

This presentation premiered at WaterSmart Innovations

watersmartinnovations.com



ROLE OF CITIES IN THE VIRTUAL WATER NETWORK OF U.S. COMMODITY FLOWS

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Climate change and surging population,
putting pressure on fresh water
resources.



There are increasing water concerns in US cities , such as



El Paso



San Francisco



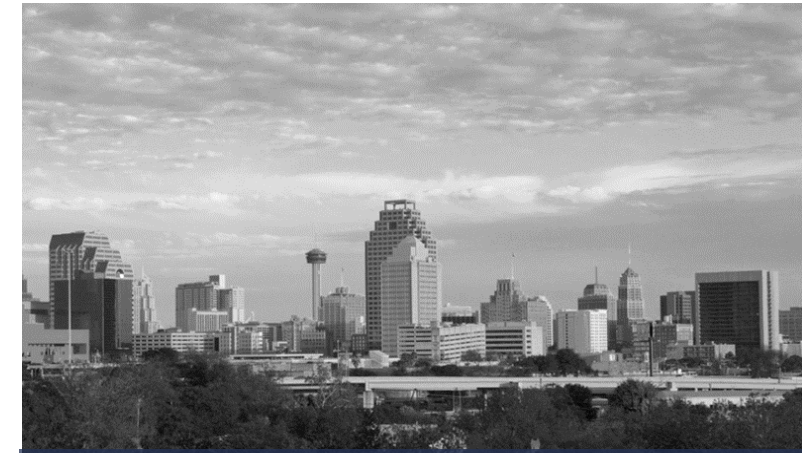
Los Angeles



Houston



Washington, D.C.



San Antonio

Why cities?



Currently, 80 percent of the United States population resides in cities



This increase in urbanization and population comes with increased demand for scarce fresh water resources

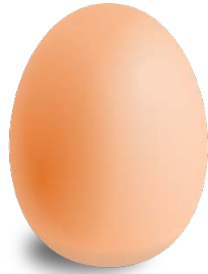


Most policy decisions are made at the city level

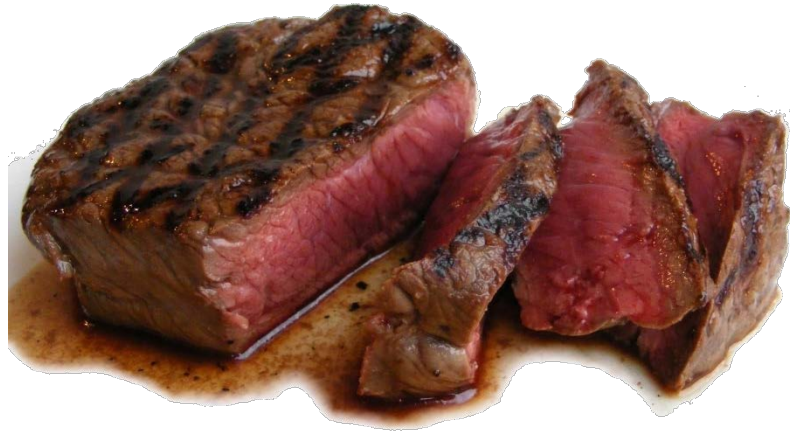
How much (virtual) water are we using?



1.1 Gallons
per almond



135 Liters
per egg



5400 Liters
per steak (300gr)

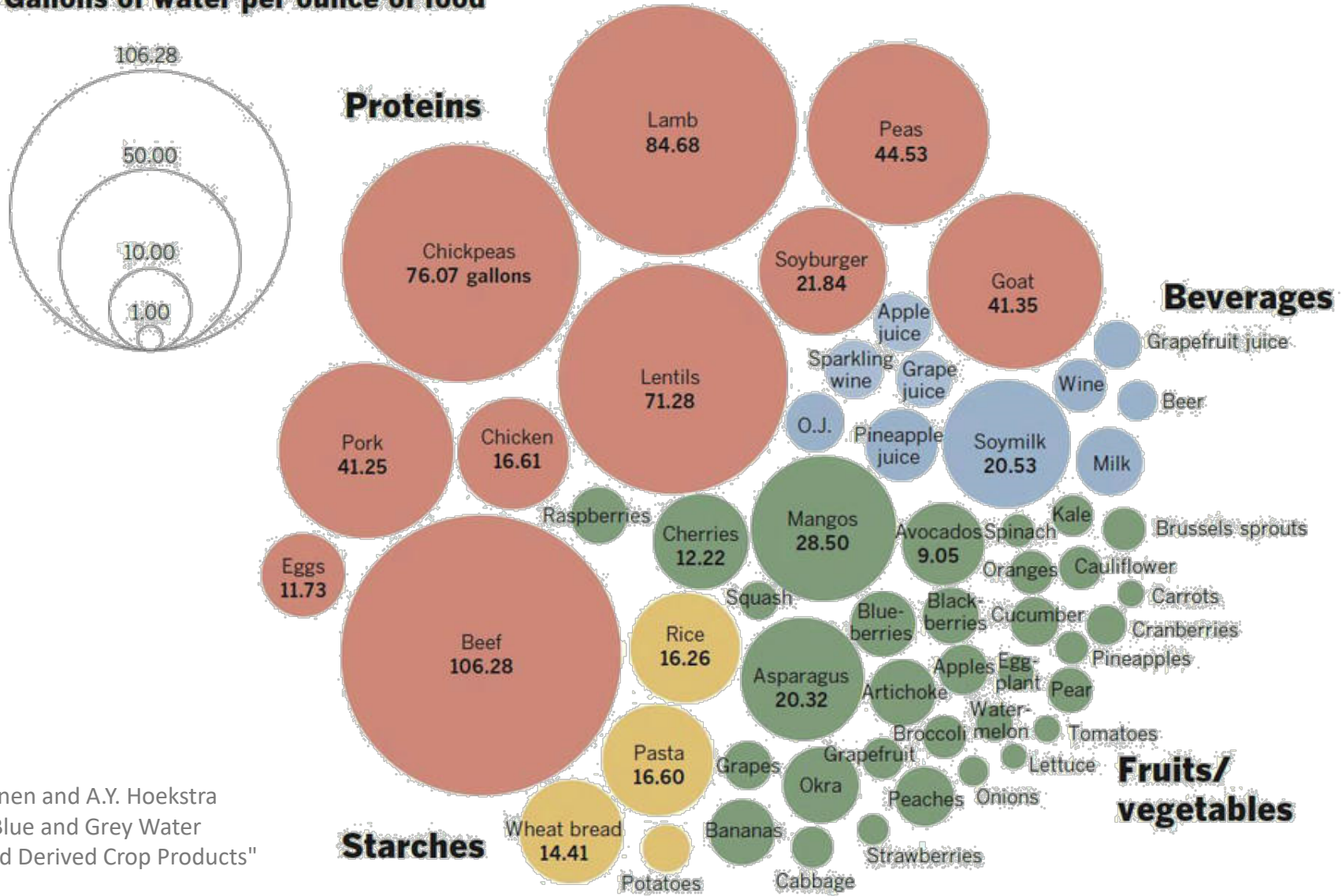


7600 Liters
per 1 pair

Source: waterfootprint.org



Gallons of water per ounce of food



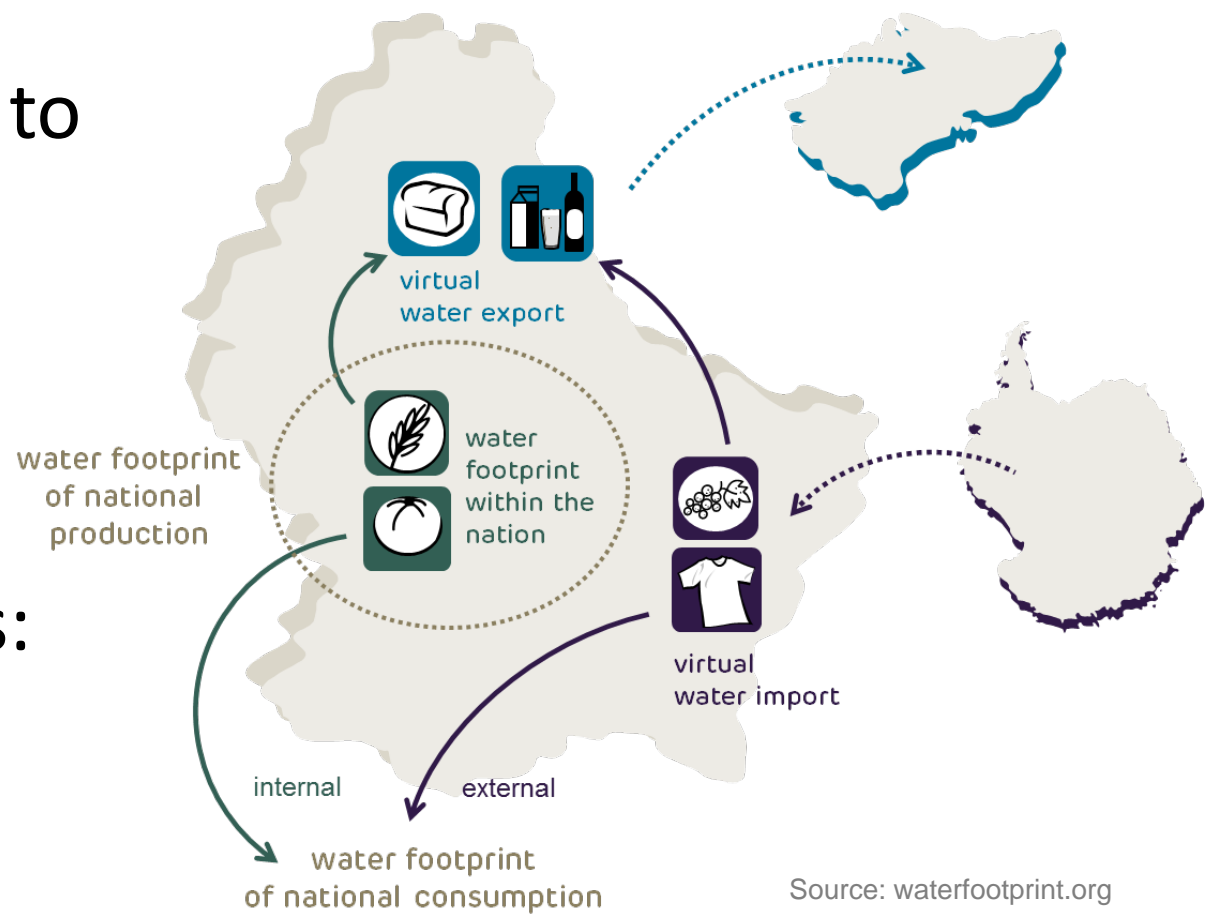
Source: M.M. Mekonnen and A.Y. Hoekstra (2010), "The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products"



How do we define water footprint?

As the volume of freshwater used to produce a product, summed over the various steps of the production chain.

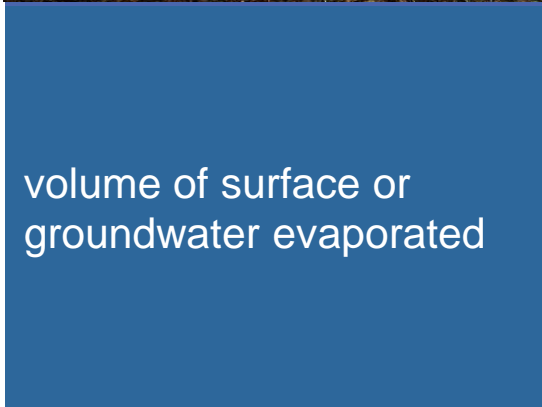
For a city, there are 2 perspectives:
Production and consumption



Water footprint can be seen through different lenses



volume of rainwater evaporated.



