National Energy & Transportation Infrastructure Design

National Energy & Transportation Sustainability, Cost, & Resiliency
NETSCORE21
Research Project

http://www.ece.iastate.edu/research/netscore-21/

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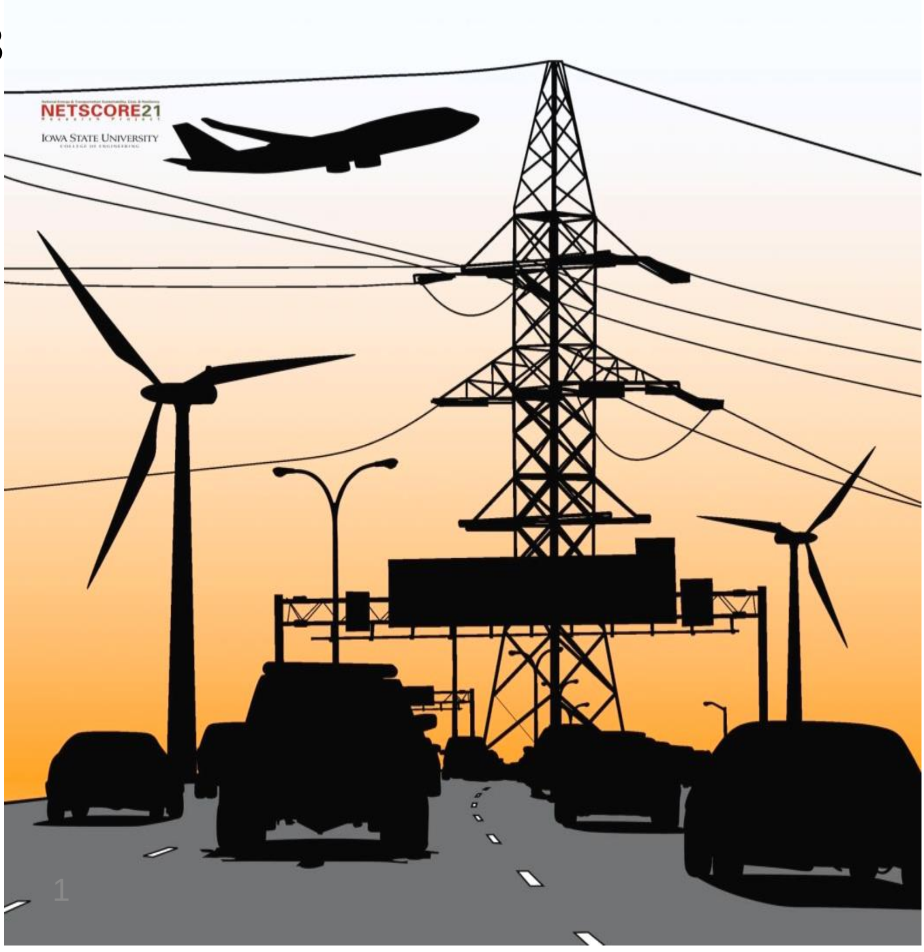
Presented at the Workshop on Energy, Transportation & Water Infrastructures: Policy & Social Perspectives
Iowa State University
July 18, 2013



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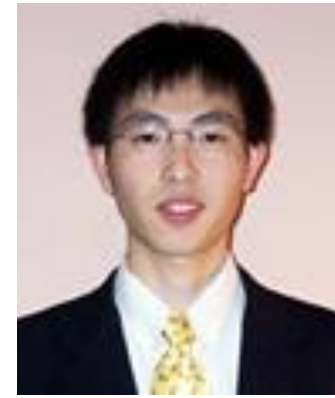

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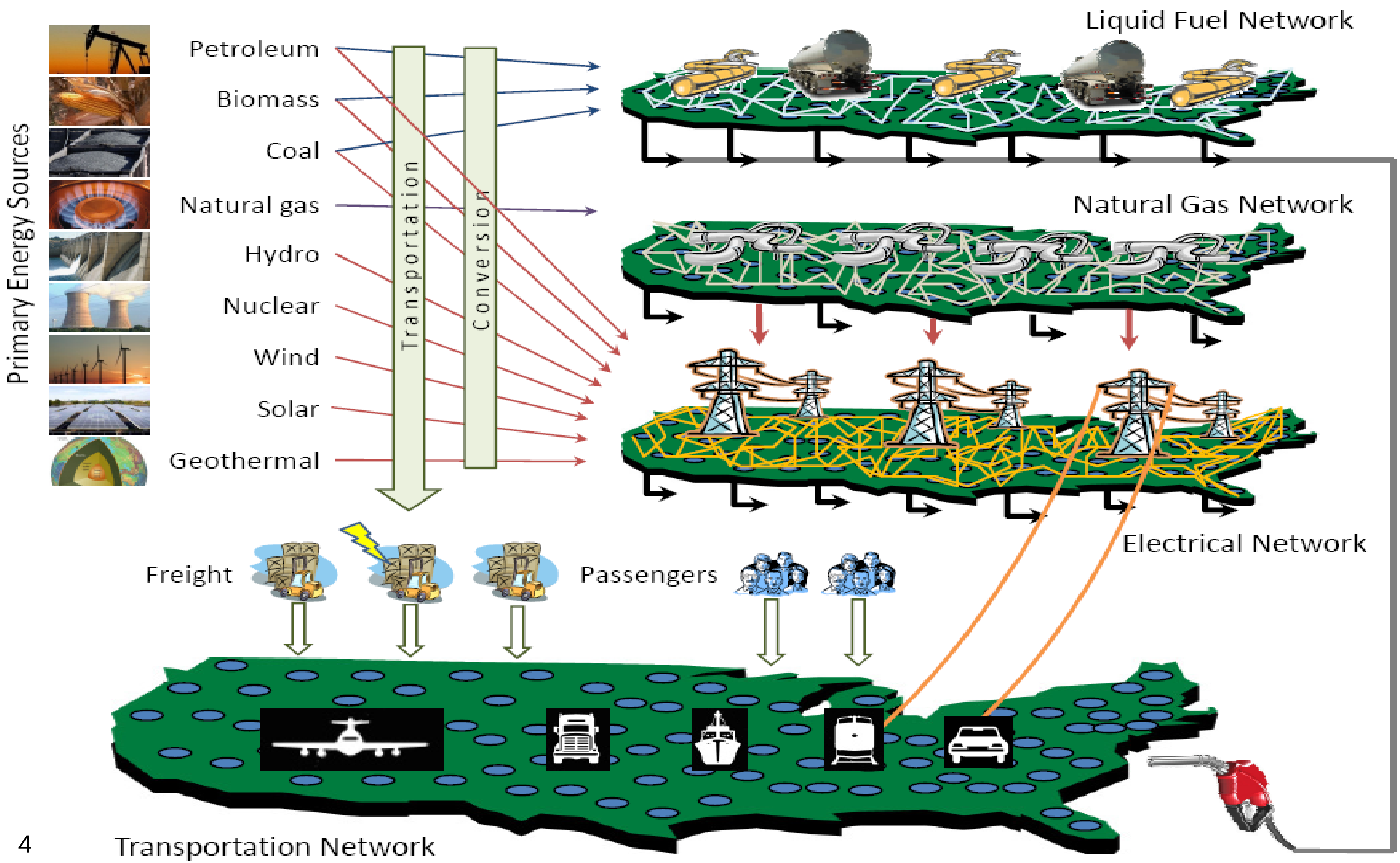
and 7 Senior design teams
and Iowa Lakes Community College

