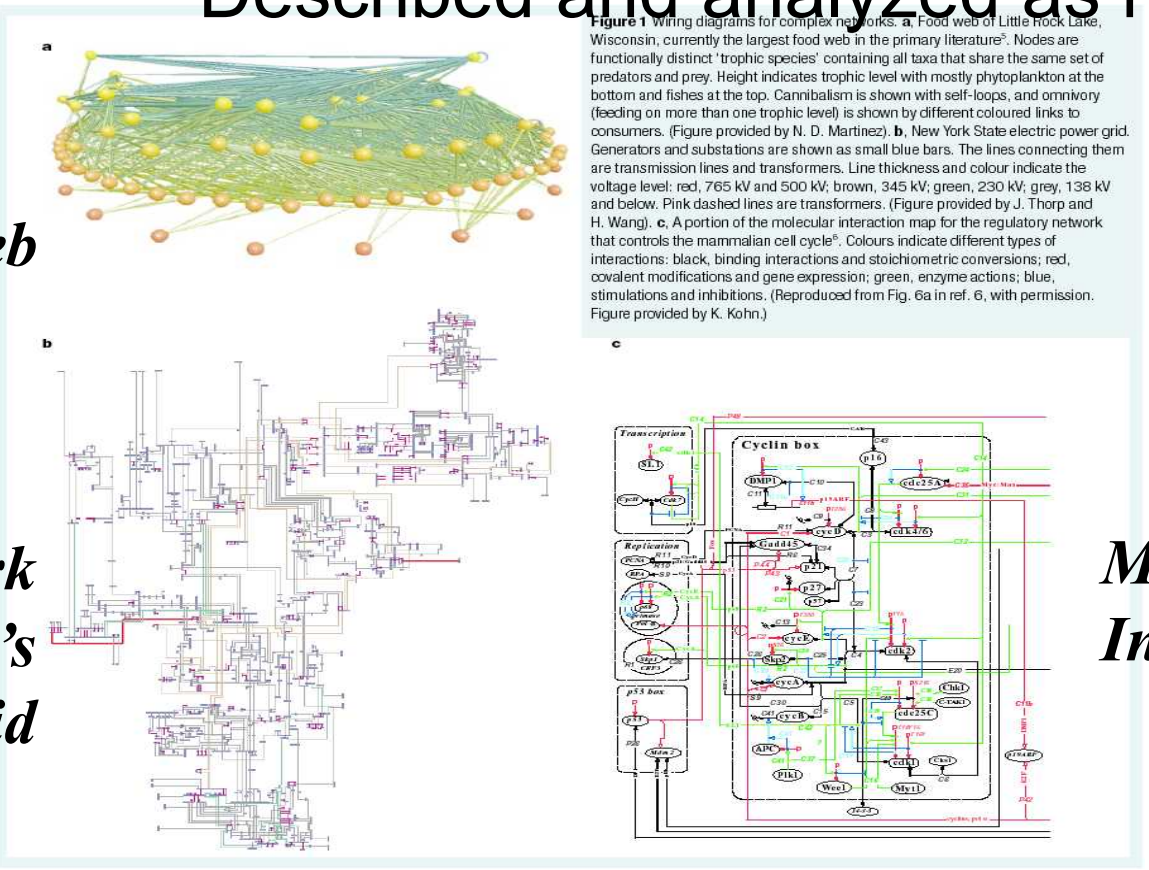


Figure 1 Wiring diagrams for complex networks. **a**, Food web of Little Rock Lake, Wisconsin, currently the largest food web in the primary literature[5]. Nodes are functionally distinct 'trophic species' containing all taxa that share the same set of predators and prey. Height indicates trophic level with mostly phytoplankton at the bottom and fishes at the top. Cannibalism is shown with self-loops, and omnivory (feeding on more than one trophic level) is shown by different coloured links to consumers. (Figure provided by N. D. Martinez). **b**, New York State electric power grid. Generators and substations are shown as small blue bars. The lines connecting them are transmission lines and transformers. Line thickness and colour indicate the voltage level: red, 765 kV and 500 kV; brown, 345 kV; green, 230 kV; grey, 138 kV and below. Pink dashed lines are transformers. (Figure provided by J. Thorp and H. Wang). **c**, A portion of the molecular interaction map for the regulatory network that controls the mammalian cell cycle[6]. Colours indicate different types of interactions: black, binding interactions and stoichiometric conversions; red, covalent modifications and gene expression; green, enzyme actions; blue, stimulations and inhibitions. (Reproduced from Fig. 6a in ref. 6, with permission. Figure provided by K. Kohn.)

Food Web

New York state's Power Grid

Molecular Interaction

Illustrations of natural and constructed network systems from Strogatz [2001].