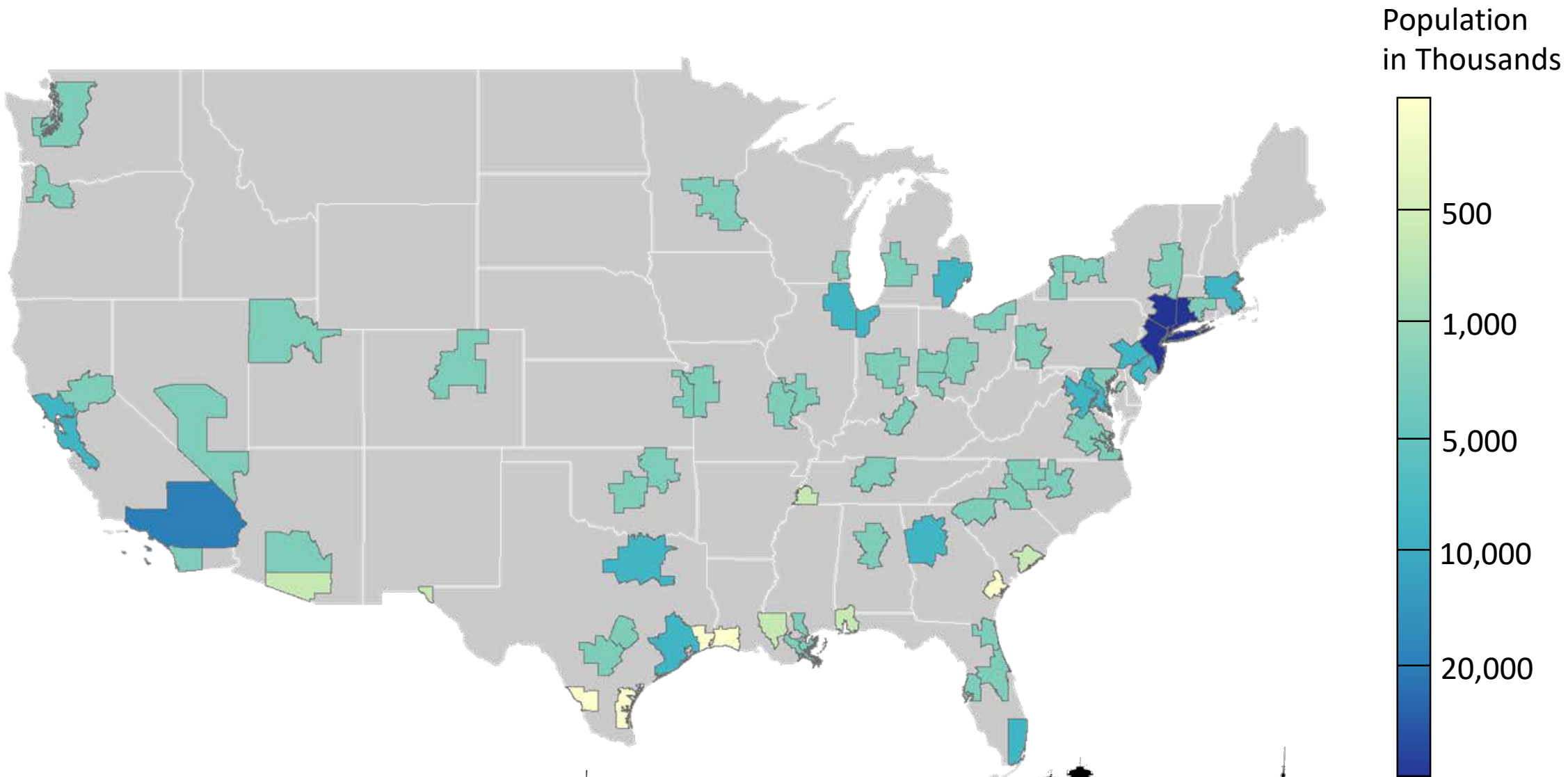
volume of surface or groundwater evaporated

Objective: characterize the VW network with complex network theory.

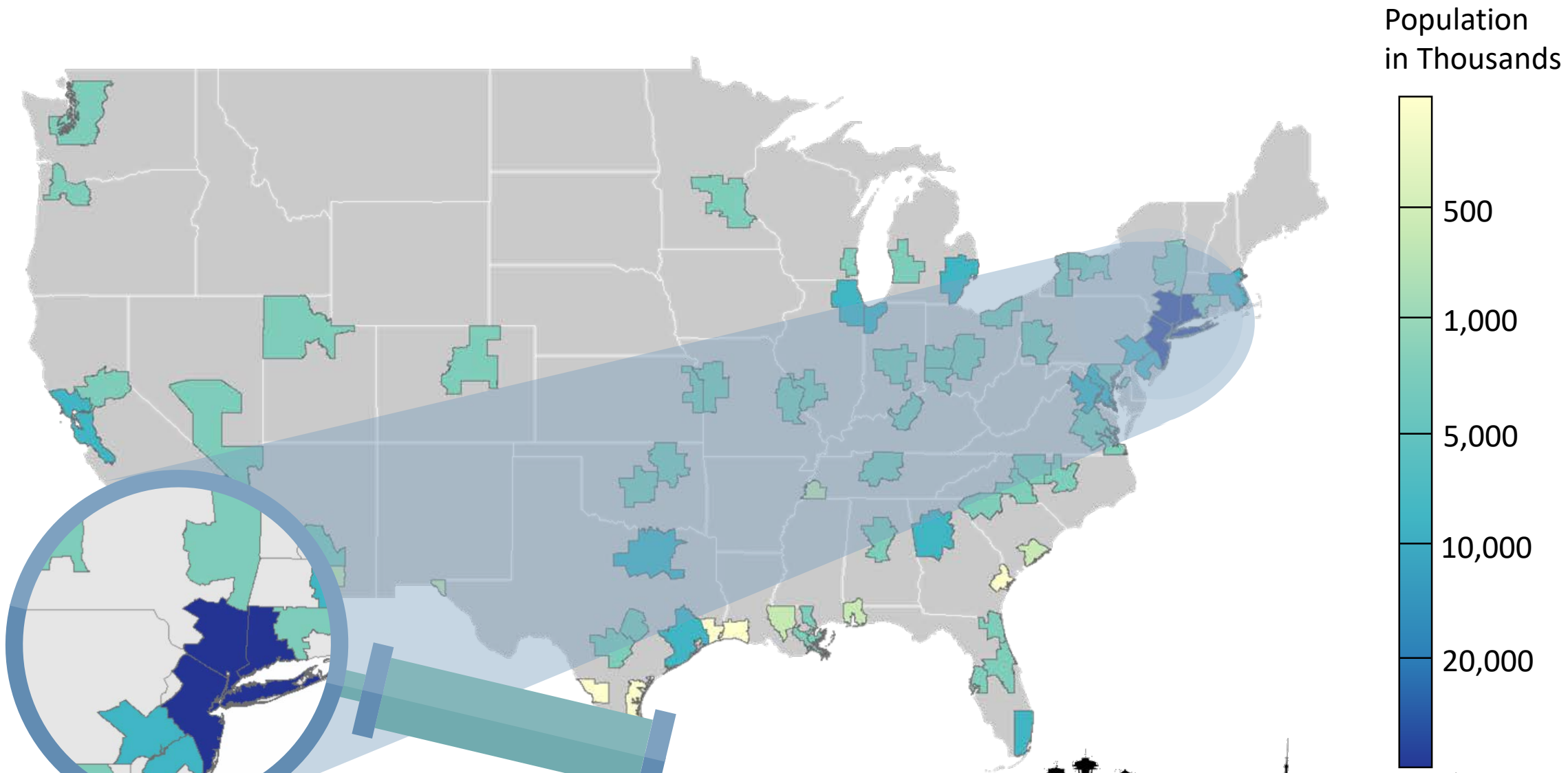
Hypothesis: The presence of hubs, megaregions, and scaling behavior.