Overview

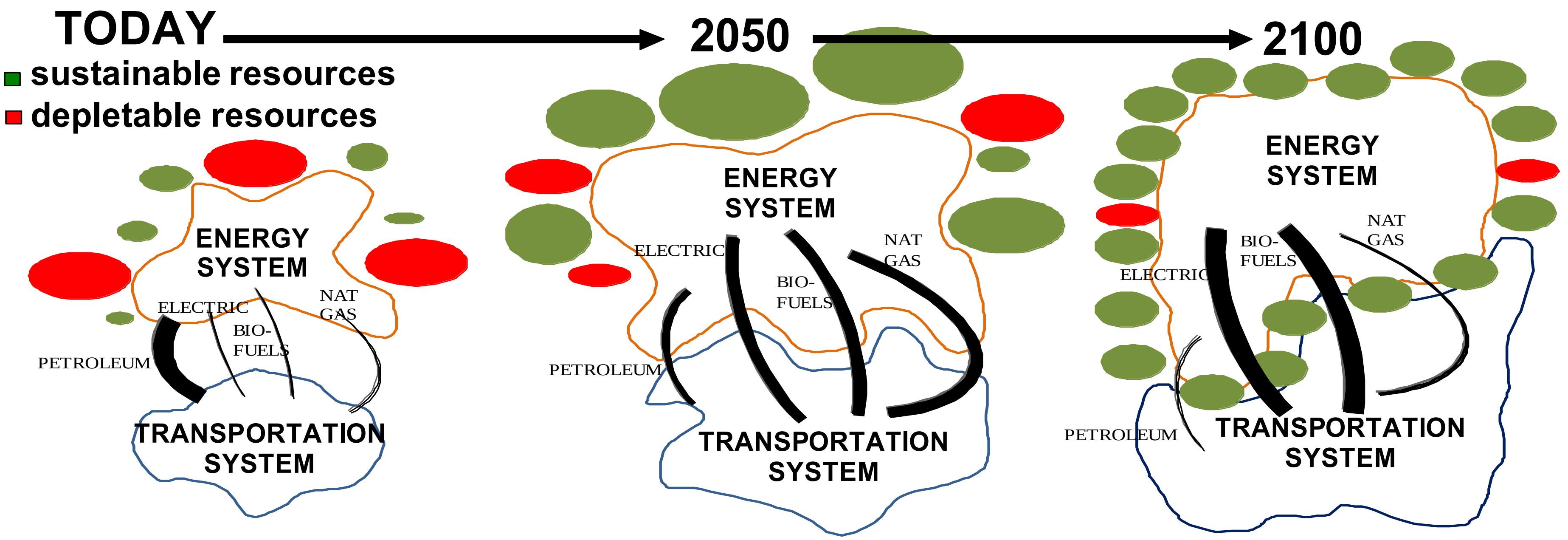
<u>OBJECTIVE OF THIS PRESENTATION</u>:
Describe several infrastructure enhancements for energy and transportation; illustrate the power of computational models for exploring the future; and characterize the different policy approaches for moving these forward.

1. **Orientation of work**
2. **Modeling approach**
3. **Design results**
   a. **High-speed rail**
   b. **Generation**
   c. **Flex-fuel polygeneration**
   d. **Natural gas & light-duty vehicles**
   e. **Interregional transmission**
4. **Two questions:**
   - **Addressing uncertainty**
   - **Policy and awareness**

Orientation: Multi-sector (fuel, electric, transportation), national, long-term planning