Network analysis can find features that are important for the system as a whole

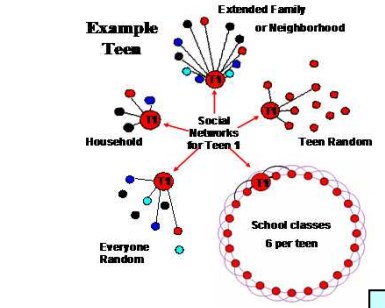
Los Alamos NATIONAL LABORATORY

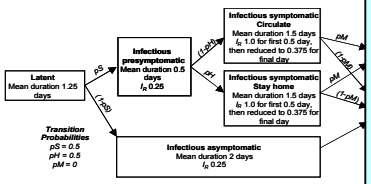
NISAC

Sandia National Laboratories

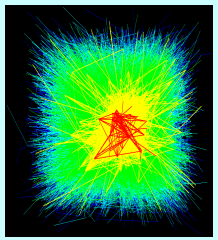
NISAC Network Applications

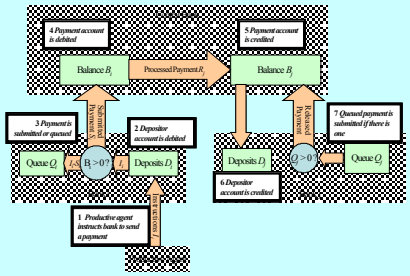
Infectious Disease Spread



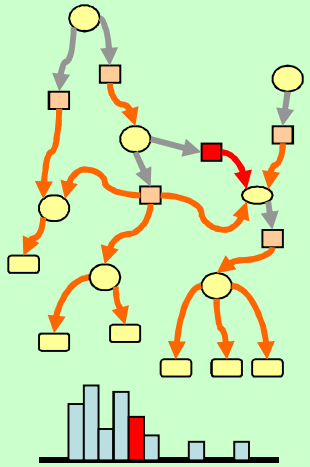


Banking Interactions

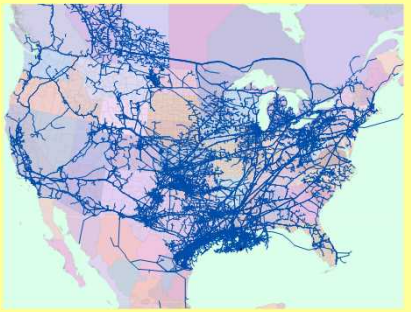


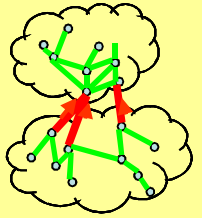


Petrochemical Interdependencies