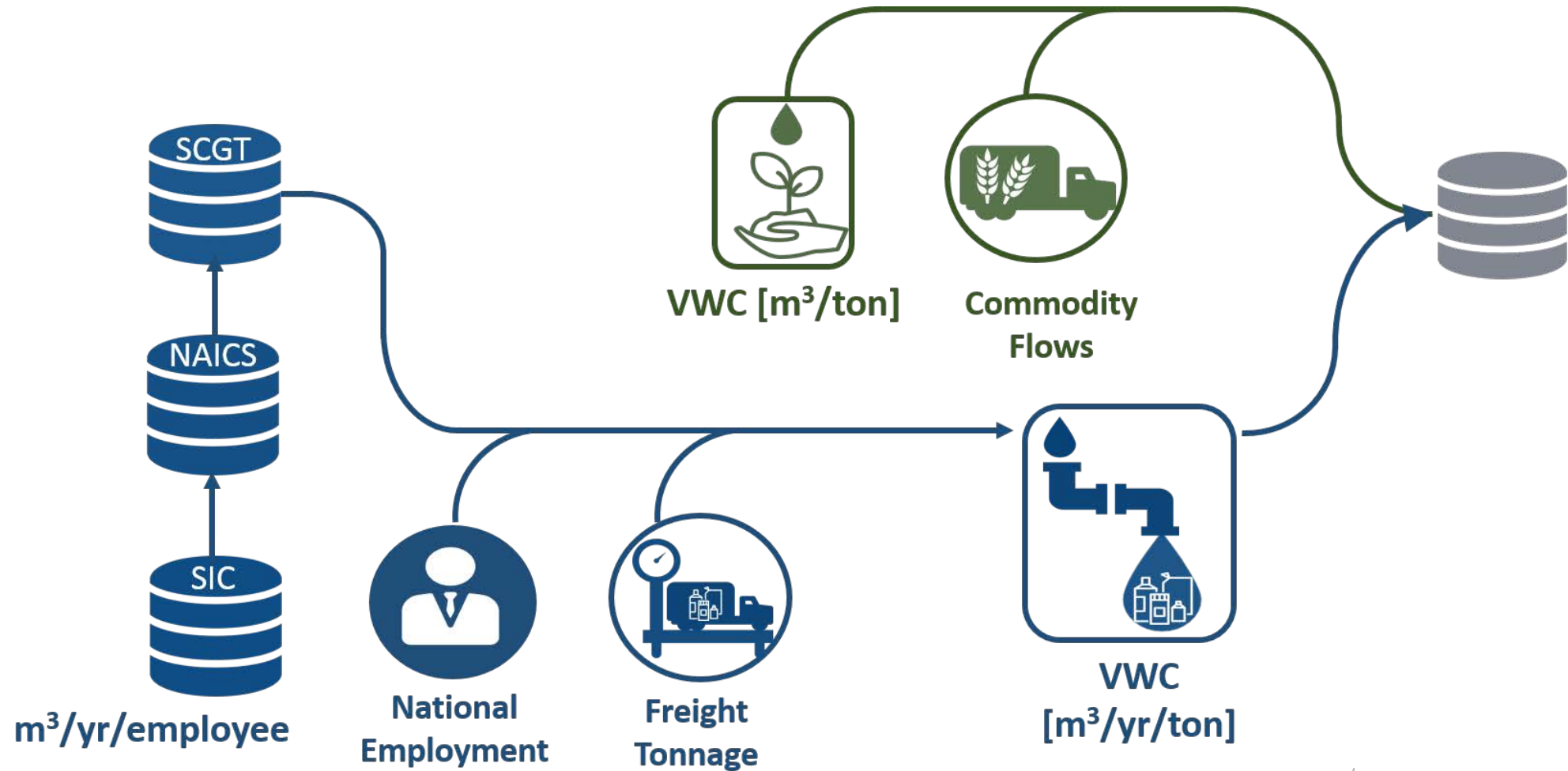
Our study area includes 65 major cities



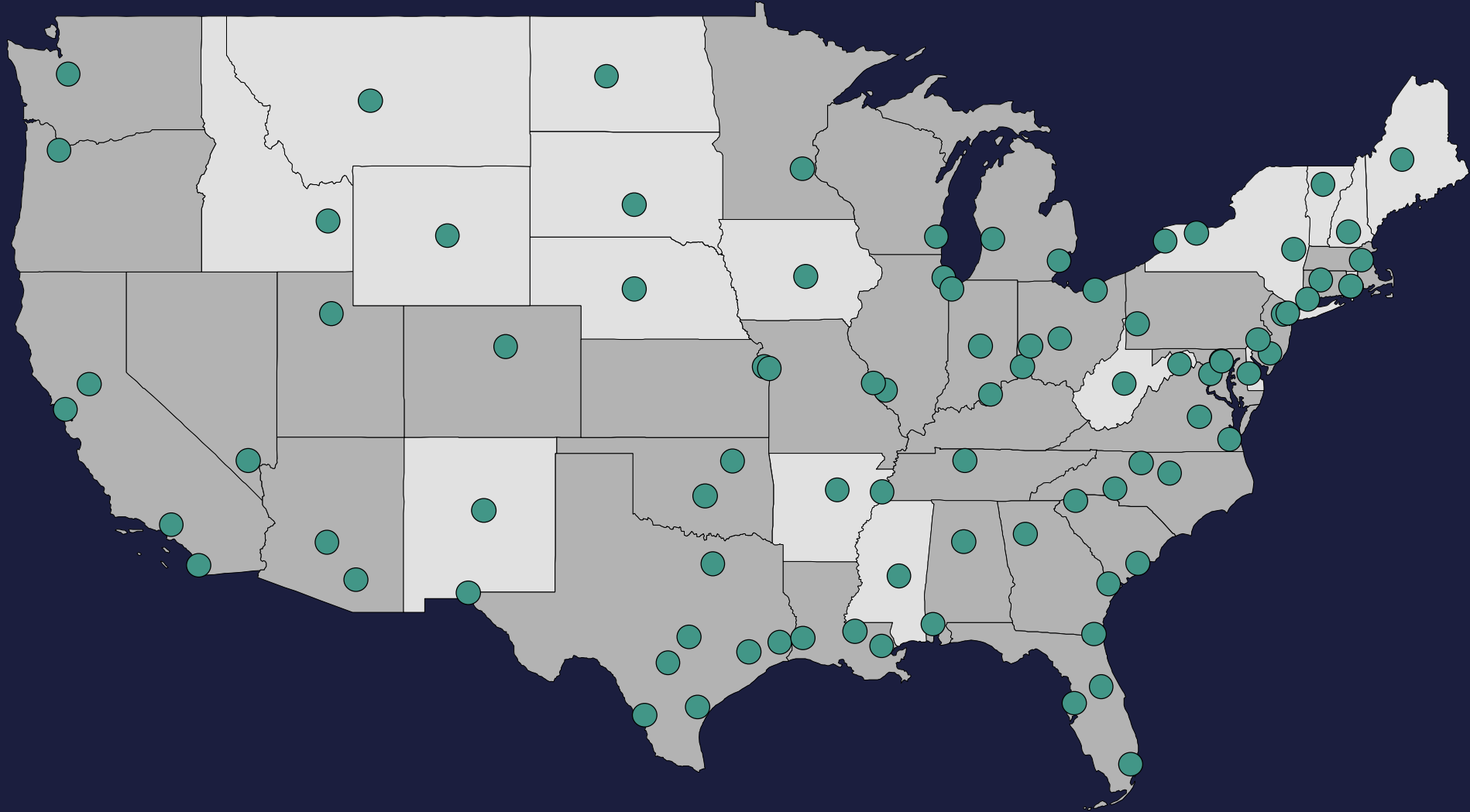
Our study area includes 65 major cities



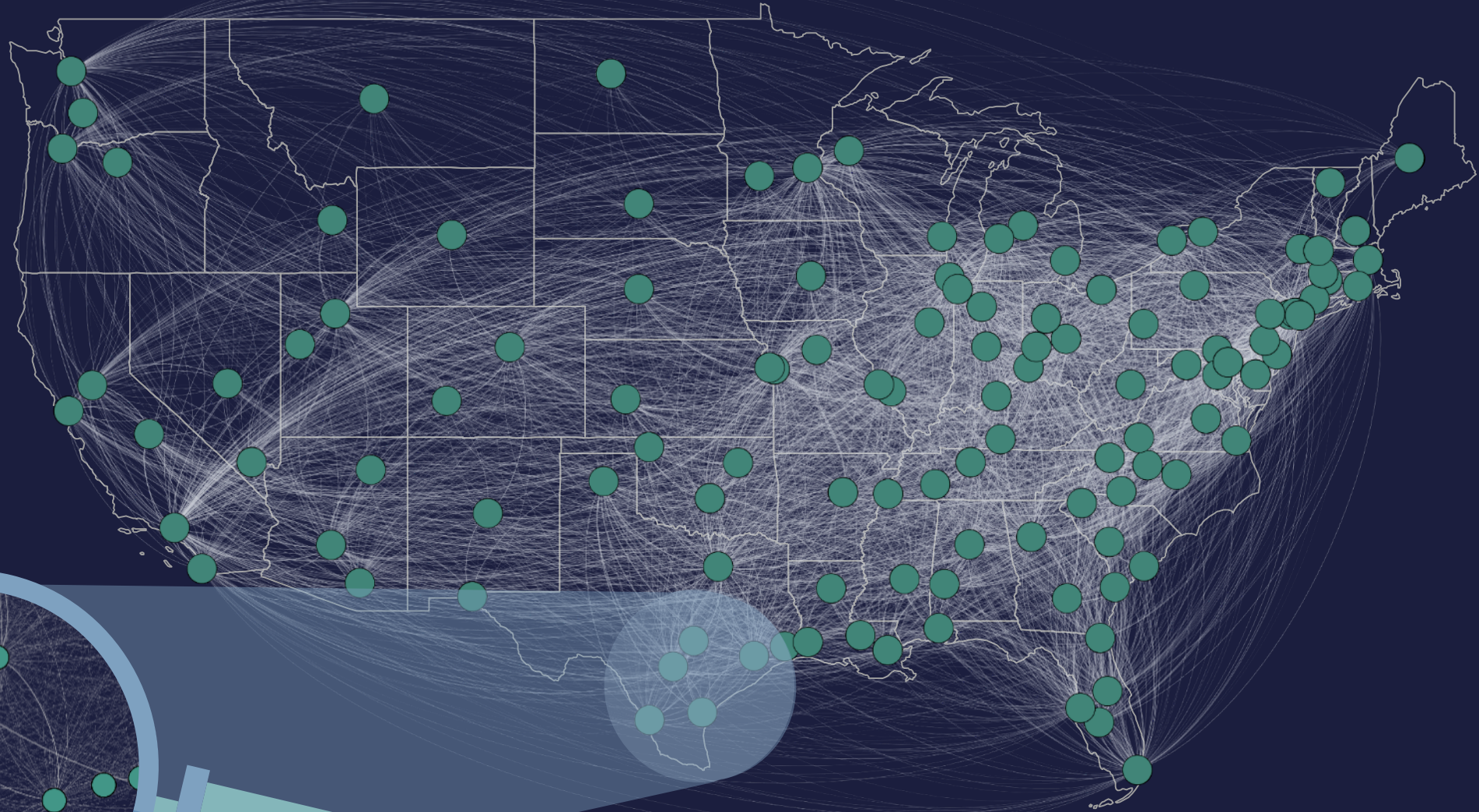
Industrial virtual water from different commodity classification systems



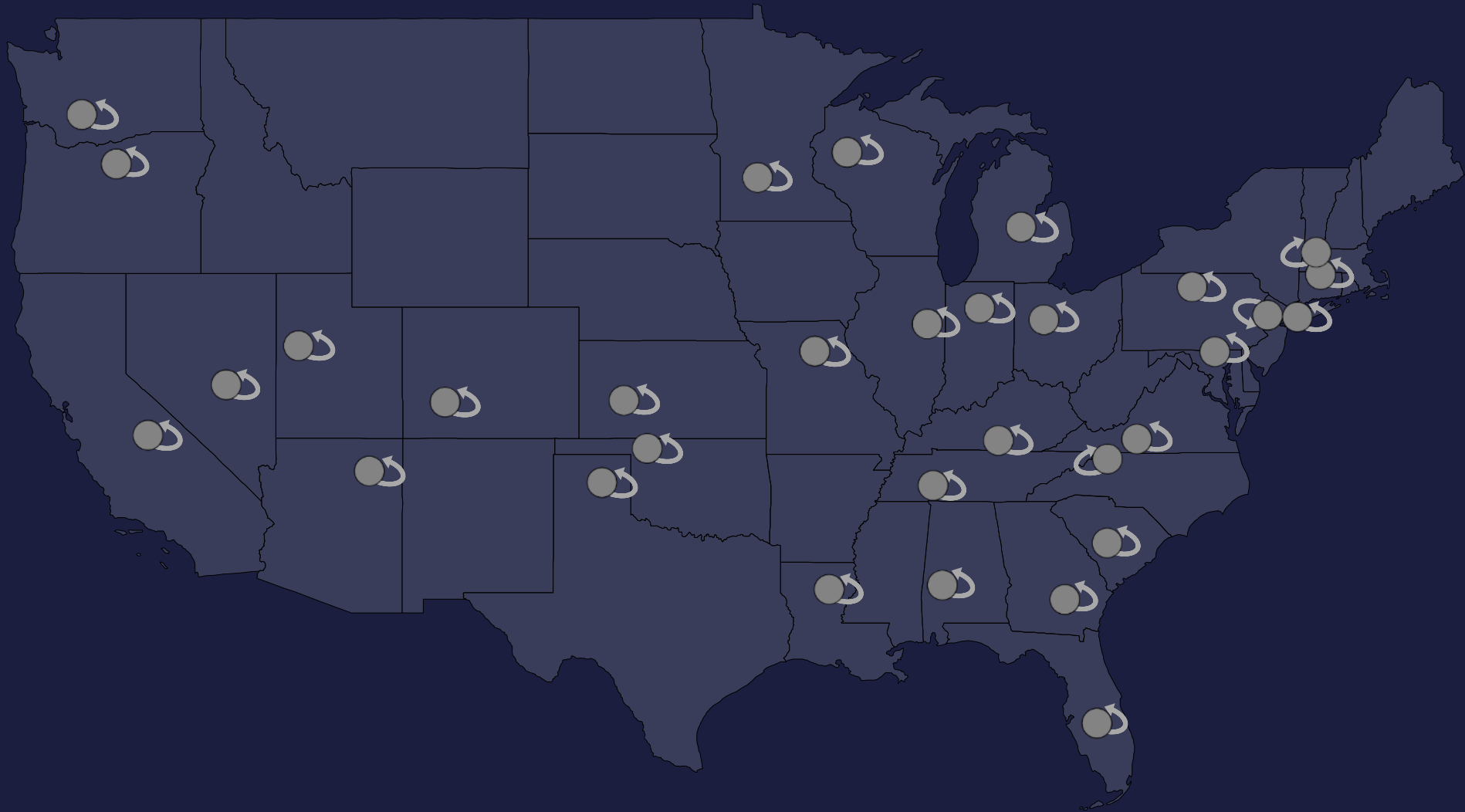
The network is composed of 123 nodes...



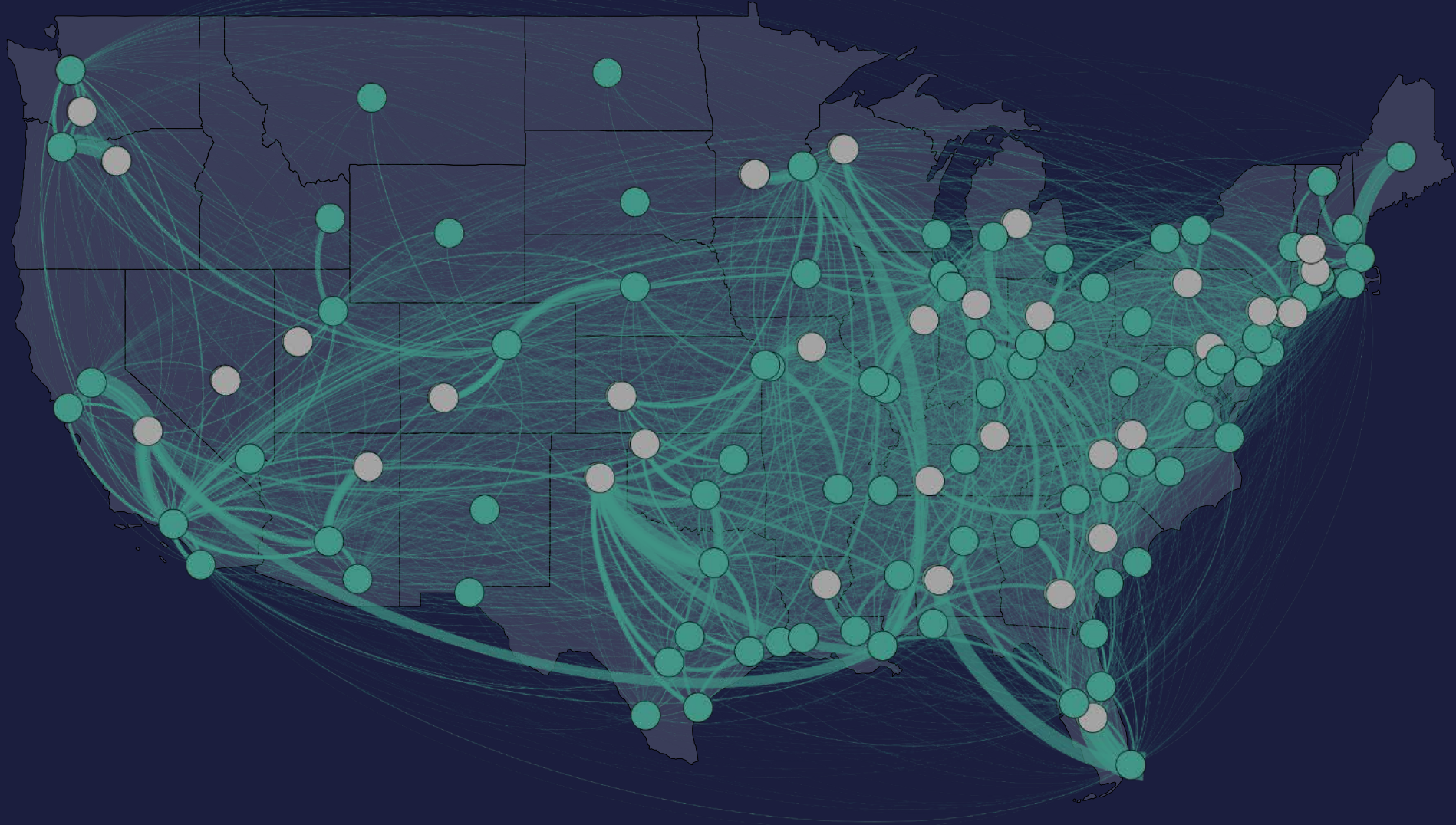
linked through weighted directed edges.