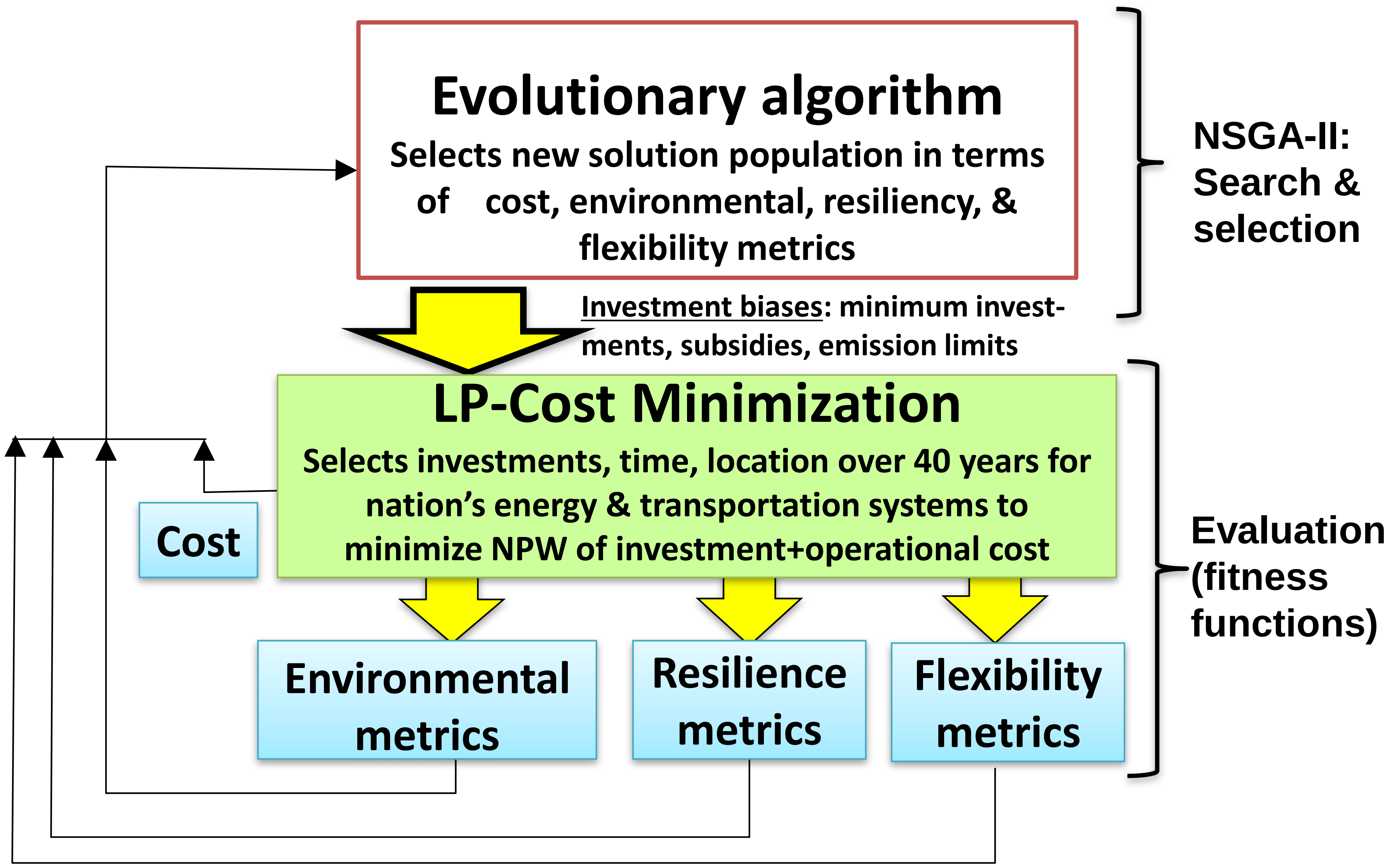


Orientation: Multi-sector (fuel, electric, transportation), national, long-term planning



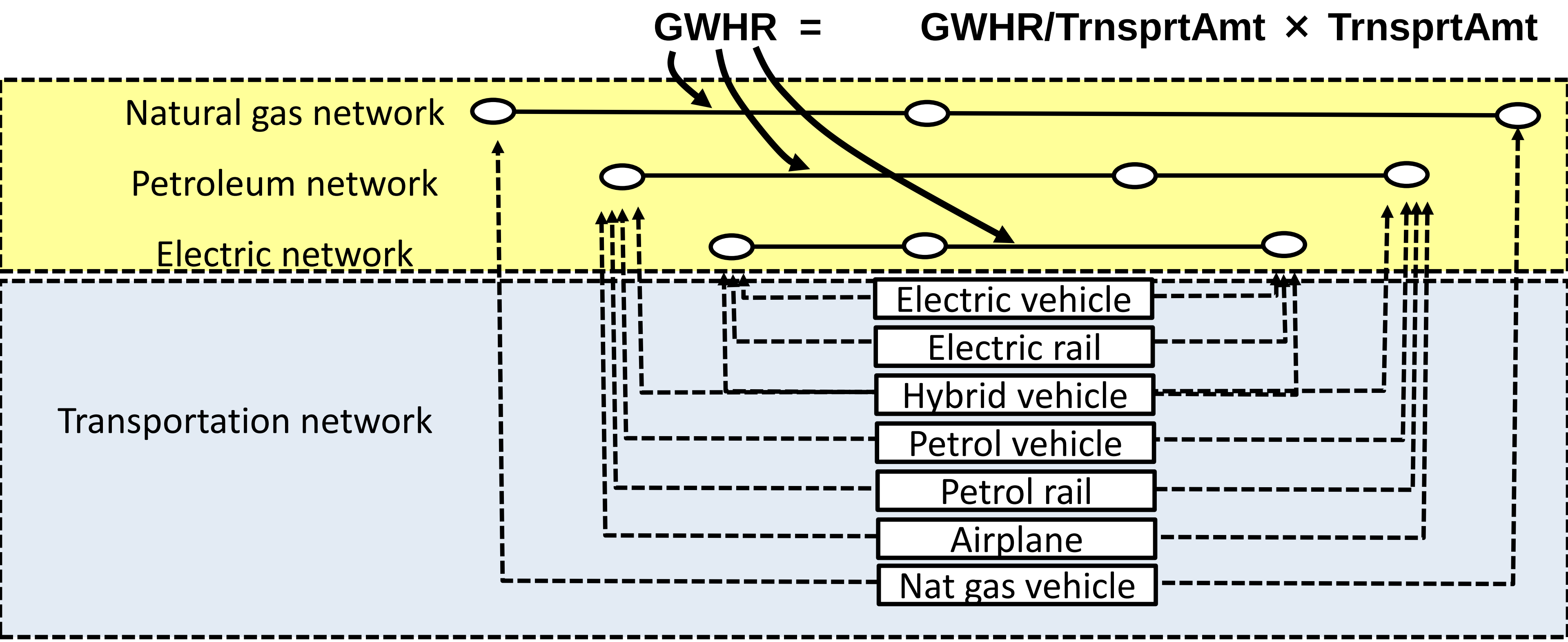
- Probes future infrastructure designs via computation
- Separates "good" from "bad" choices & informs societal dialogue and political debate
- 100-year infrastructure designs: a sustainability practice

Modeling:
NETPLAN, multi-objective optimization

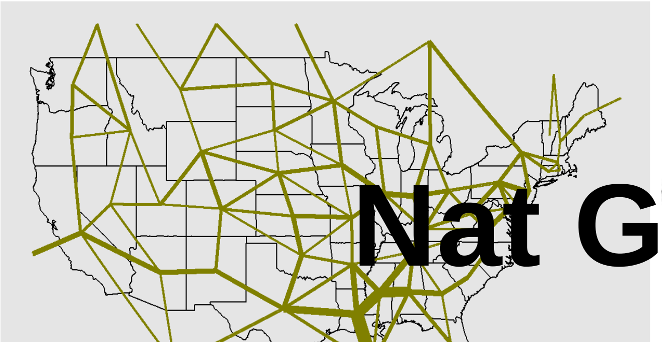


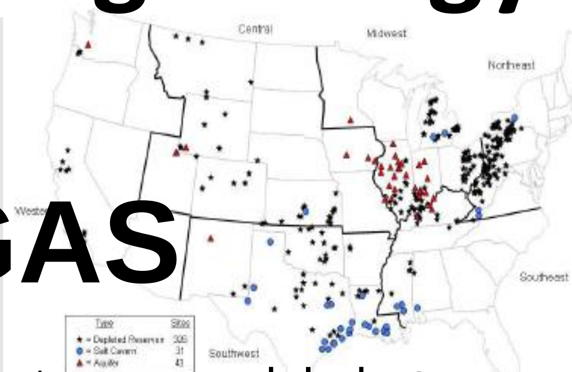
Transportation system loading on energy

Every transportation mode produces demand in energy networks



Modeling: energy system





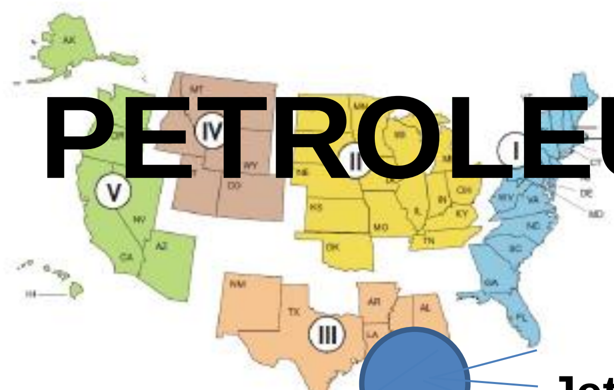
Nat GAS

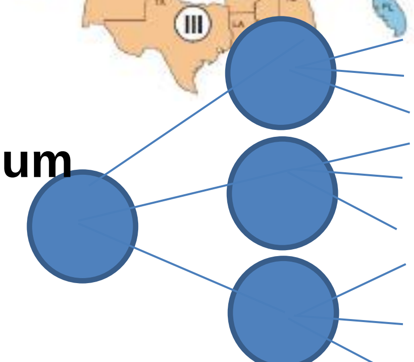
Gulf/Tx/Canadian resources & storage modeled.
Demand: nonpower (1% grwth), power by state.
Gas pipelines modeled between adjacent states.
Gas network uses monthly step sizes.