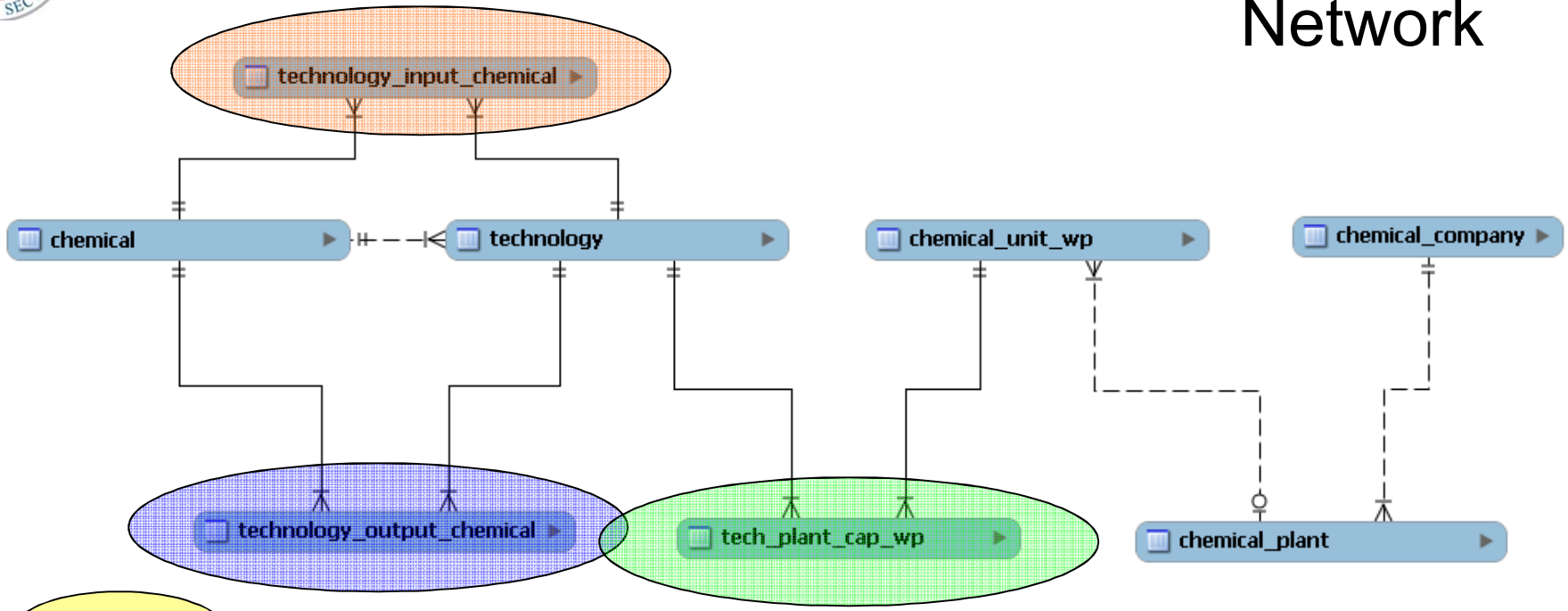


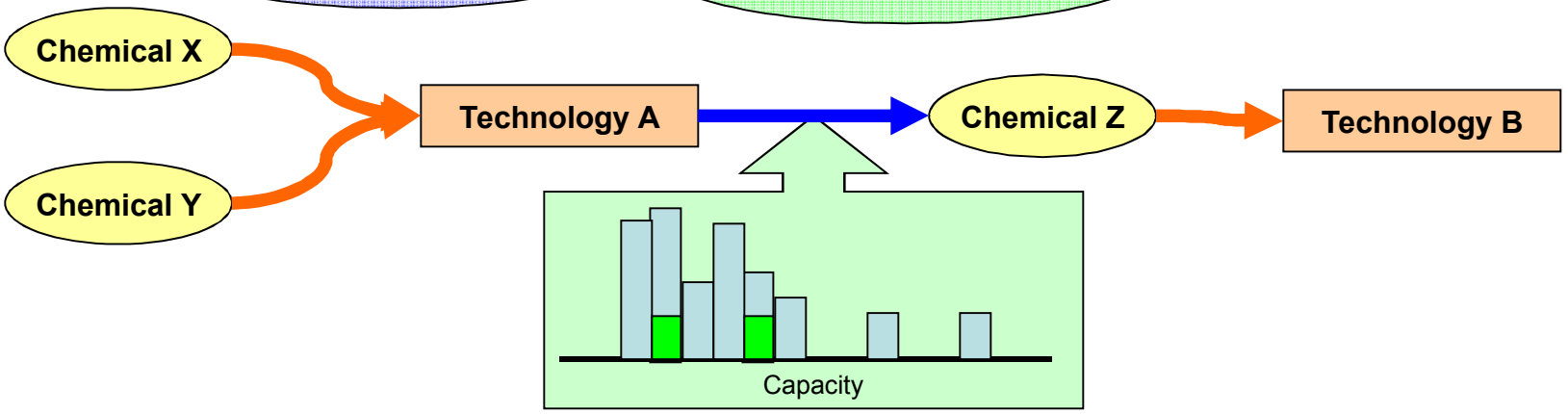
Natural Gas Transmission





Defining the Petrochemical Network





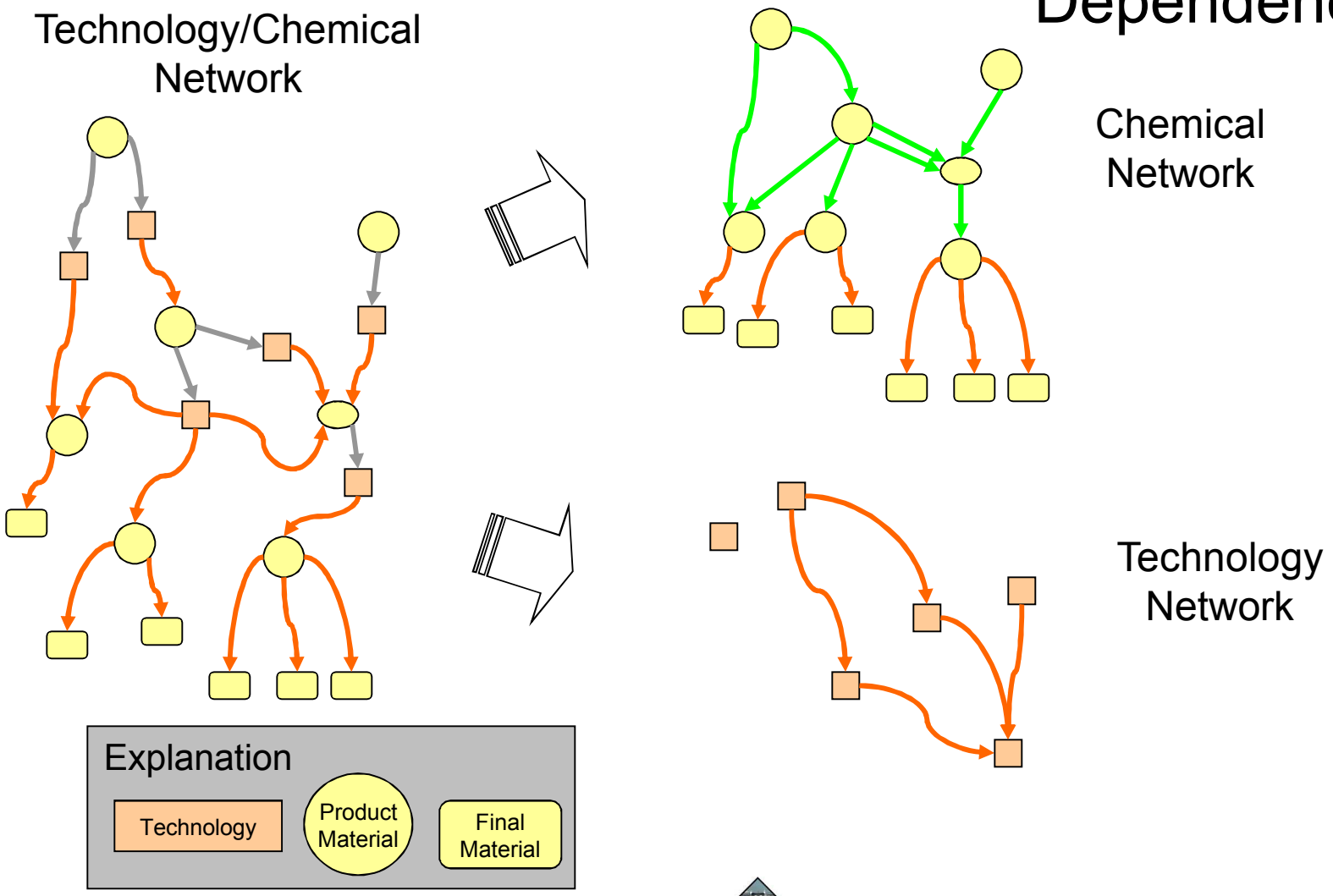
Petrochemical Network Structure

Los Alamos NATIONAL LABORATORY

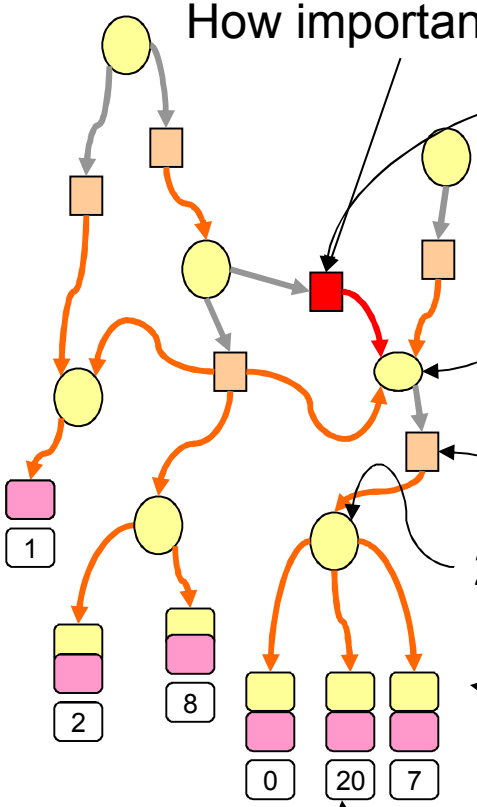
NISAC

Sandia National Laboratories

Derived Networks of Chemical and Technology Dependencies



Customized Importance Measures



1) Process availability ➡ 0

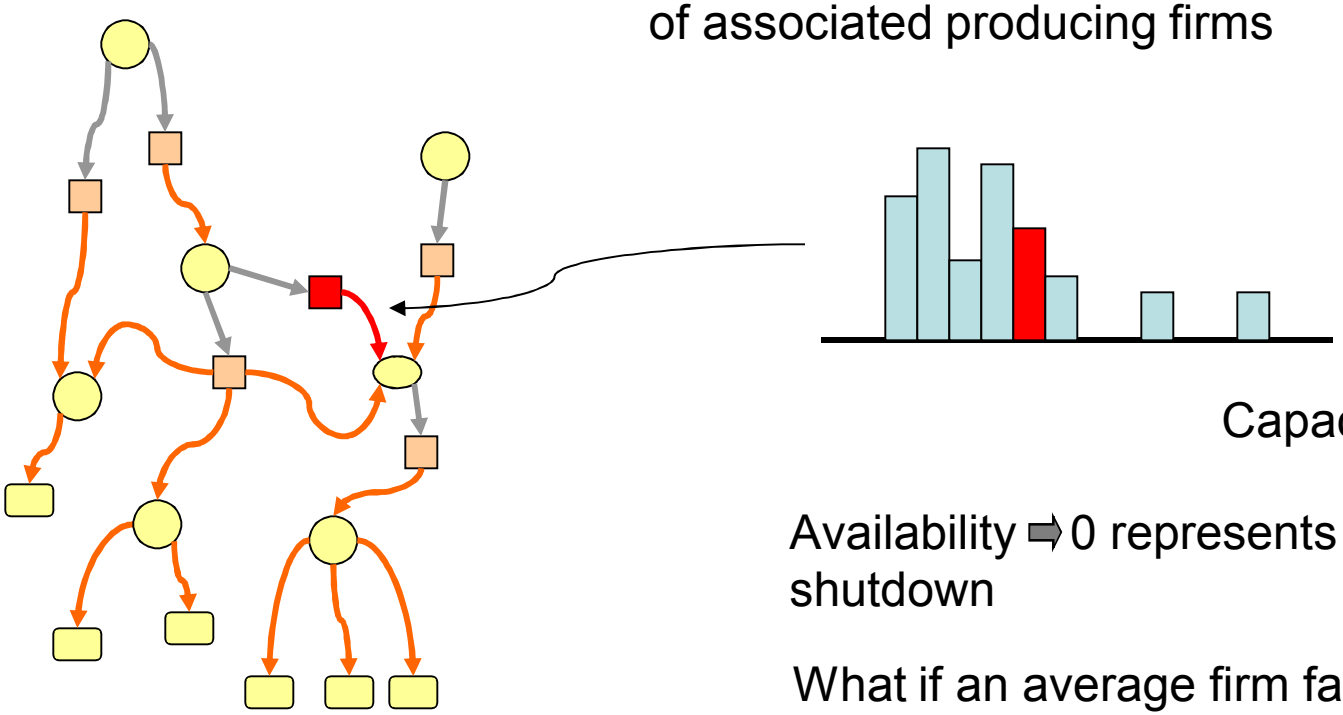
2) Product availability ➡
fraction of remaining capacity