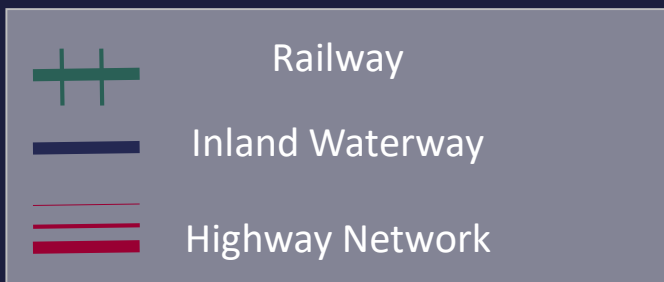
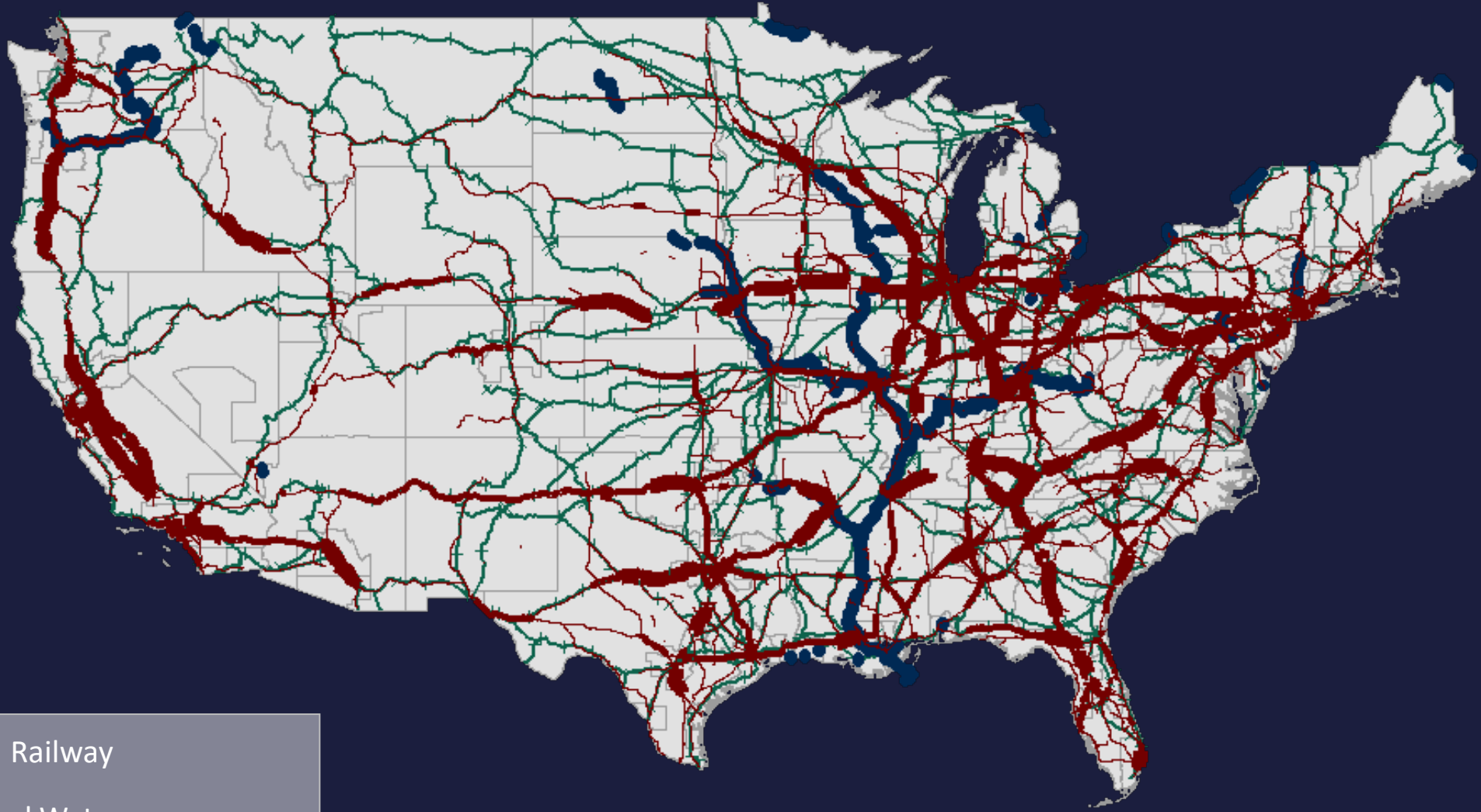
Remainders of states are disconnected components...



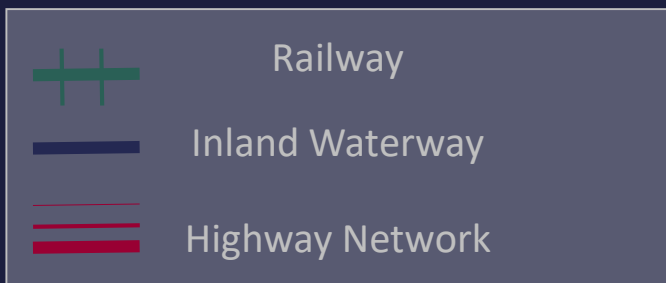
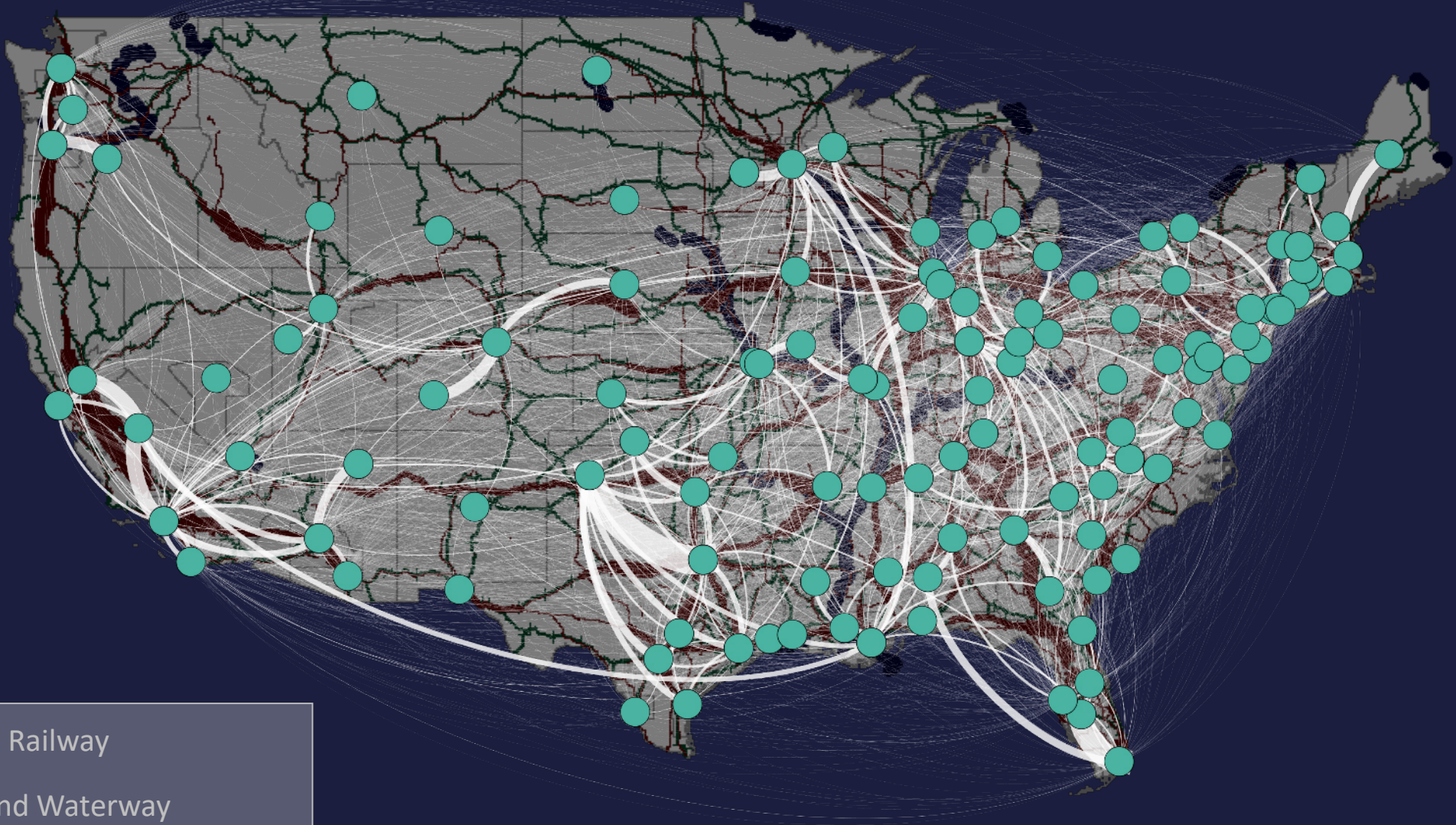
connected through cities.



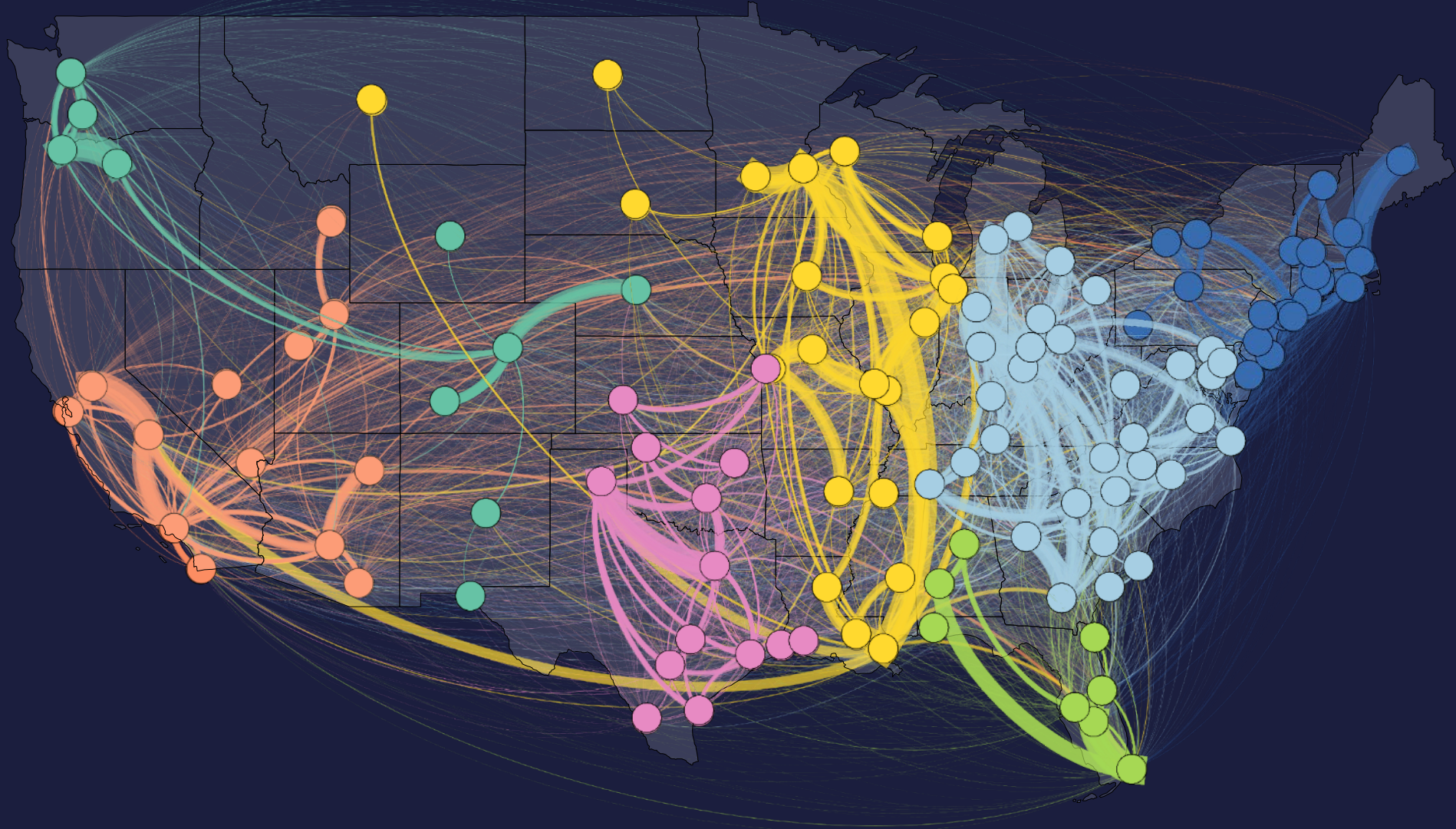
These three freight transportation corridors are essential...