COAL

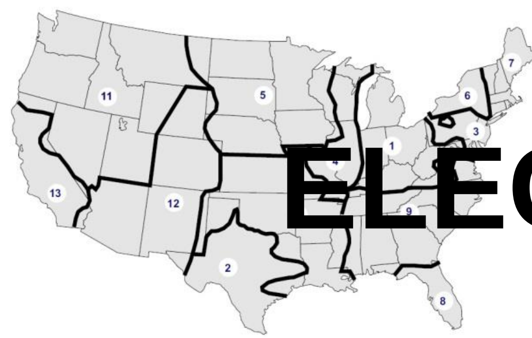
24 states comprise coal resources.
Demand is all power by state.
Coal resources connected to all states.
Coal network uses yearly step sizes.

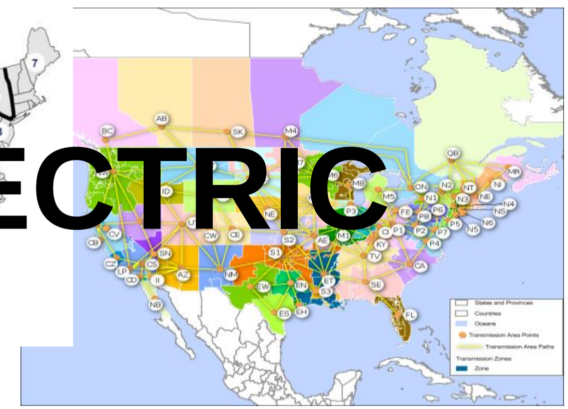
PETROLEUM





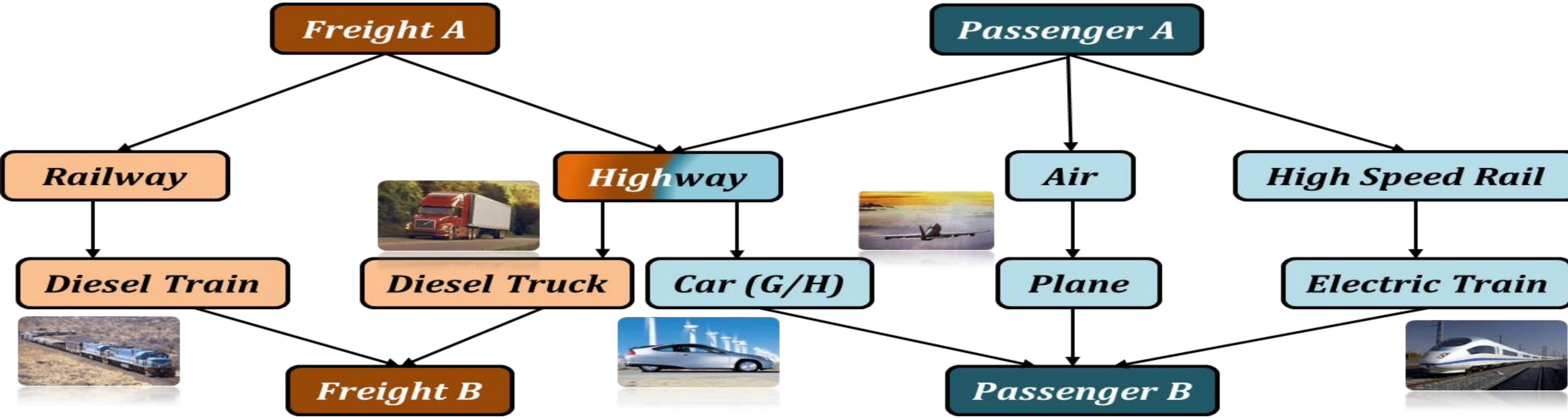
ELECTRIC

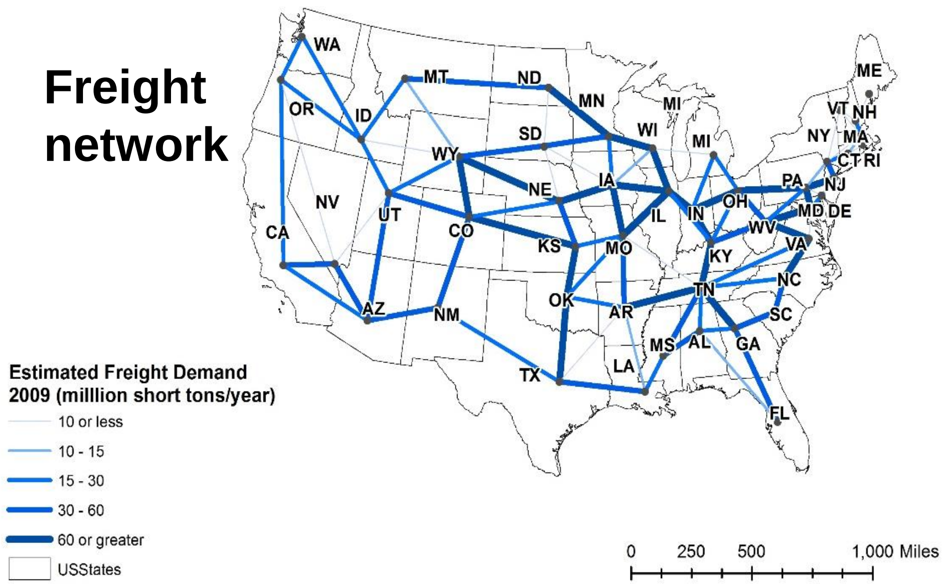


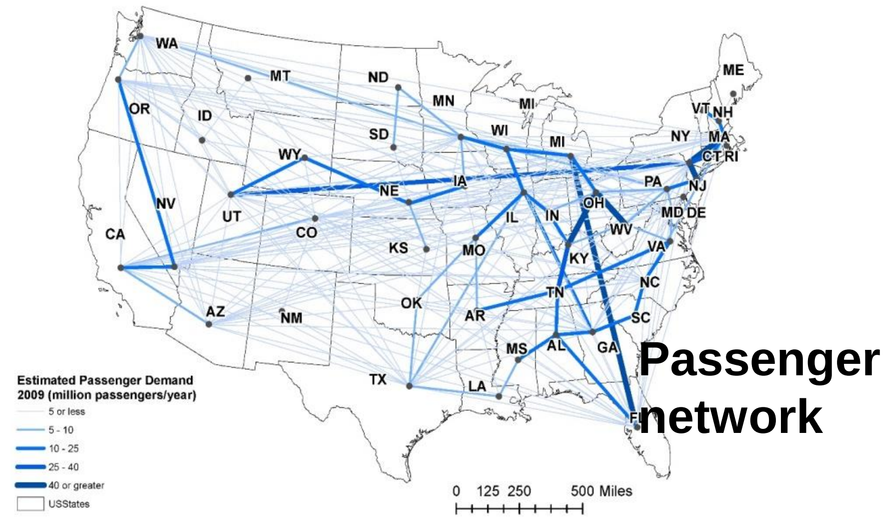


Each node models 15 gen types.
Existing trans modeled between nodes.
Electric network uses monthly step sizes.

Modeling: transportation





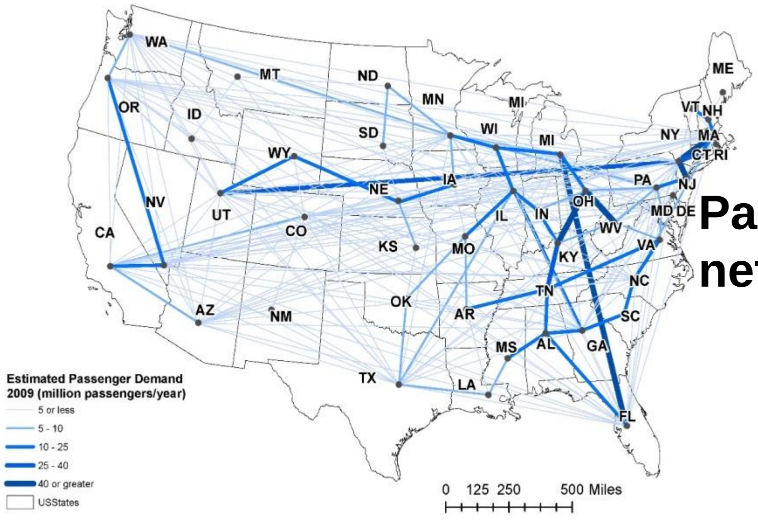


Transportation demand is specified node-to-node, except for energy commodities.

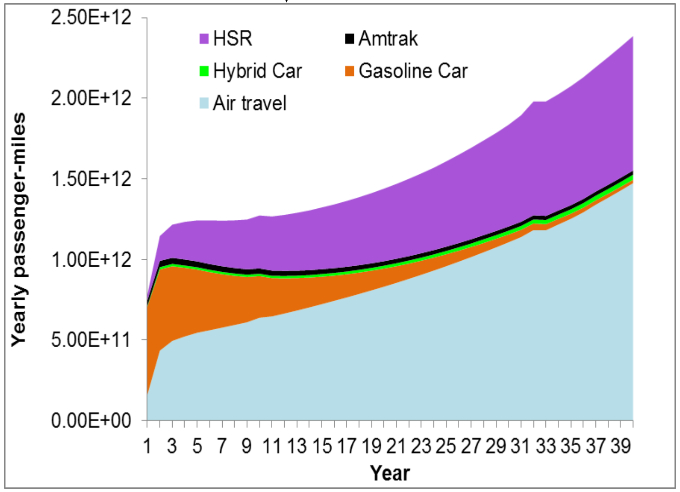
Design: High-speed rail (HSR)

- Long-distance travel only: 95 state-state + 140 additional heavily-traveled routes
- Possible modes are highway, air, HSR
- Travel time penalized 24$/hr for all modes
- Cost includes investment + operational cost of energy & transportation
- Fixed transport infrstrctre modeled with ∞ capacity➔investment only in fleets
- Trnsprt demand grows 3%/year

Attribute	No HSR	With HSR
HSR penetration (%)	0	30.5
Total Cost (T$)	11.61	11.15
Emissions (e10 short tons)	2.59	2.51 (-3.1%)
Gasoline (E+3 MGallon)	29.84	19.92 (-33.2%)
Jet Fuel (E+3 MGallon)	320.55	211.25 (-34.1%)
Electric Energy (E+6 TWh)	194.23	198.24 (+2.06%)
Cost Savings (B$)	Reference	460