3) Process availability ➡
minimum of input material availability
Nonlinearity blocks superposition

2) …

4) Final material availability ➡
(minimum) input material availability

5) Final materials are weighted in some way to give a consequence measure if the processes disappears



Each process/product link has a *population* of associated producing firms

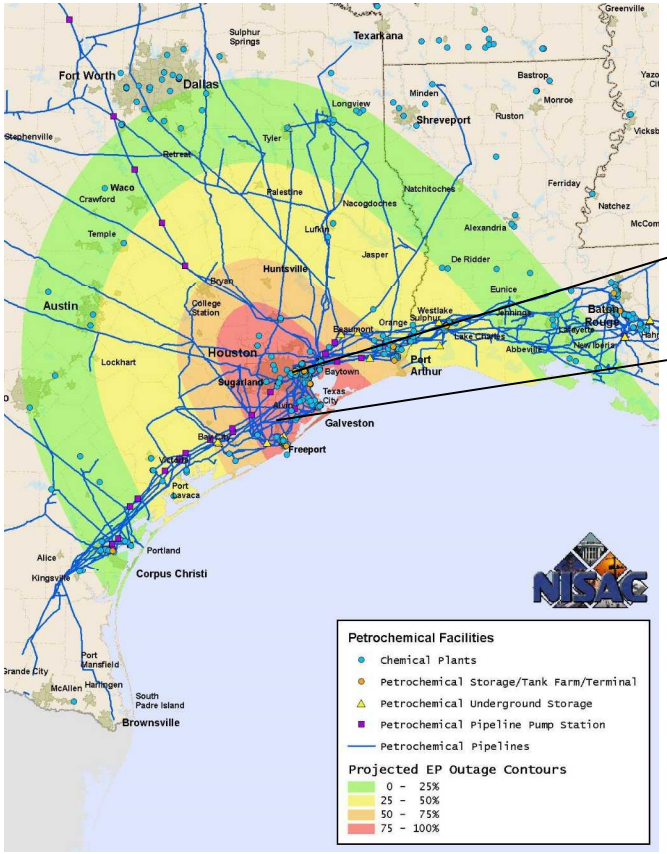
Capacity

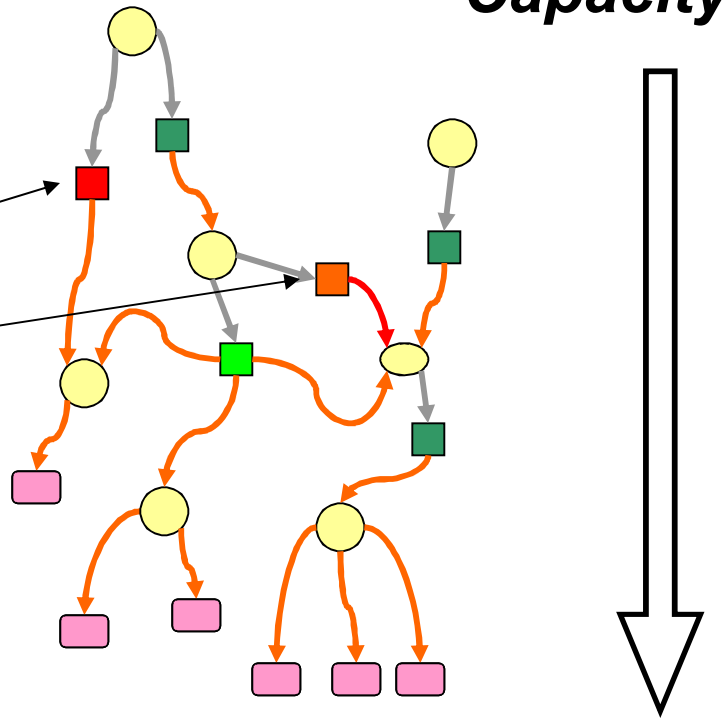
Availability ⇨ 0 represents universal shutdown

What if an average firm fails?
What if the largest fails?