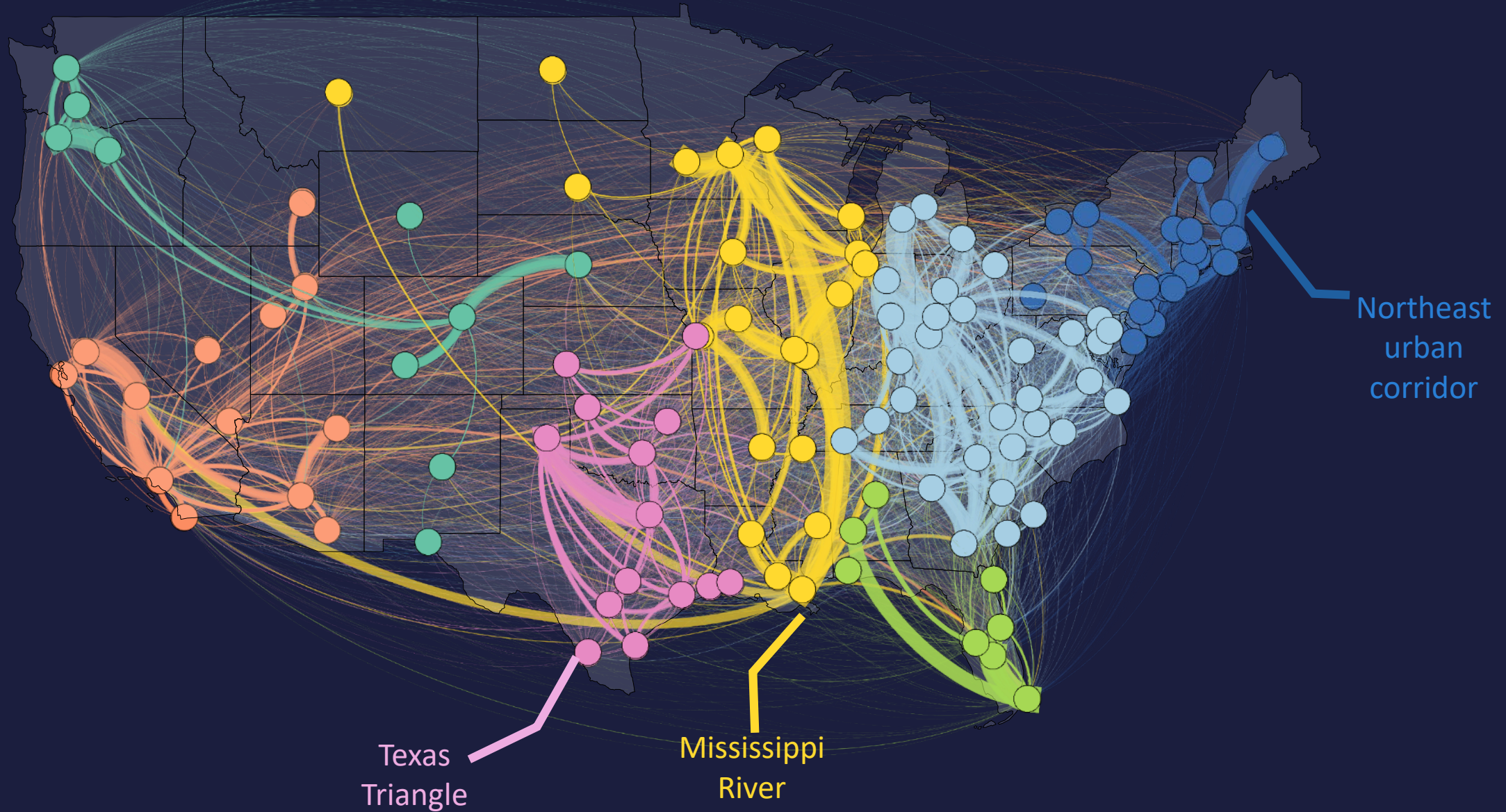
to connect cities



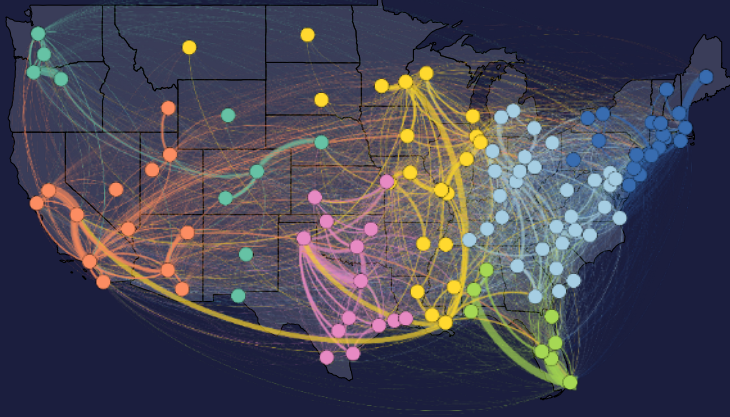
The network presents communities...



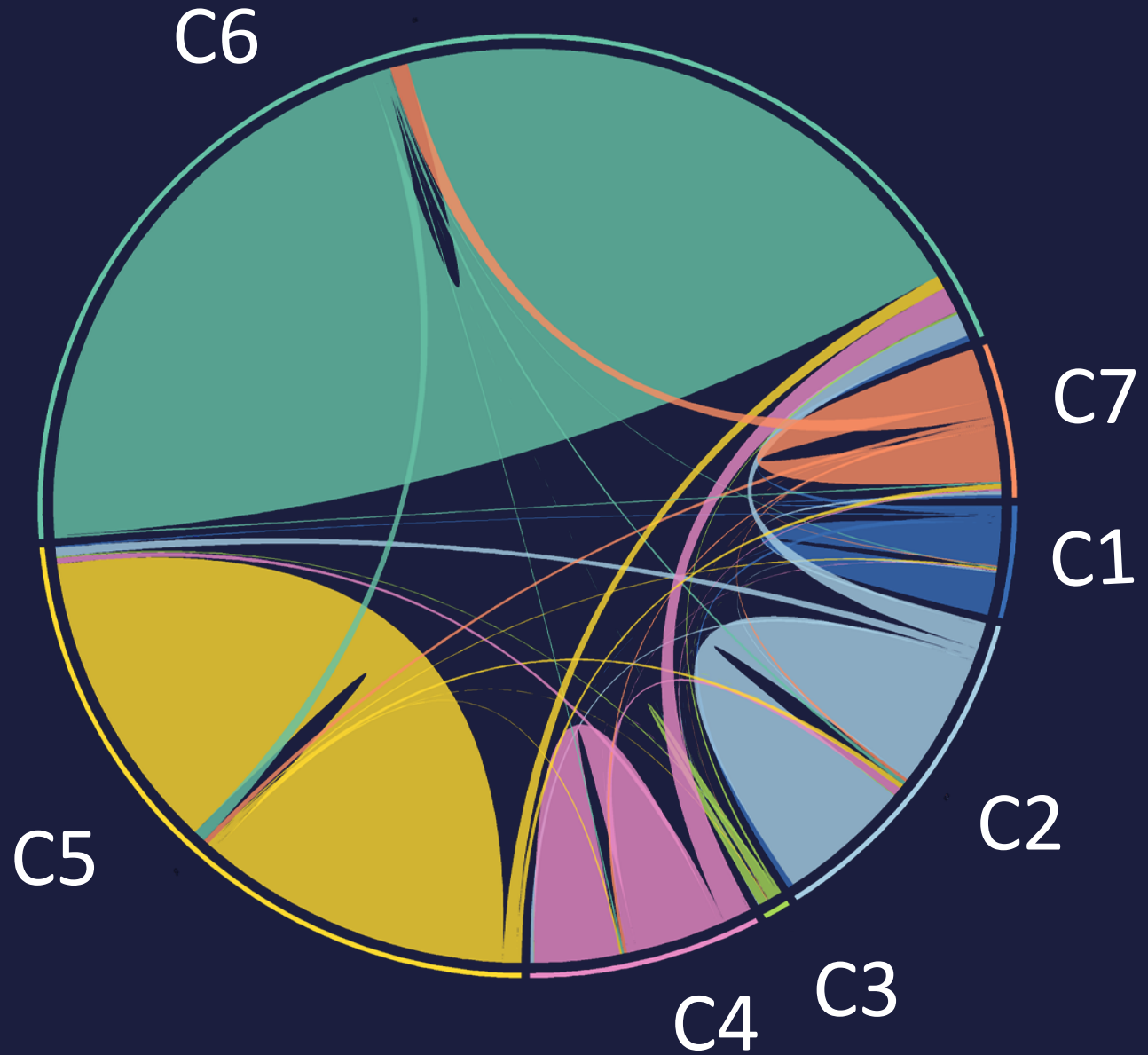
The network presents communities...



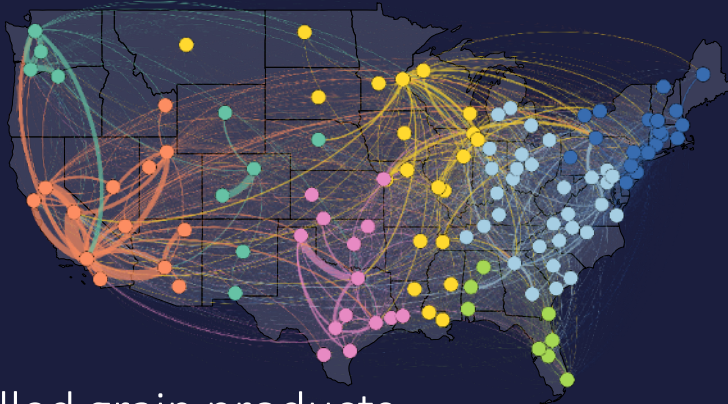
with distinctive connectivity patterns...



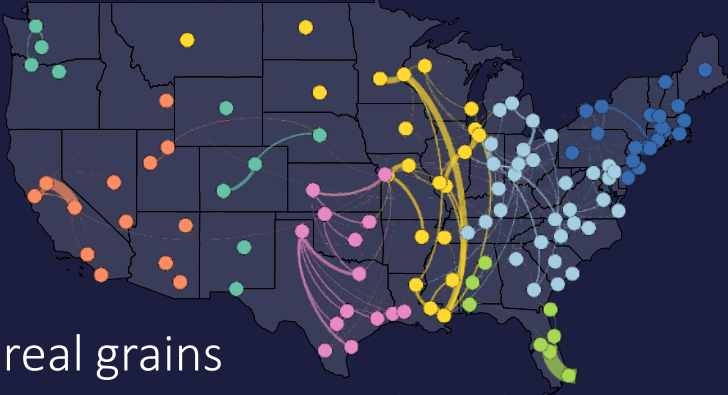
Agricultural WF Flow Across Communities



that vary across commodities.



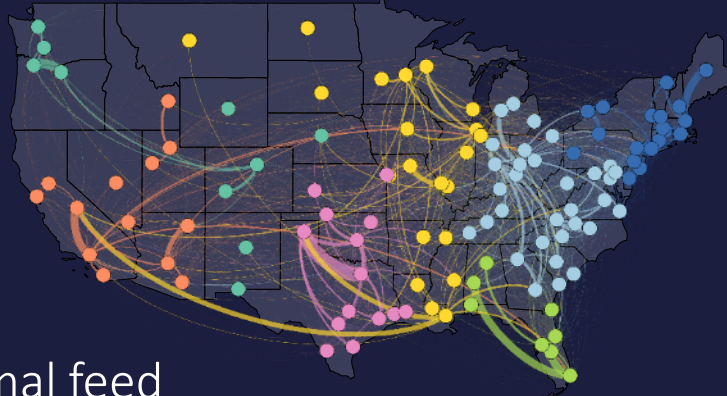
Milled grain products



Cereal grains



Meat & seafood

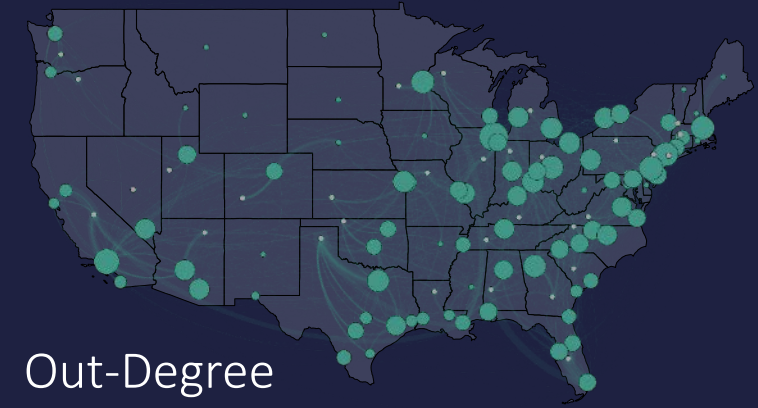
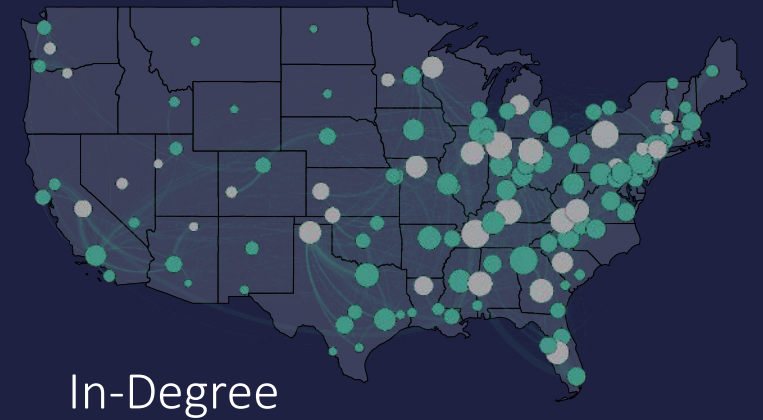
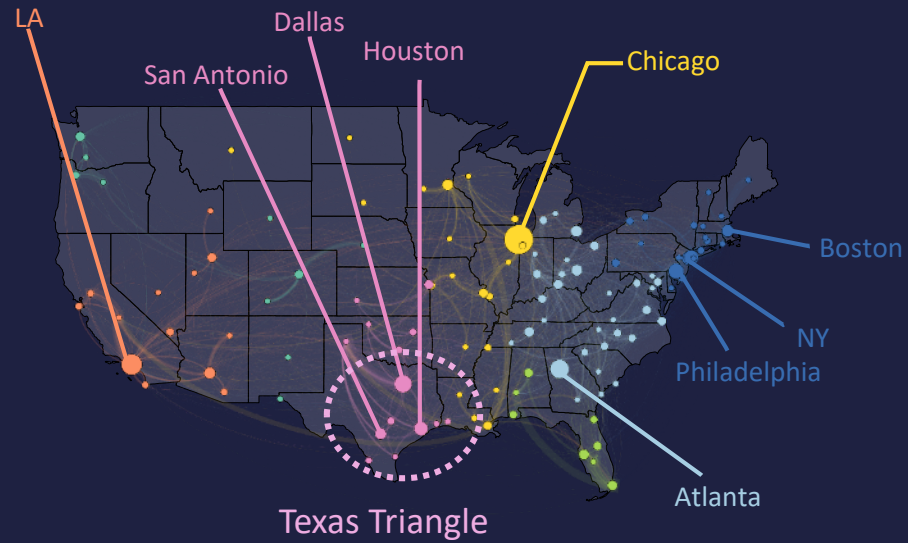
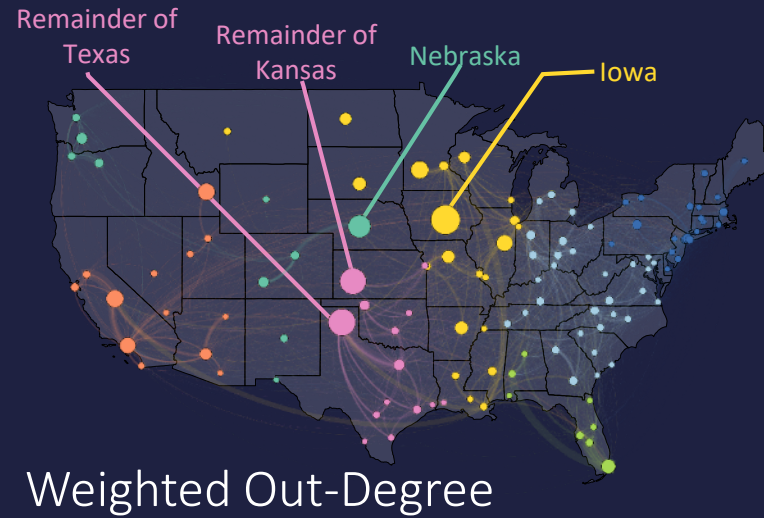
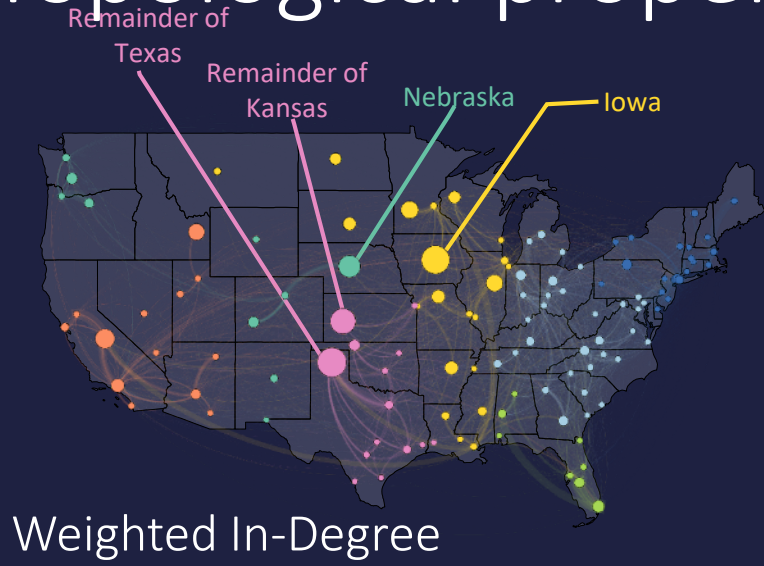