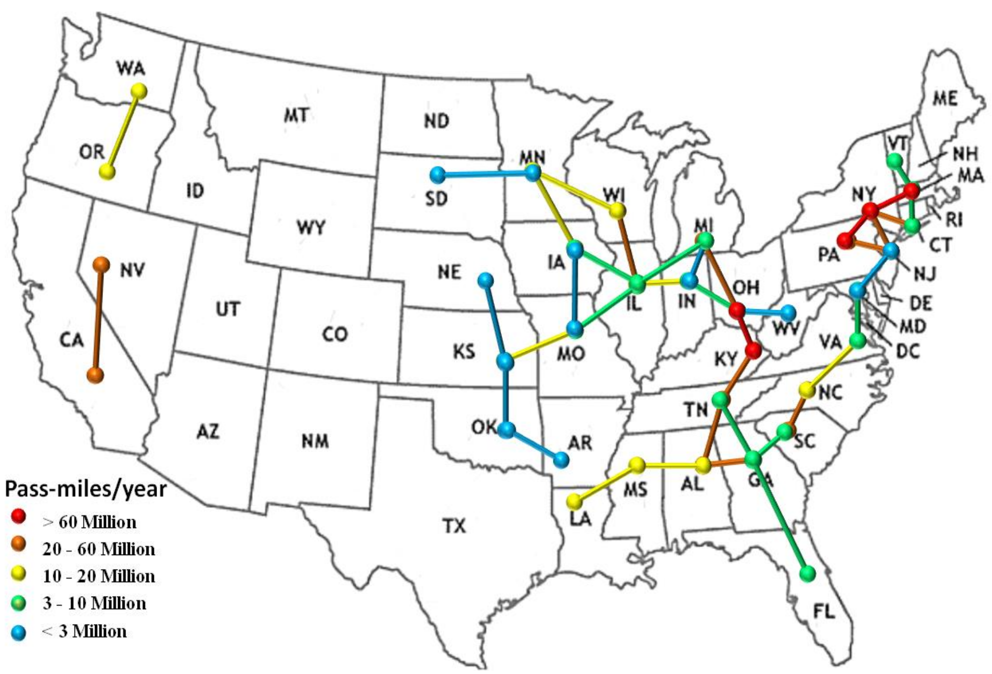


Passenger network

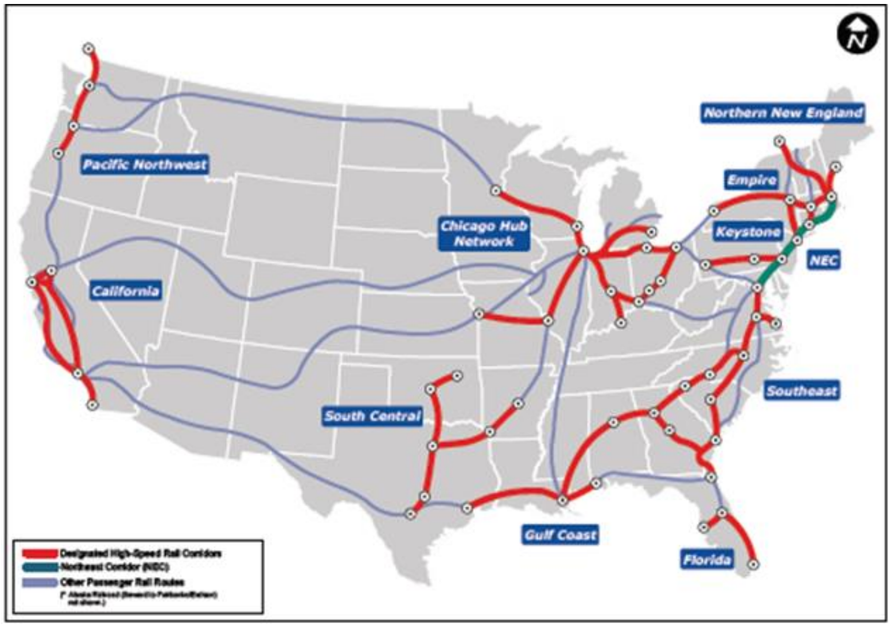


Design: High-speed rail (HSR)

Results are similar to the high-speed rail corridors designated by DOT.



Netplan Results

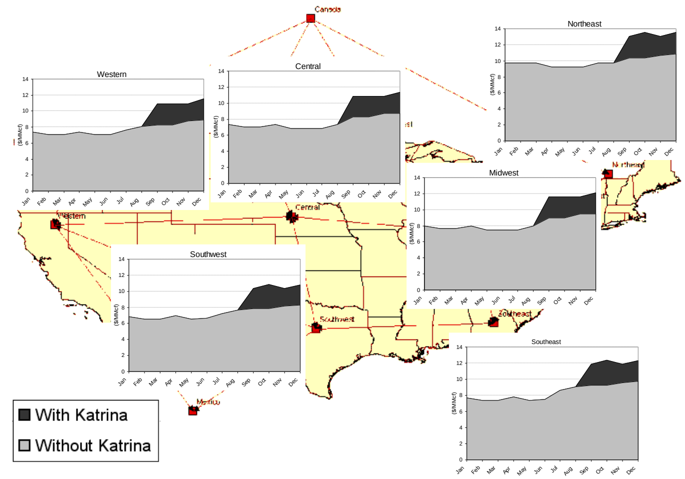


DOT Designations

Resilience

<u>Resilience</u>: Ability to minimize & recover from event consequences of extreme events.

EXAMPLE: KATRINA/RITA



<u>Other Conceived Extreme Events</u>:

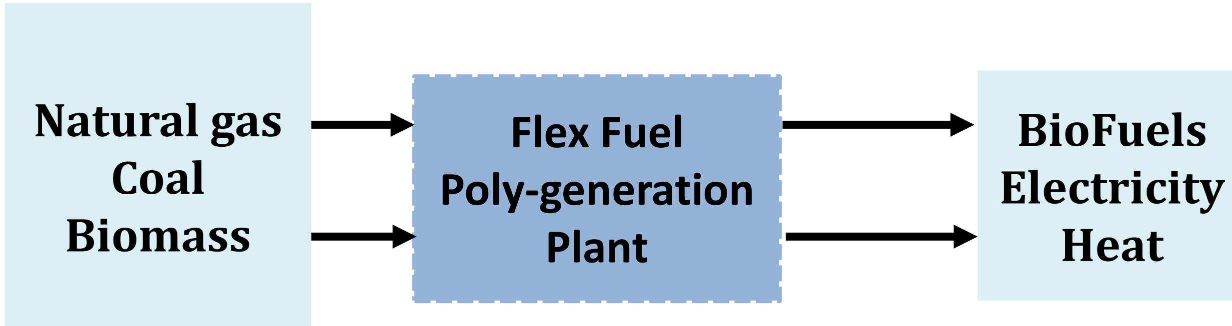
- **6 mnth loss of rail access to Powder River Basin coal;**