Scenario Analysis

Disrupted Facilities ⇨ ***Reduced Production Capacity***

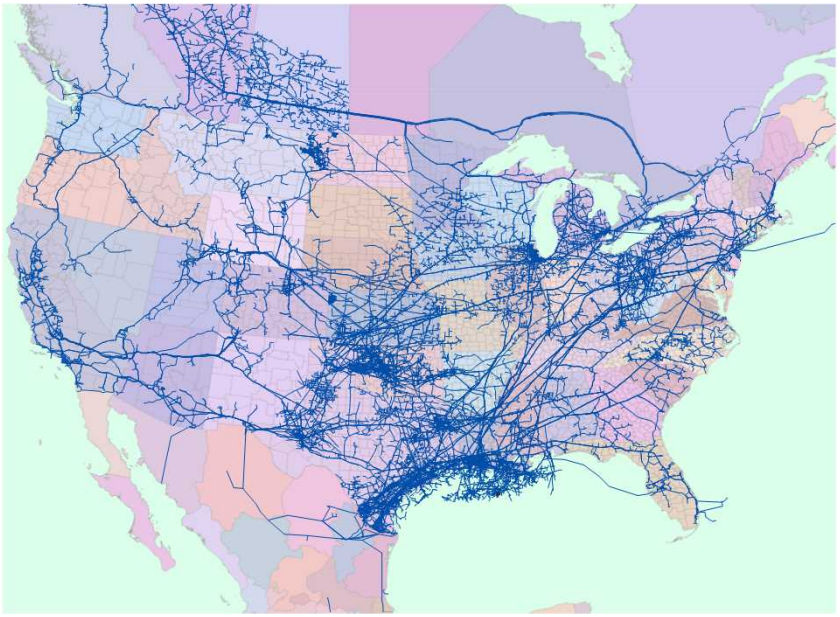


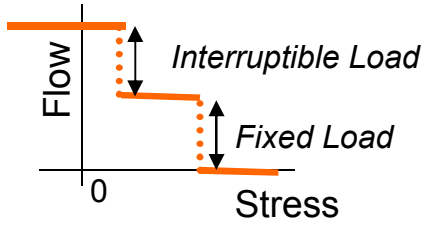


Diminished Product Availability

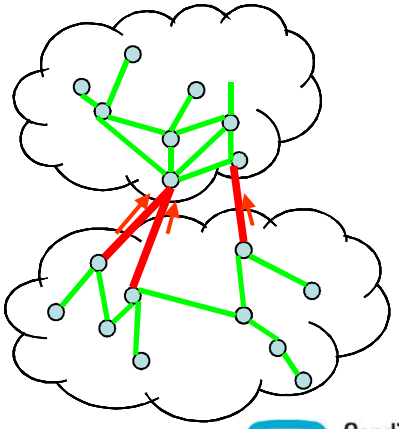
Natural Gas Availability Model

- **Network built from industry data**
  - 17,442 Receipt/Delivery Points
  - 40,403 Pipeline Segments
  - Data describe components, not a connected system
  - Different level of detail in different regions
  - Occasional inconsistencies and omissions as with any large dynamic data set
  - Goal is a flow network that helps answer questions, not a simulation of the real network per se
- **Flow functions reflect business rules**
  - Describe source/sink/storage behavior as a function of "stress"
  - Stress is a mechanism for balancing flows at the chosen scale, analogous to pressure or price