Animal feed

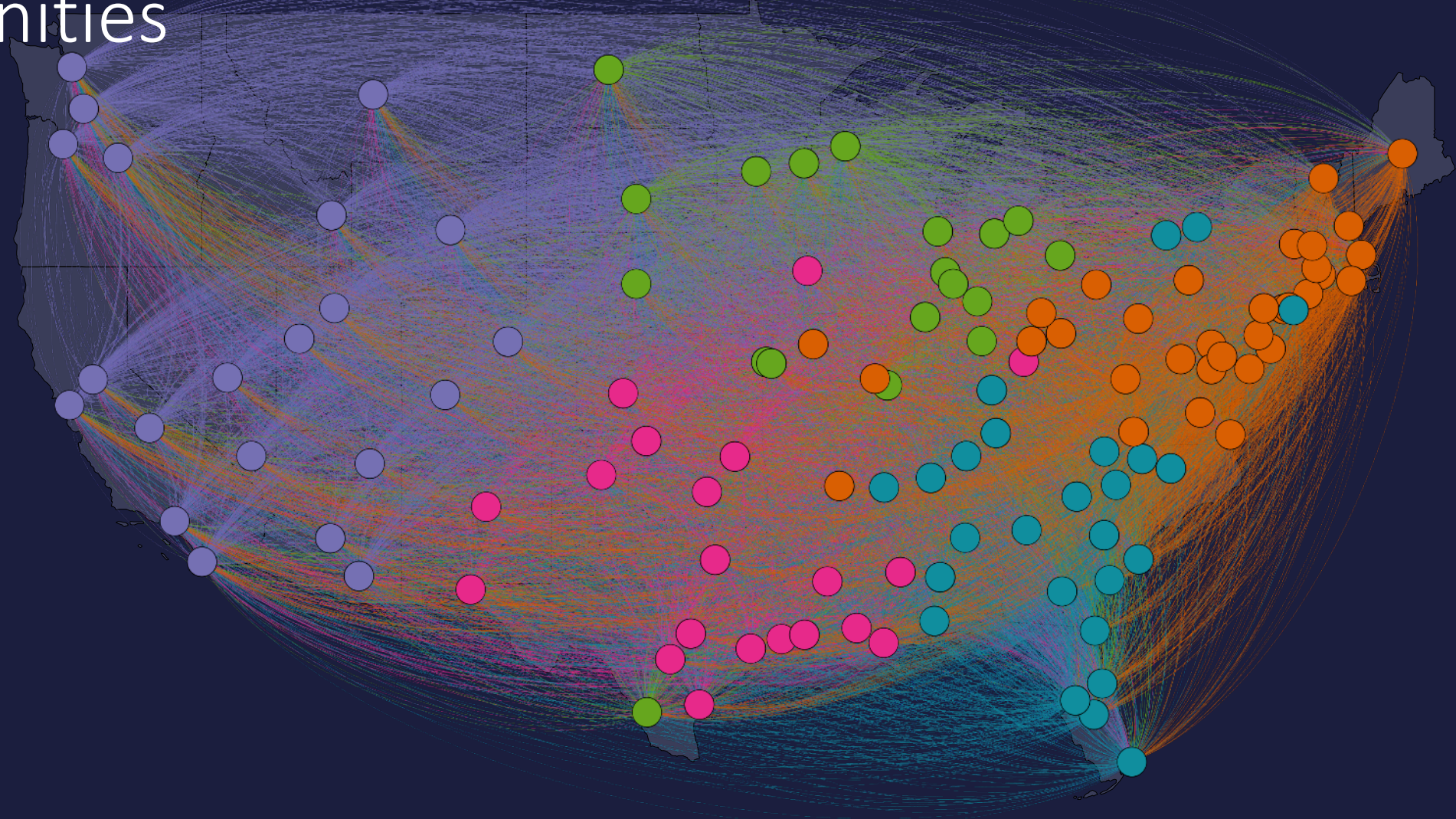


Live animals & fish

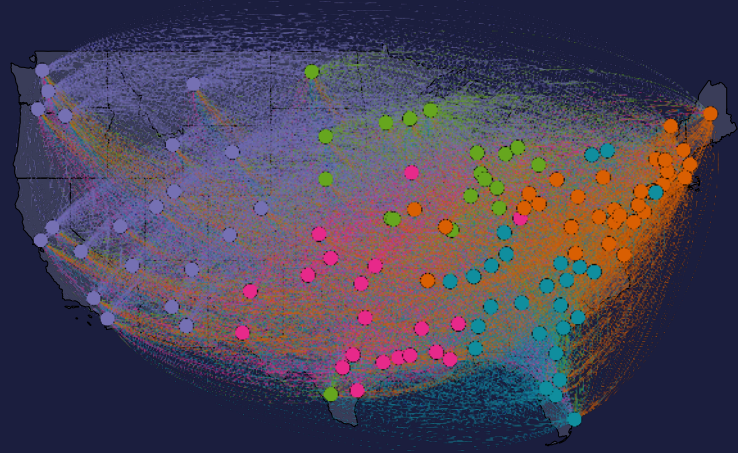
Topological properties show the presence of hubs



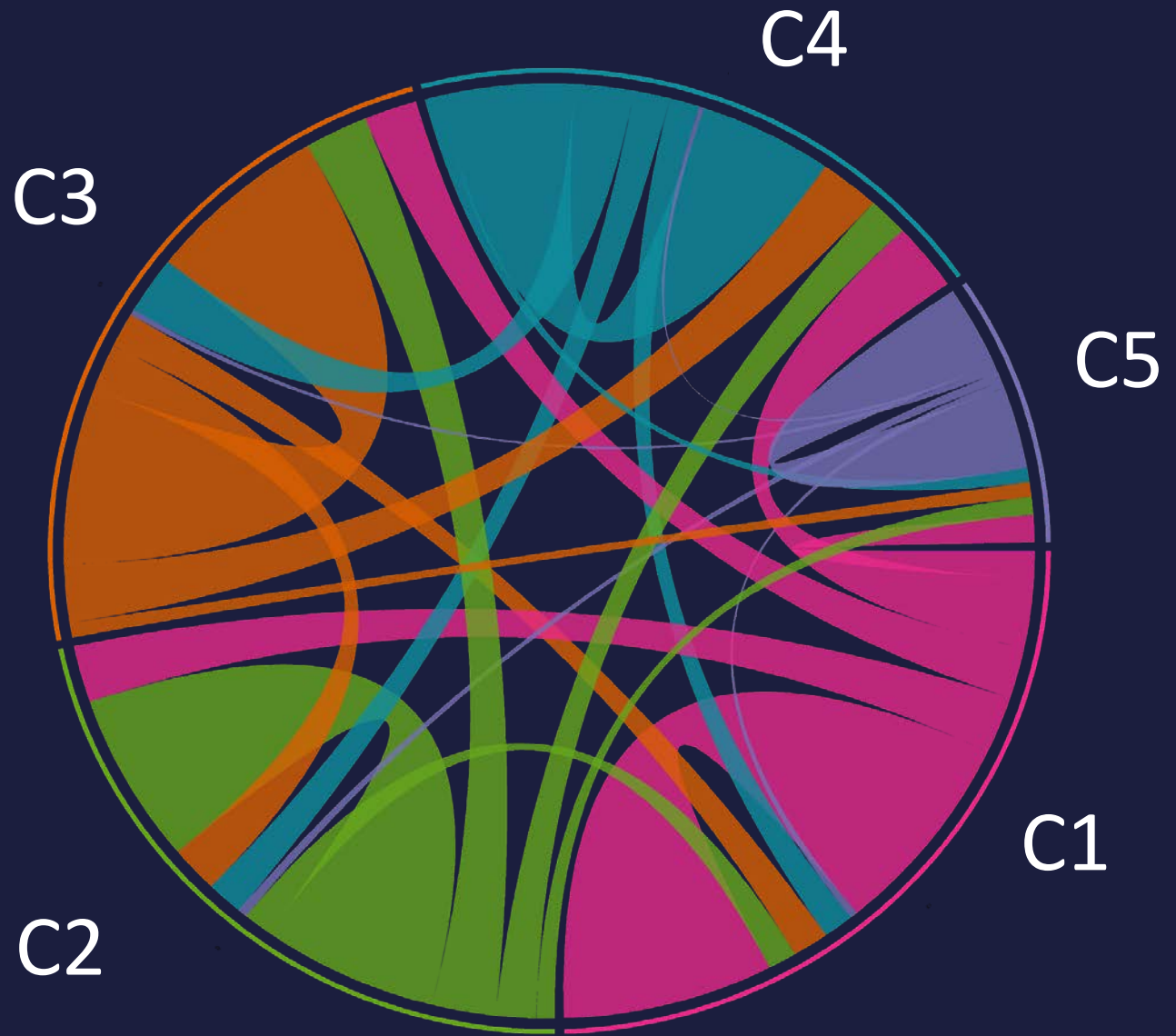
The industrial WF network shows a different set of communities