- **1 yr interruption of 90% of Middle East oil;**
- **Permanent loss of U.S. nuclear supply;**
- **6 mnth interruption of Canadian gas supply;**
- **1 yr loss of US hydro due to extreme drought;**
- **Sustained flooding in Midwest destroying crops, reducing biofuels, interrupting E-W rail system.**

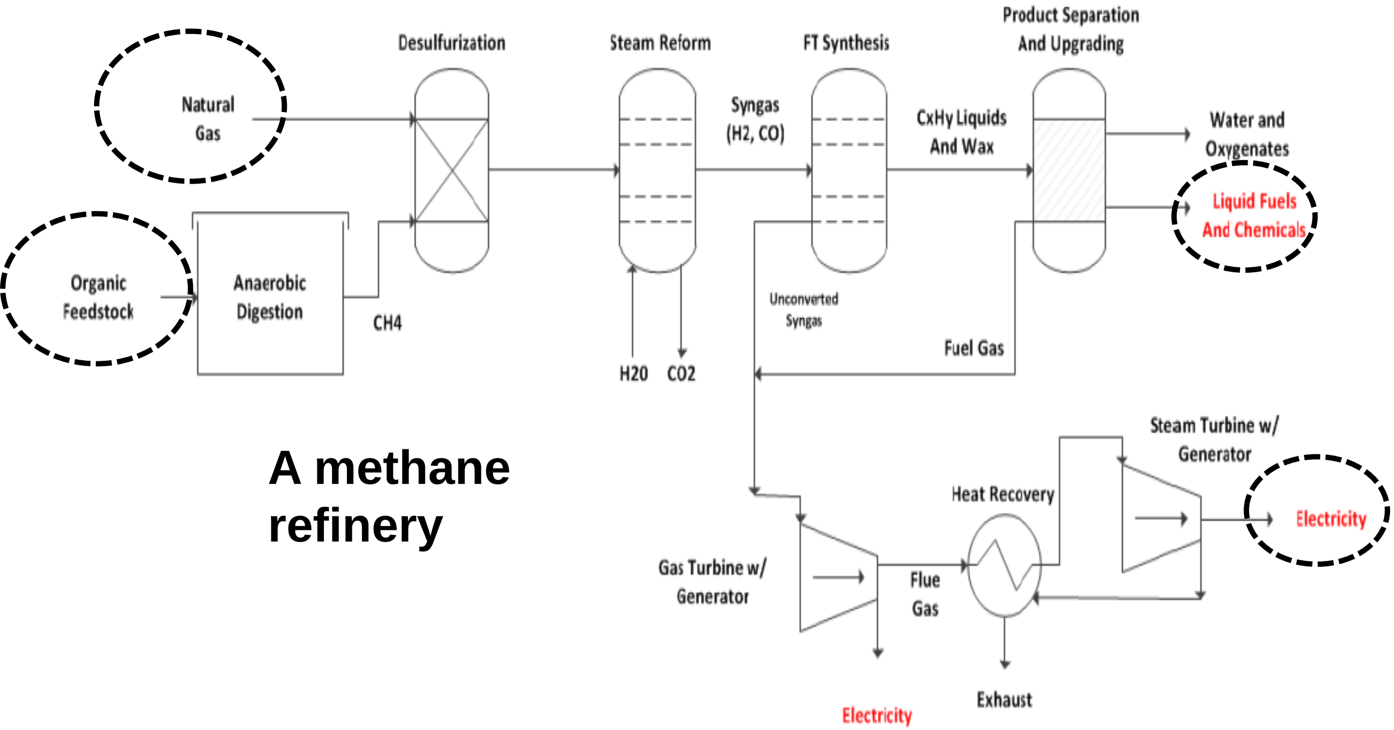
<u>Experiment</u>: For a 40 year investment strategy, simulate total failure of each of 14 generation technologies at year 25.
<u>Resilience metric:</u> Averaged the 1 year operational cost increase across 14 events with respect to the no-event case.