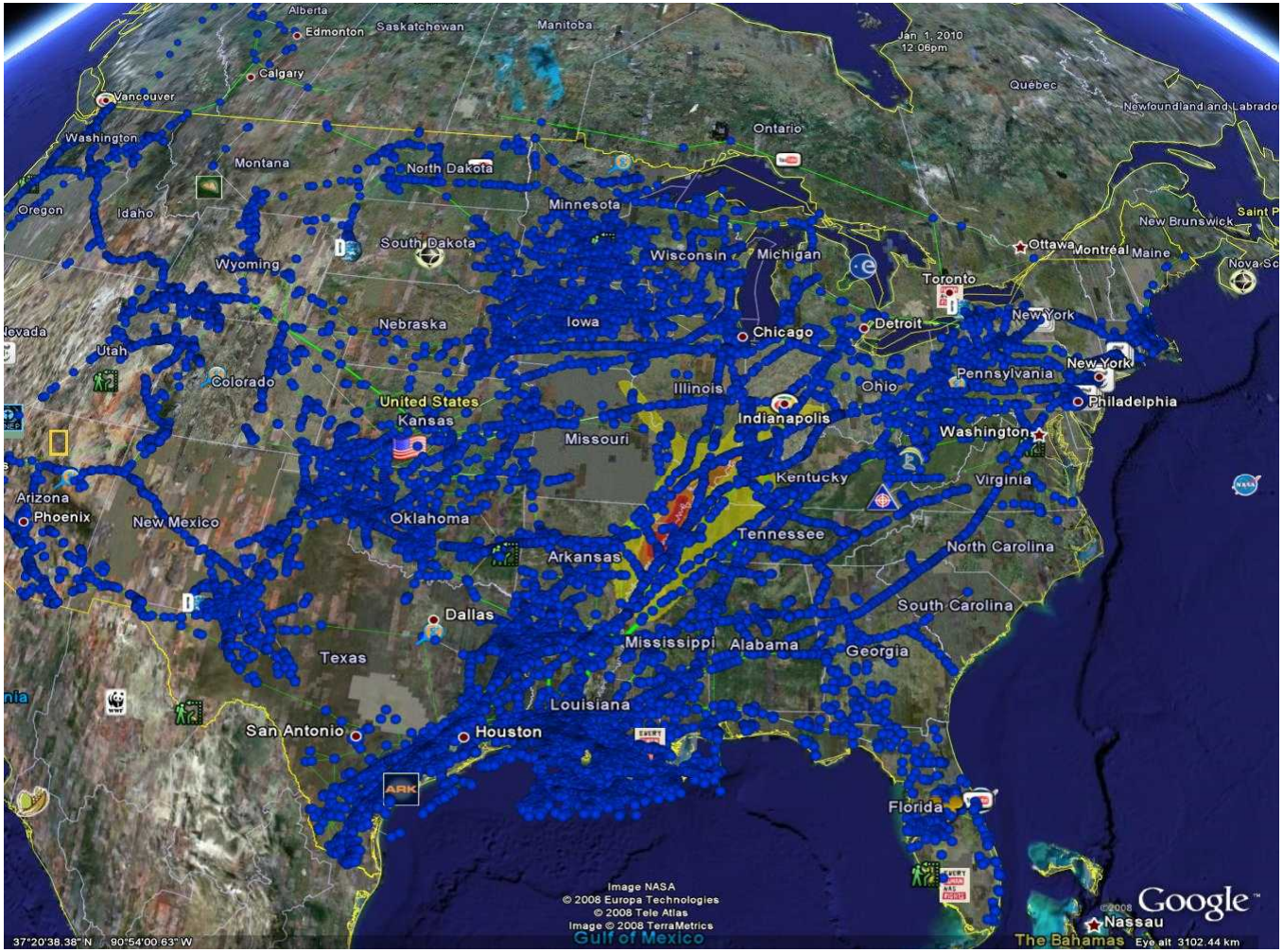




- **Gas may be limited by supply constraints or by pipeline disruptions**



Natural Gas Network



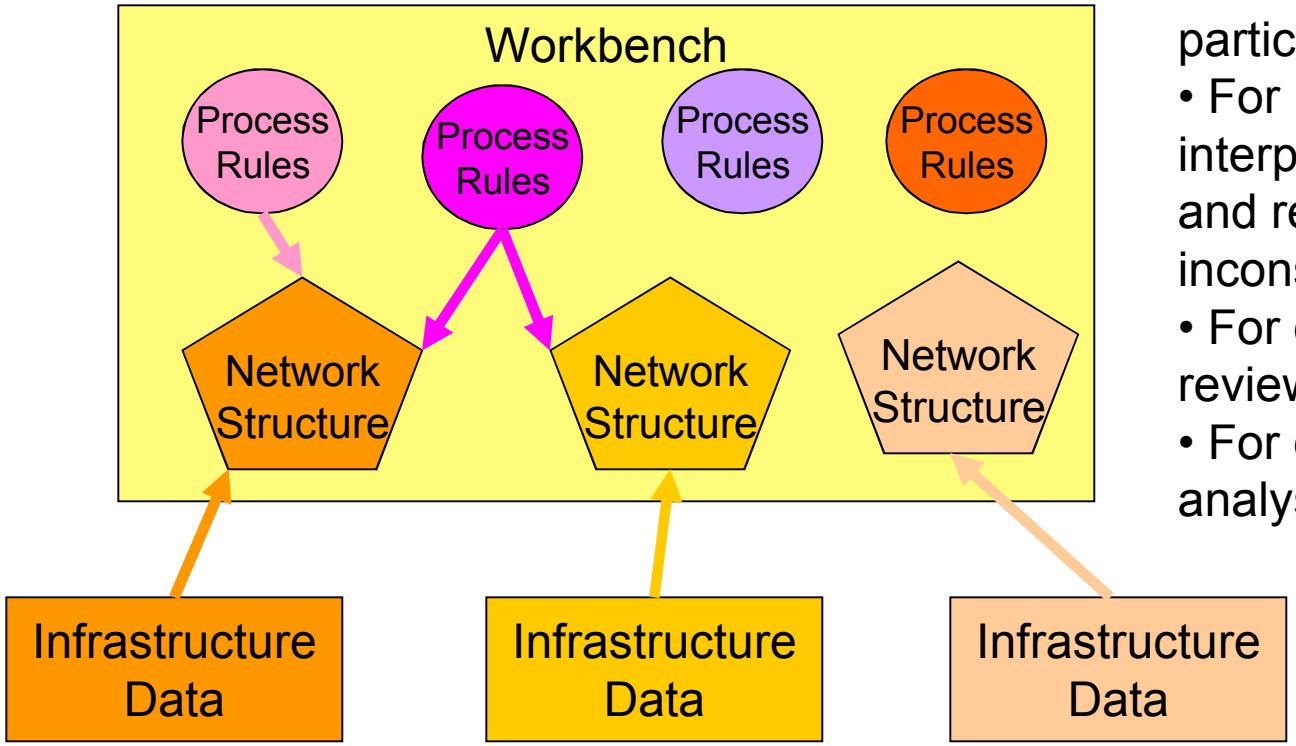
Los Alamos NATIONAL LABORATORY

NISAC

Sandia National Laboratories

Modeling Network Interdependencies

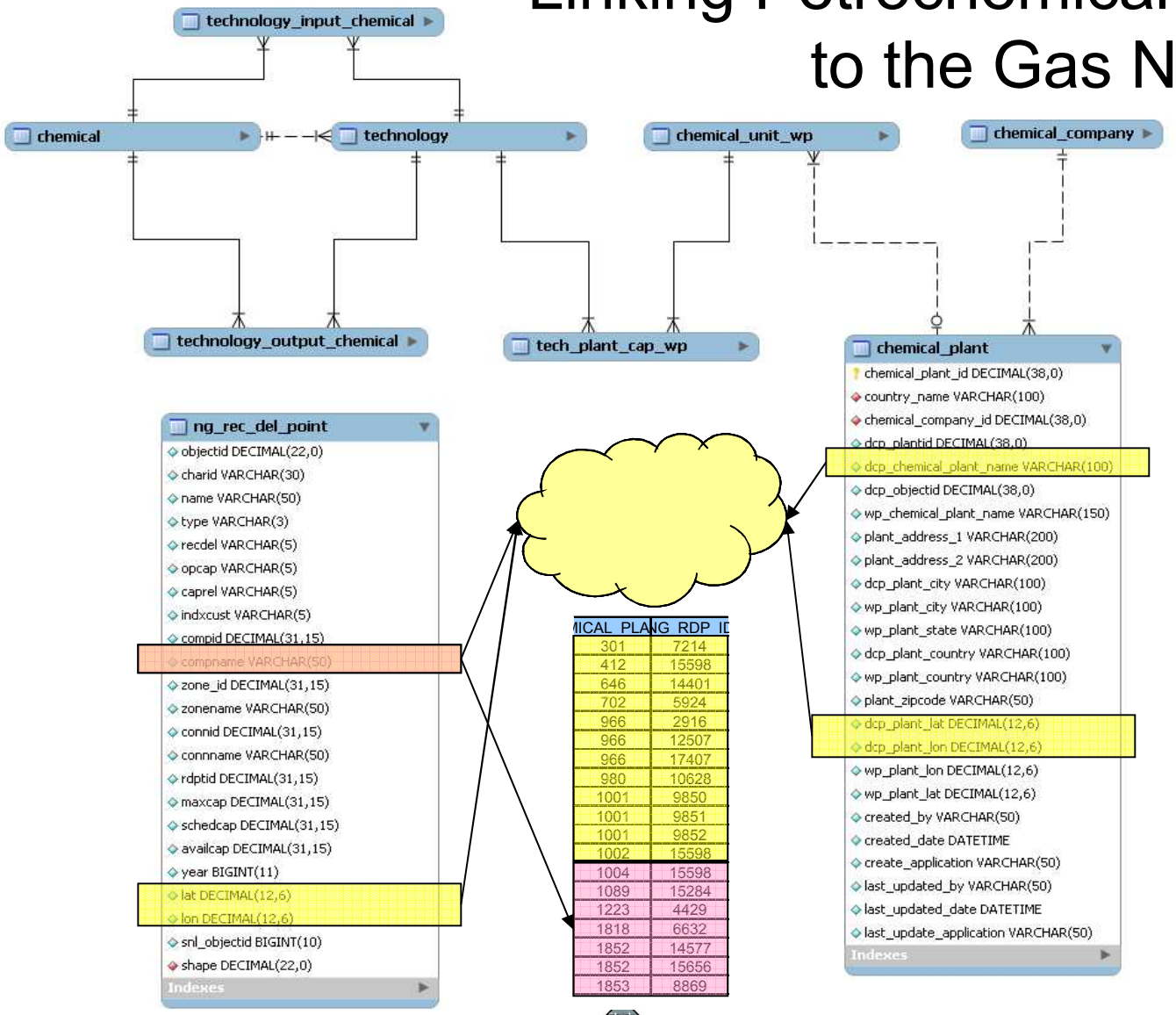
The network Workbench will create a platform for describing networks And processes in a consistent way. It will integrate existing work (FAIT, Existing network tools and models) and broaden applications for new contributions