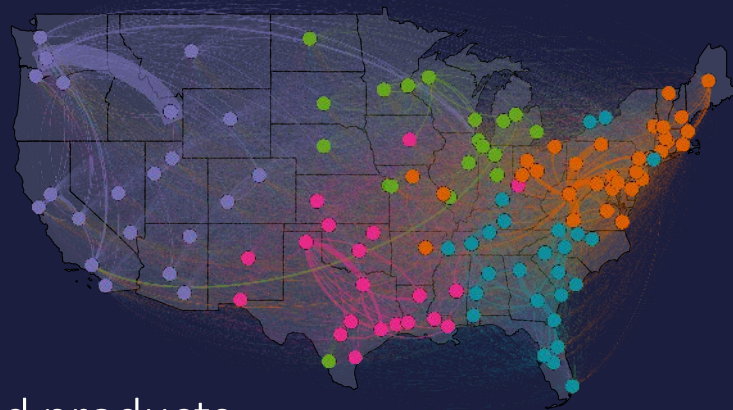
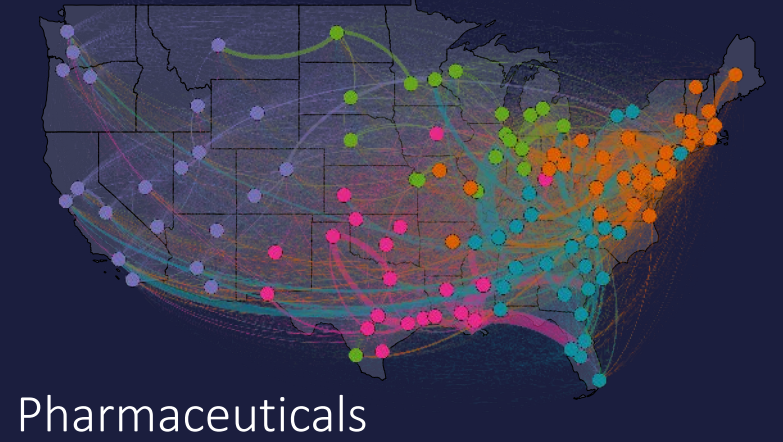
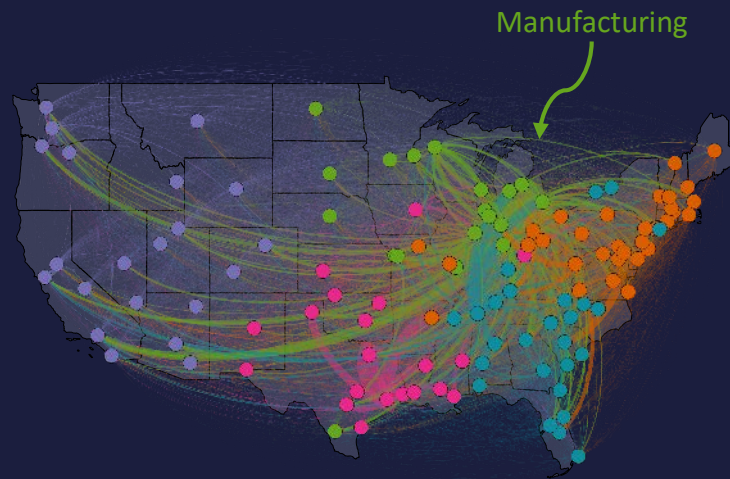
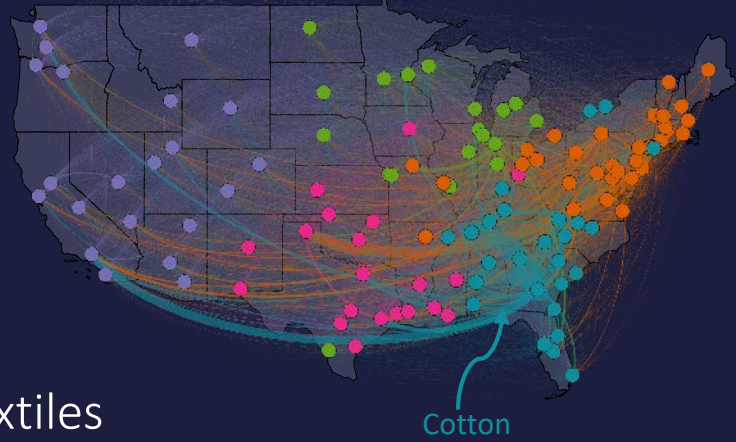
With a more homogeneous connectivity



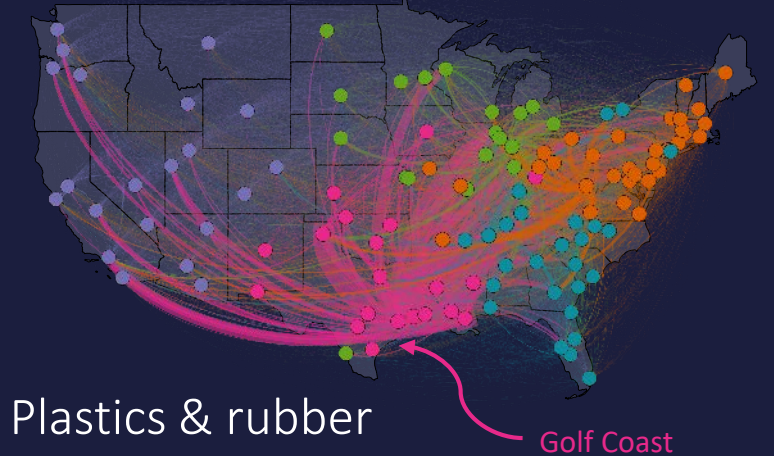
Industrial WF Flow Across Communities



And distinctive connectivity patterns that vary across commodities



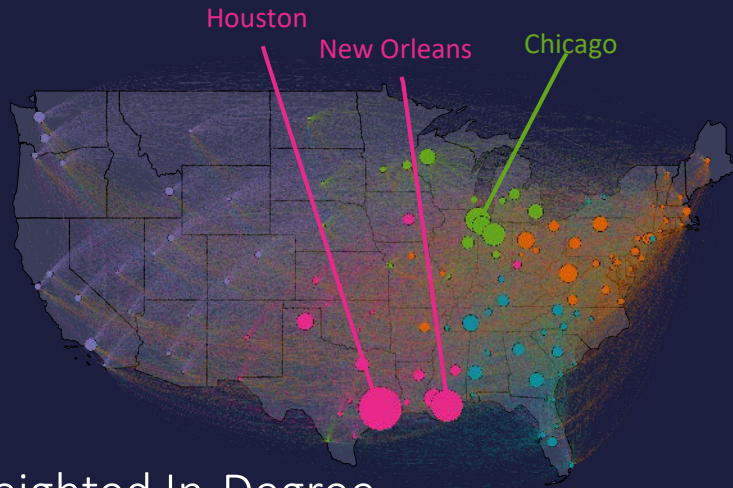
Motorized Vehicles



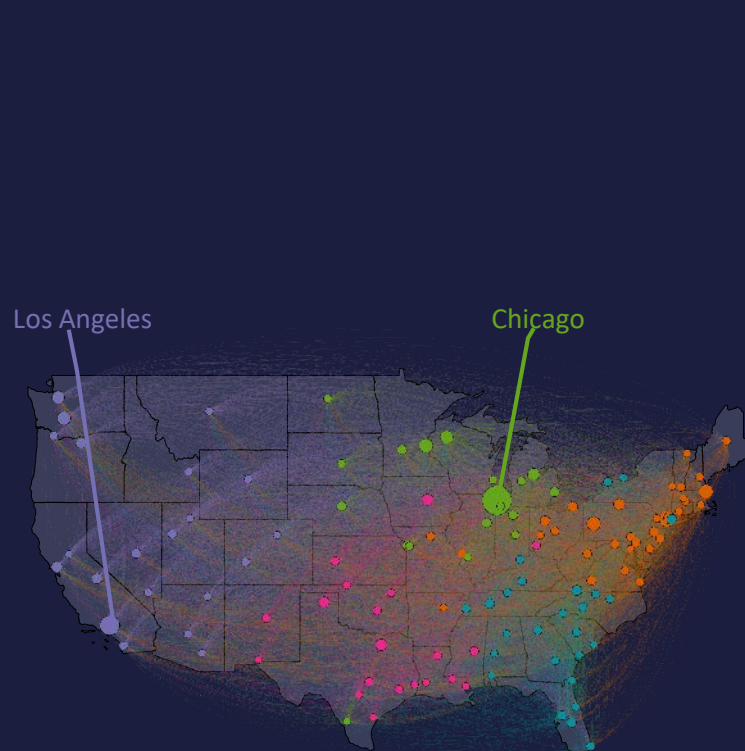
Wood products

Plastics & rubber

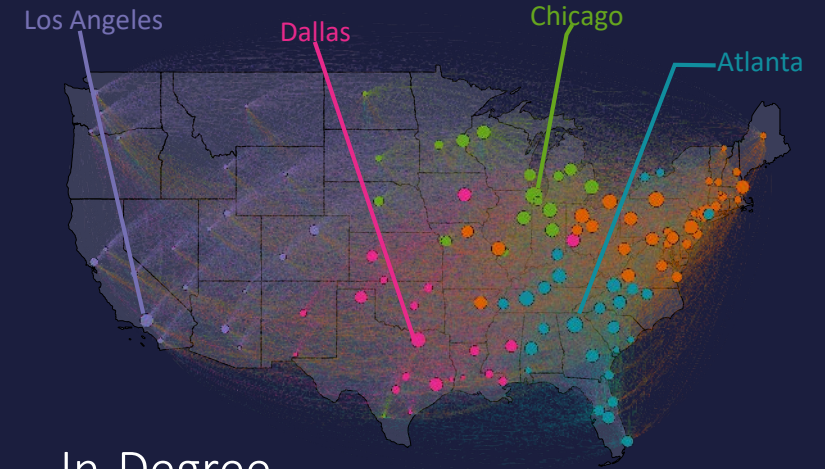
Topological properties also shows the presence of hubs