FINDINGS: RESILIENCE IMPROVES WITH

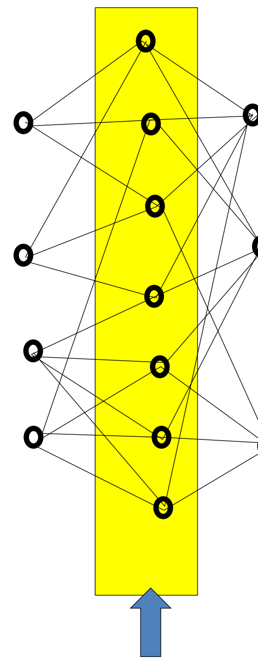
- **INTERCONNECTEDNESS**
- **DIVERSIFICATION**

Design: Flex Fuel Poly-generation





A methane refinery



Energy converters

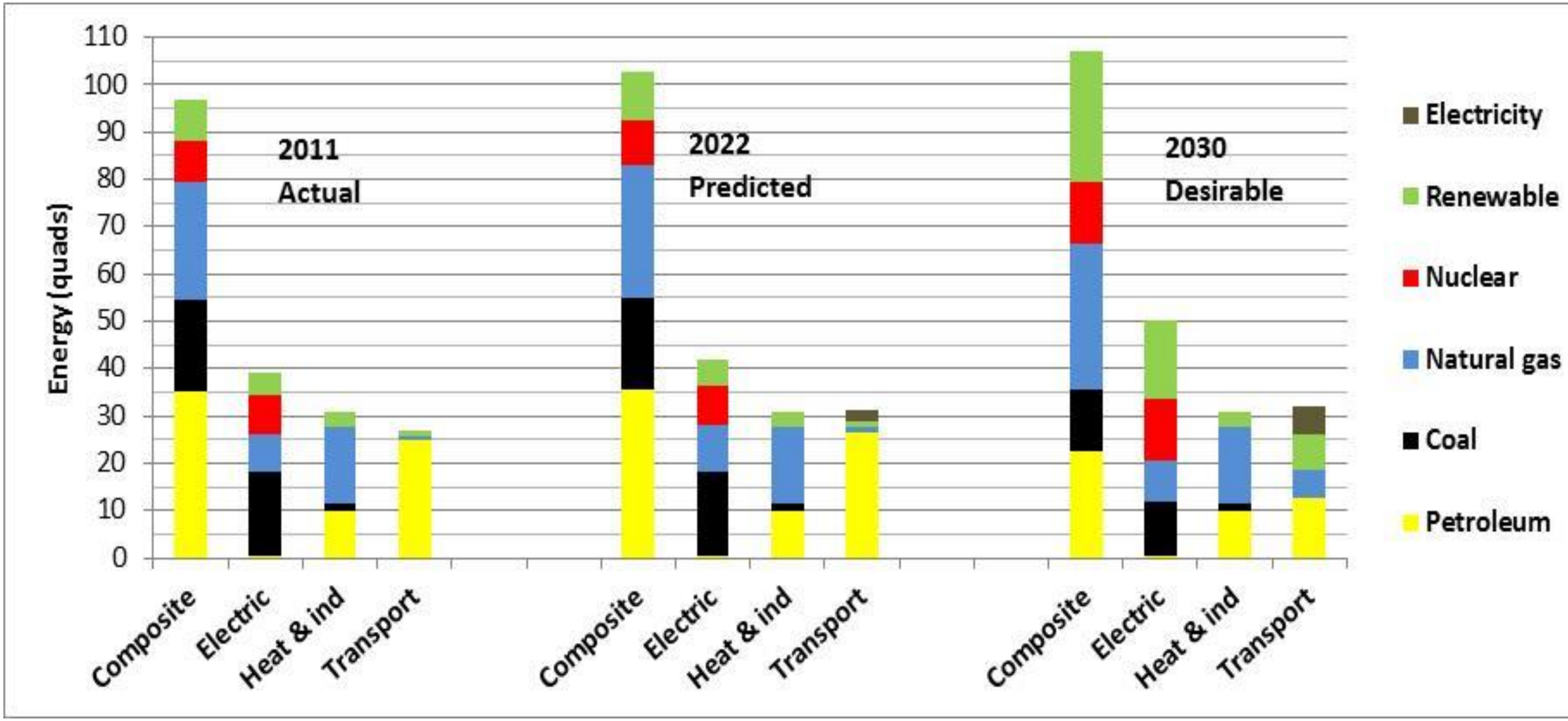
Multiple input, Multiple output: creates nodes with multiple connections, increases network density and thus system resilience.

Design: natural gas (NG) & light-duty vehicles (LDV)

<u>Lifetime</u>: Infrastructure investments live for 40-60 years; not easy to "turn" once developed.
<u>Depletability</u>: R/P ratios 10-90 yrs: how volatile will price be as exports grow & as gas depletes?
<u>Fracking</u>: Will public resistance grow?
<u>CO_2 emissions</u>: Can coal-to-gas shift reduce enough?
<u>Diversification</u>: How will resilience for all energy sectors change? For each energy sector?

<u>A resilience criterion</u>: Balance portfolio in all sectors' & within each sector.

Design: natural gas (NG) & light-duty vehicles (LDV)



A resilience criterion: Balance portfolio in all sectors' & within each sector.