Industry expertise and participation is *essential*

- For identifying and interpreting basic data, and resolving gaps and inconsistencies
- For defining and reviewing process rules
- For defining and using analyses

Linking Petrochemical Plants to the Gas Network



Los Alamos NATIONAL LABORATORY

NISAC

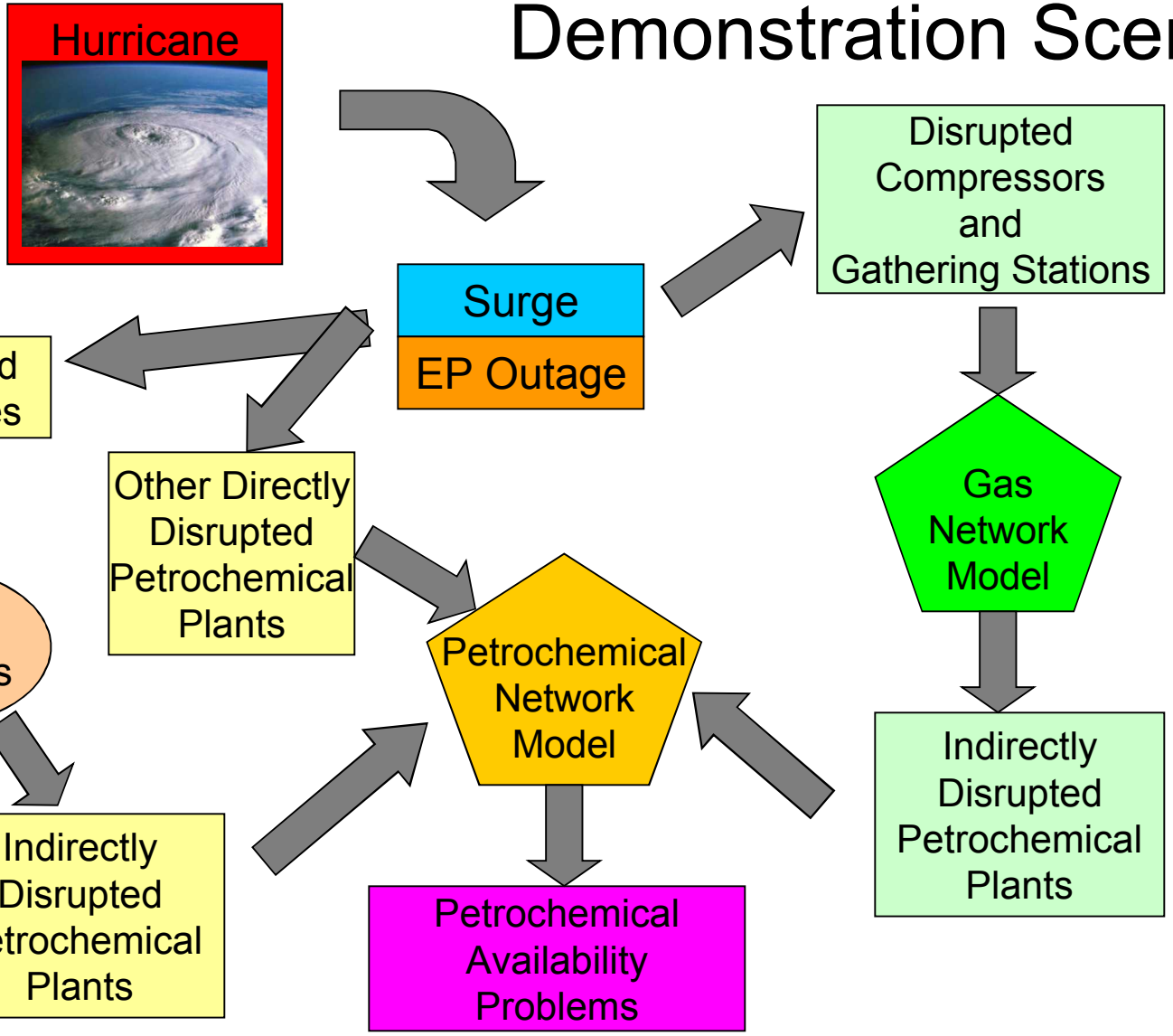
Sandia National Laboratories

Limitations of Current Interconnection

- Errors in names or locations can frustrate matching
- Cannot resolve connections below the plant level – which facilities are involved?
- Technology inputs have not been used to identify required connections (underway)
- Connections through distribution companies or intrastate transmission systems are invisible
- Cannot distinguish between feedstock and fuel use (if there is any)