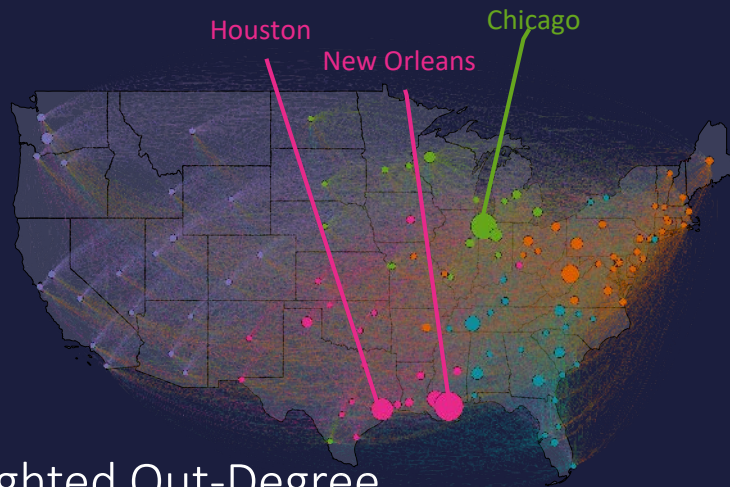
Weighted In-Degree



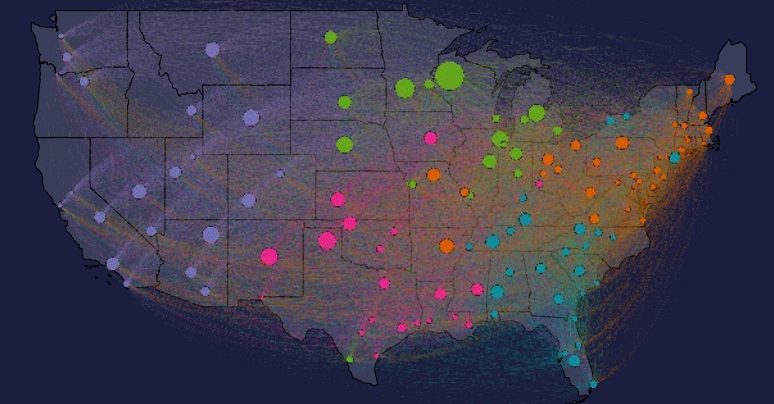
Betweenness Centrality



In-Degree



Weighted Out-Degree

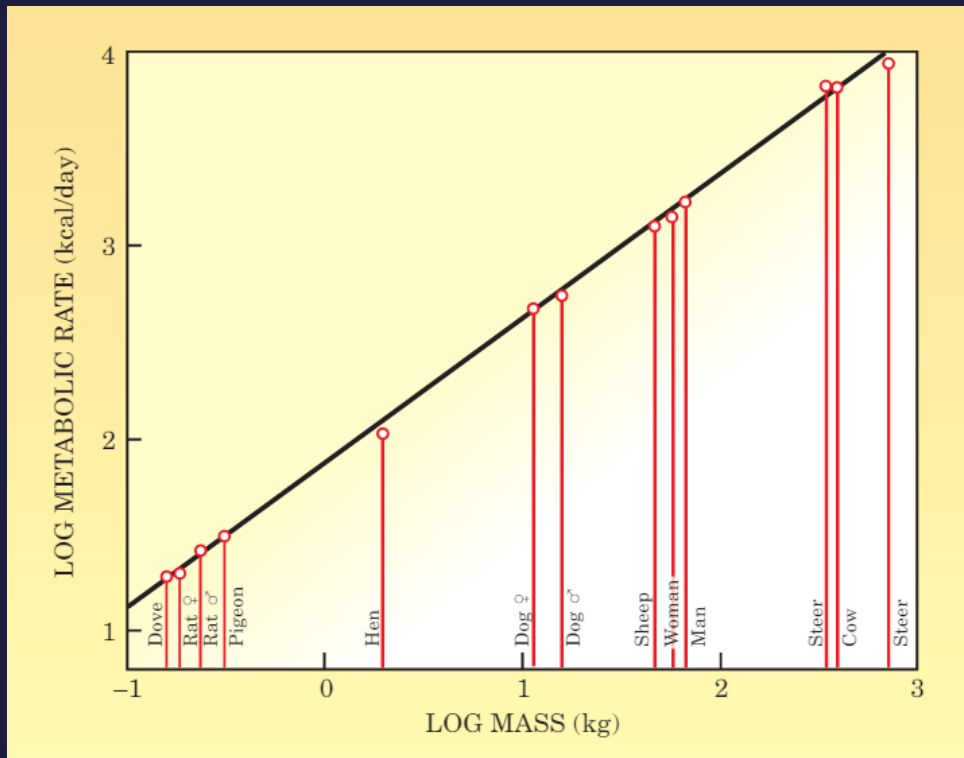


Out-Degree

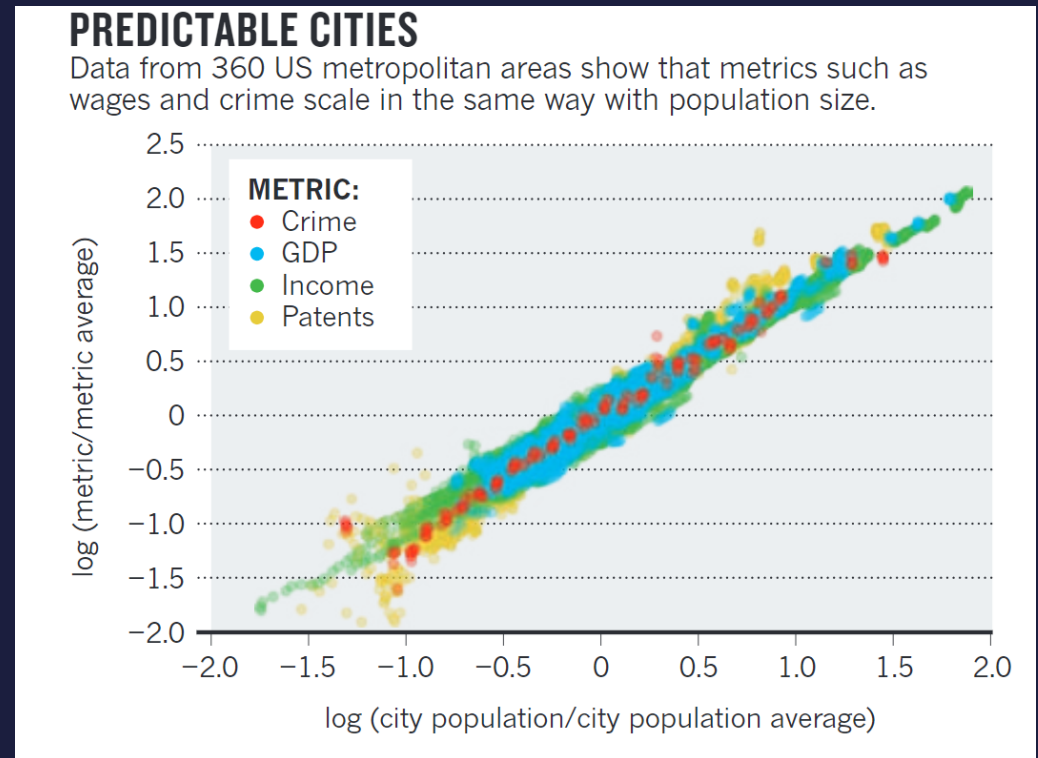
Scaling Behavior

“Life at all scales is sustained by optimized, space filling, hierarchical branching networks, which grow with the size of the organism as uniquely specified approximately self similar structures”.

Luis Bettencourt – Santa Fe Institute

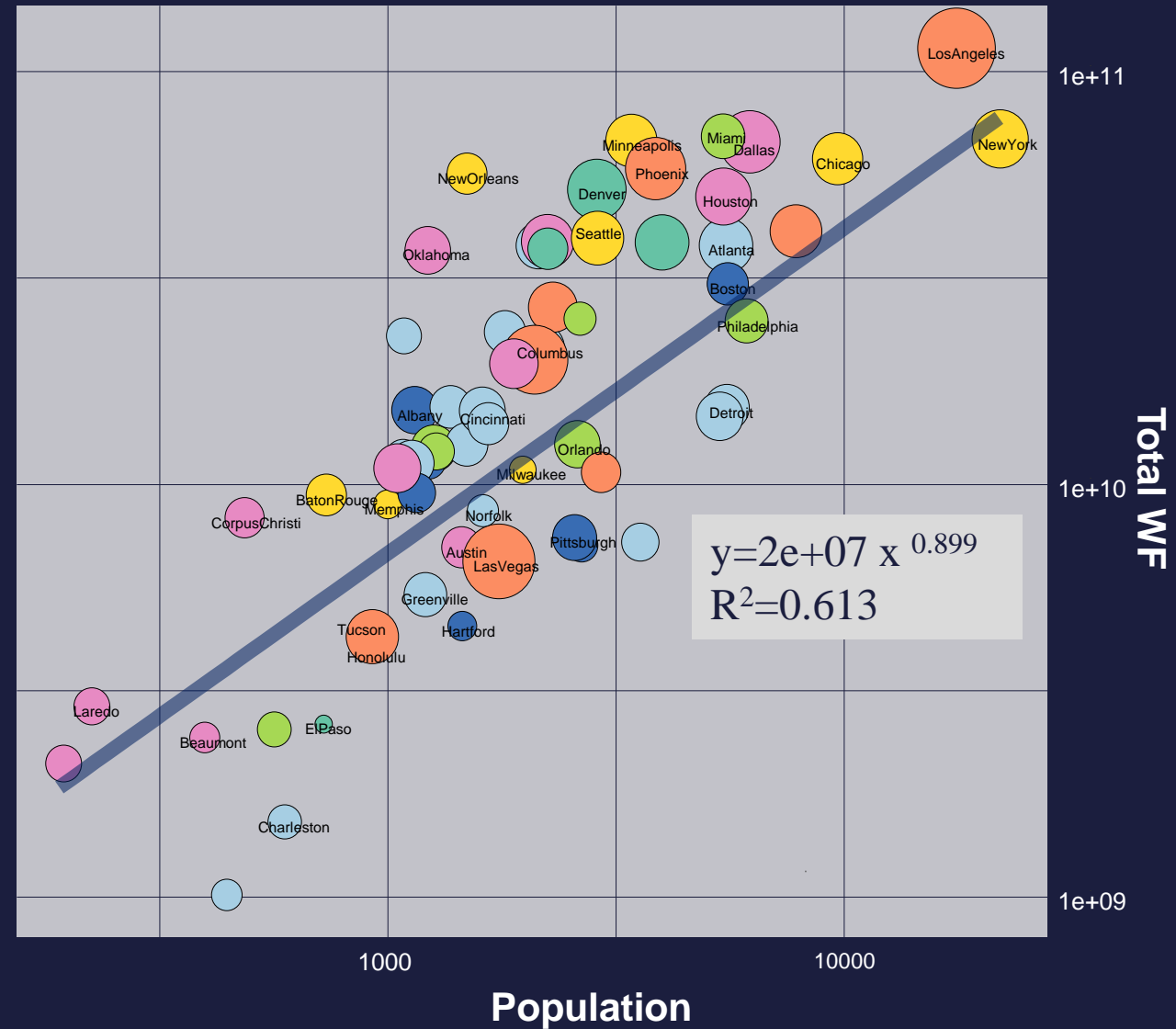
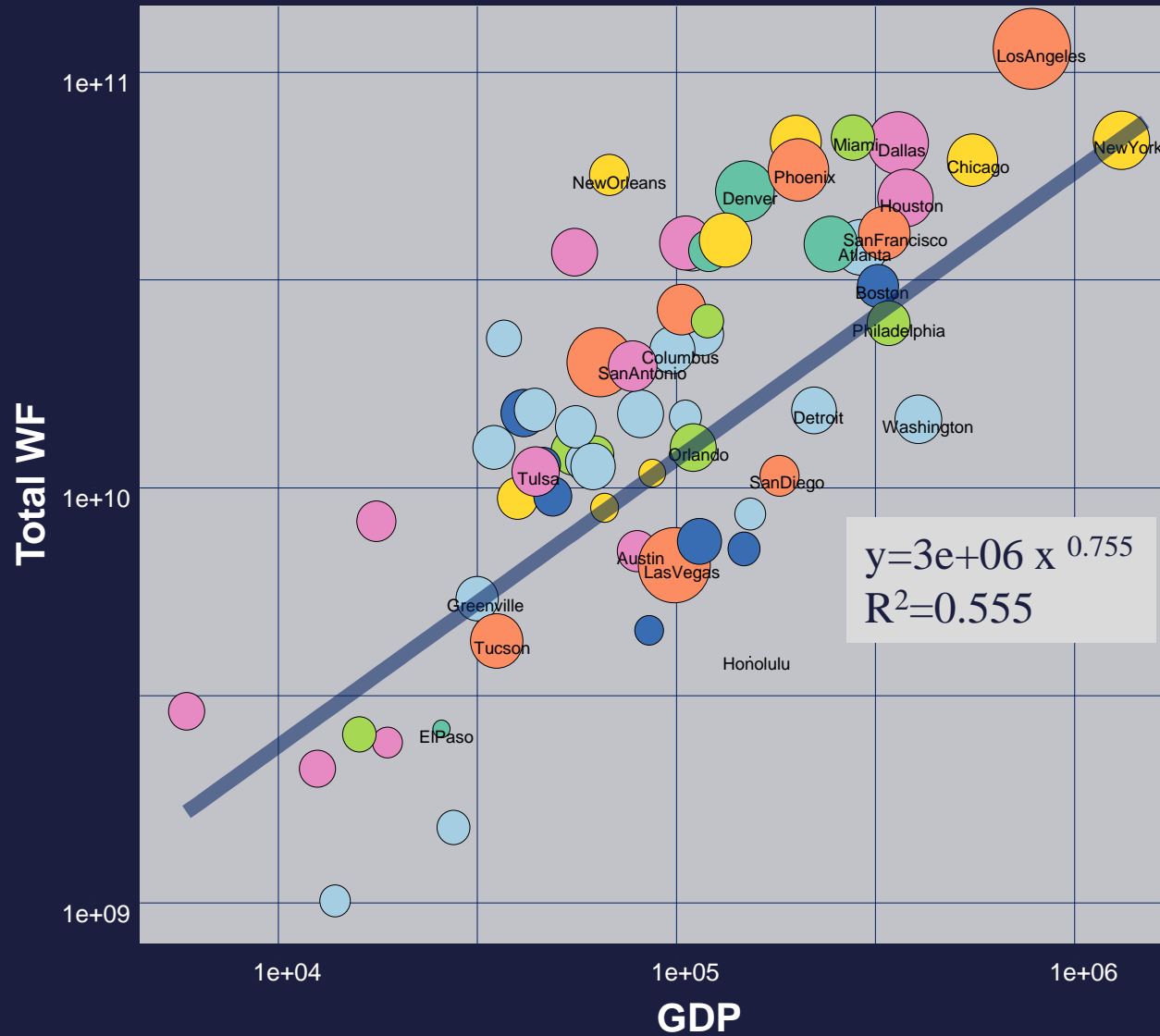


Source: Life's Universal Scaling Laws. Geoffrey West. *Physics Today*, 2004..
Originally plotted by Max Kleiber in 1932.



Source: A Unified Theory of Urban Living. Luis Bettencourt. *Nature*, 2010.

Cities present scaling behavior



Color based on community and size based on city area

Summarizing...

- Large US cities have a lower domestic WF per capita than small cities
- Future work should seek to understand how to best invest in food production, water resources, and transportation infrastructure in critical nodes
- This provides policy makers at the city level with information to allocate their water resources better.

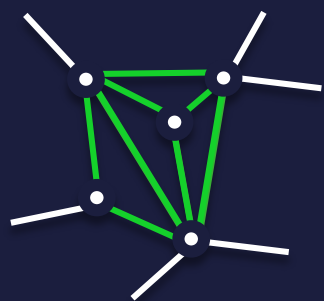
Our work will be expanded to

- Include a temporal component
- Analyze cascading effects and vulnerabilities in the network

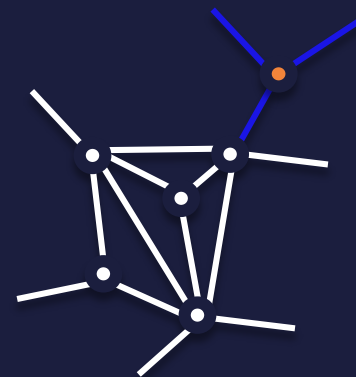
Questions?

How are communities detected?

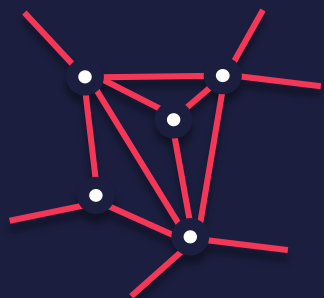
$$\Delta Q = \left[\frac{\sum_{in} + 2k_{i,in}}{2m} \left(\frac{\sum_{tot} + k_i}{2m} \right)^2 \right] - \left[\frac{\sum_{in}}{2m} \left(\frac{\sum_{tot}}{2m} \right)^2 - \left(\frac{k_i}{2m} \right)^2 \right]$$



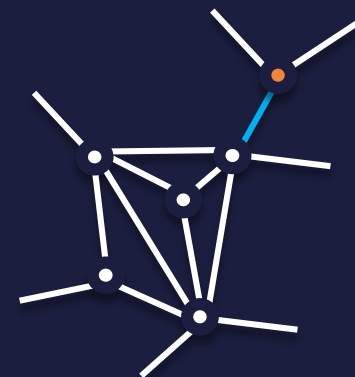
Sum of weights of links inside community C



Sum of weights of links incident to nodes i



Sum of weights of links incident to nodes in community



Sum of weights of links from i to nodes in

m

Normalization factor. The sum of the weights across the network

Sources of data



United States
Department of Transportation

Domestic commodity flow



Domestic, commercial and industrial water use

IWR-MAIN

Industrial water use coefficients



Industrial sector employees, Population



Agricultural virtual water content



United States Department of Agriculture

Agricultural production



U.S. Department of Commerce

Bureau of Economic Analysis

GDP