- *We welcome your advice and help on improving this process*

Demonstration Scenario



Example Results

Potential Shortfall Relative to Normal Supply

Direct Impacts

ID	DESCRIPTION	LOSTFRACTION
34	Cumene	0.064
110	Phenol	0.063
9	Acetone	0.062
7	Acetic Acid	0.039
28	Caprolactam	0.037
98	Nylon 6 Fibers	0.037
14	Adipic Acid	0.034
100	Nylon 66 Fibers	0.034
55	Ethylbenzene	0.034
139	SB Latex	0.034
141	SBR Latex	0.034
145	Styrene	0.034
147	Styrenic Copolymers	0.034
21	Benzene	0.032
35	Cyclohexane	0.032
138	Propylene Oxide	0.029
154	Toluene	0.024

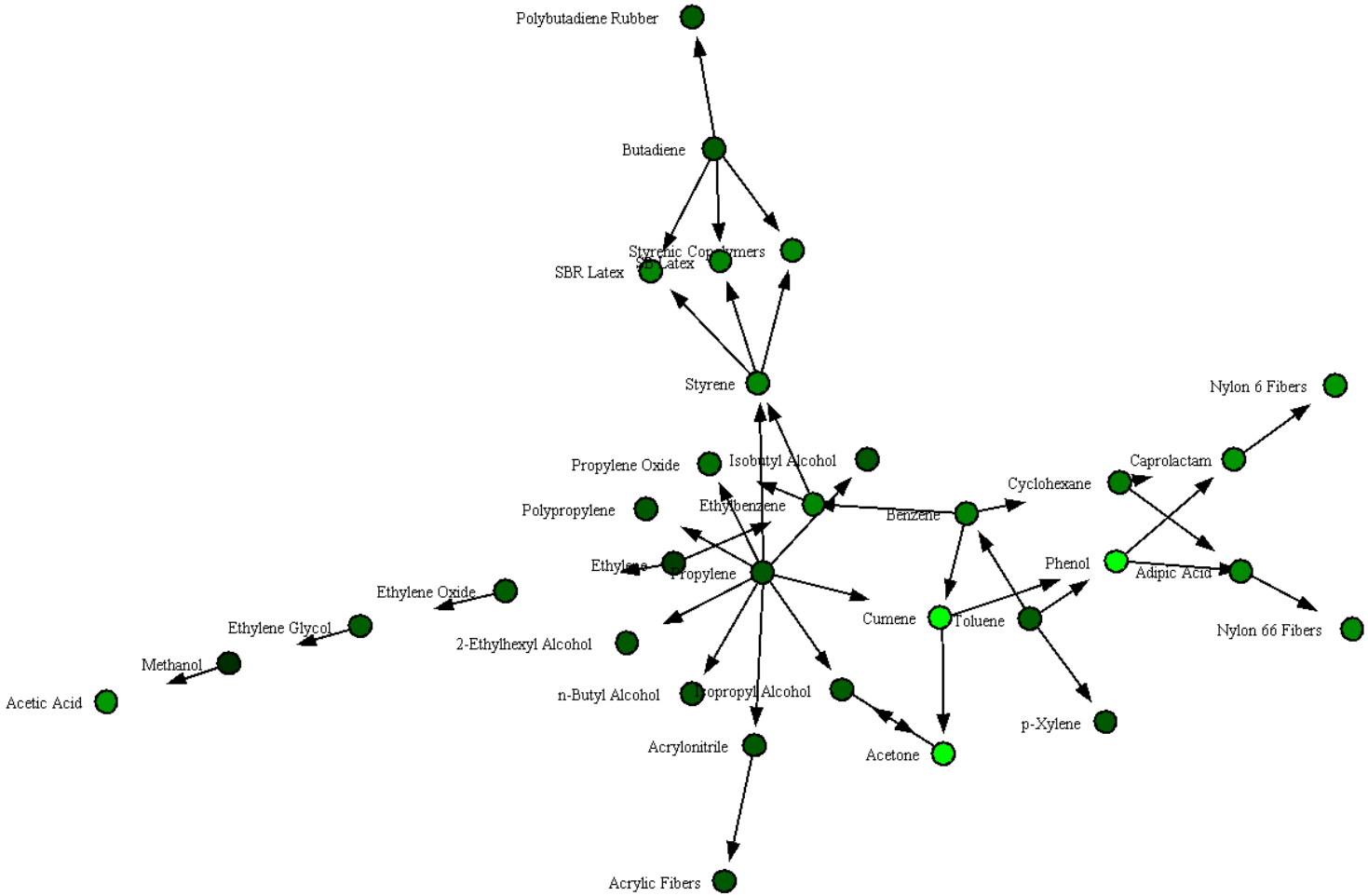
Direct + POL

ID	DESCRIPTION	LOSTFRACTION
34	Cumene	0.064
110	Phenol	0.063
9	Acetone	0.062
7	Acetic Acid	0.039
28	Caprolactam	0.037
98	Nylon 6 Fibers	0.037
14	Adipic Acid	0.034
100	Nylon 66 Fibers	0.034
55	Ethylbenzene	0.034
139	SB Latex	0.034
141	SBR Latex	0.034
145	Styrene	0.034
147	Styrenic Copolymers	0.034
21	Benzene	0.032
35	Cyclohexane	0.032
138	Propylene Oxide	0.029
154	Toluene	0.024

Direct + POL + NG

ID	DESCRIPTION	LOSTFRACTION
34	Cumene	0.064
110	Phenol	0.063
9	Acetone	0.062
7	Acetic Acid	0.039
28	Caprolactam	0.037
98	Nylon 6 Fibers	0.037
14	Adipic Acid	0.034
100	Nylon 66 Fibers	0.034
55	Ethylbenzene	0.034
139	SB Latex	0.034
141	SBR Latex	0.034
145	Styrene	0.034
147	Styrenic Copolymers	0.034
21	Benzene	0.032
35	Cyclohexane	0.032
138	Propylene Oxide	0.029
154	Toluene	0.024

Network View of Chemical Shortfalls



Next Steps for Network

- Expand into other chemical sectors as data allow
- Include simple dynamics of disruption and restoration (inventories, restart latencies,…)
- Include upstream disruption propagation: producers track consumption
- Include other transportation constraints
- Exploit model simplicity to solve inverse problems: what disruptions can produce specified consequences?
- Incorporate your insights and information