Design: natural gas (NG) & light-duty vehicles (LDV)

Passenger Vehicles

	Year 1	Year 20
Gasoline	$24,000	$24,000
Conventional Hybrid	$28,000	$26,000
Plugin Hybrid (20-mile)	$35,000	$31,000
Plugin Hybrid (40-mile)	$41,000	$34,000
Plugin Hybrid (60-mile)	$50,000	$36,000
Battery Electric (100-mile)	$45,000	$35,000
Compressed Natural Gas	$27,000	$27,000

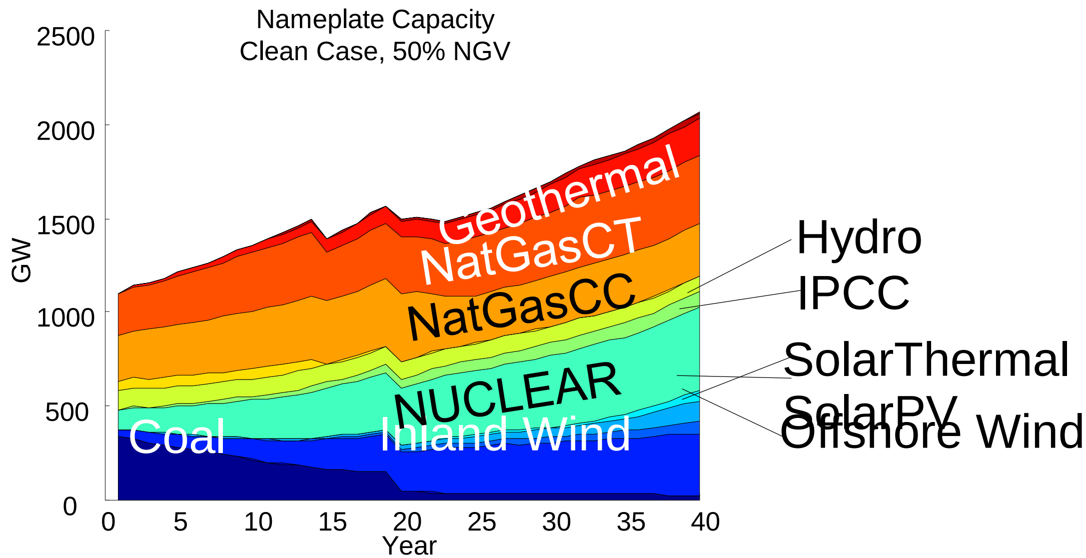
Gasoline	$3.80/Gallon
Natural gas	$3/MMBTU

Both increase 1.25%/year

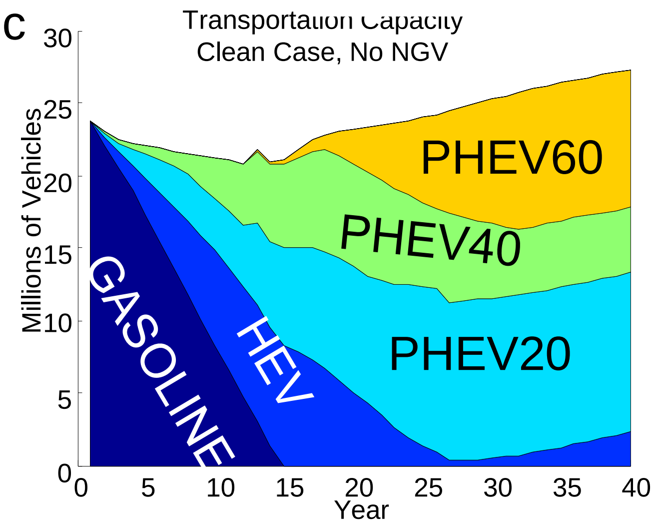
Electric generation (million$/GW)

Coal	2844
IGCC	3221
NGCC	1003
Gas Turbine	665
Nuclear	5339
Onshore Wind	2438
Offshore Wind	5975
Oil	1655
IPCC	3311
Solar PV	4755
Solar Thermal	4692
Geothermal	4141
Tidal Power	18286
Oceanic Thermal	6163

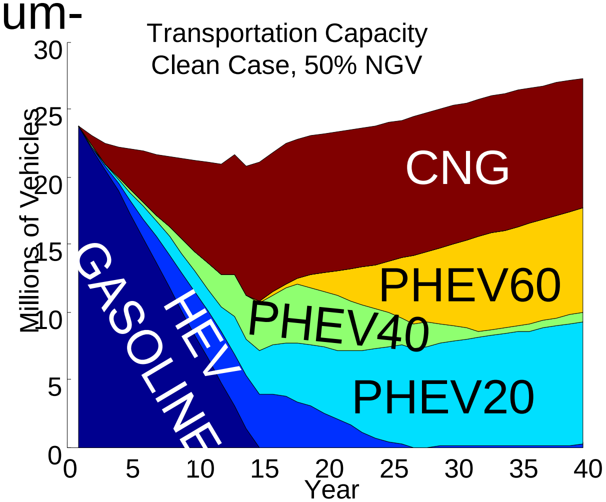
Design: natural gas (NG) & light-duty vehicles (LDV)



Petroleum-electric future



Petroleum-electric NG future

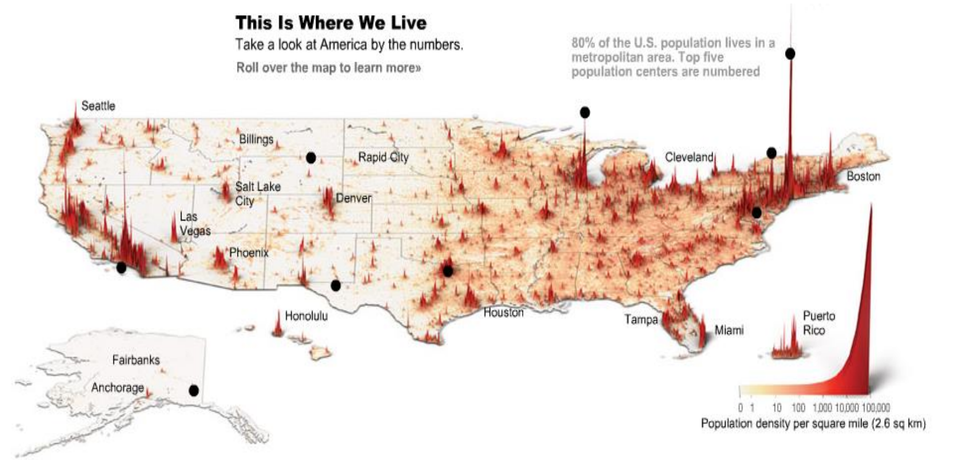


➔Total 40 year cost is 8% less for the 50% CNG case.
➔Total 40 year CO_2 emissions is slightly less for the CNG case.
➔We obtain desirable diversification while improving cost & emissions.

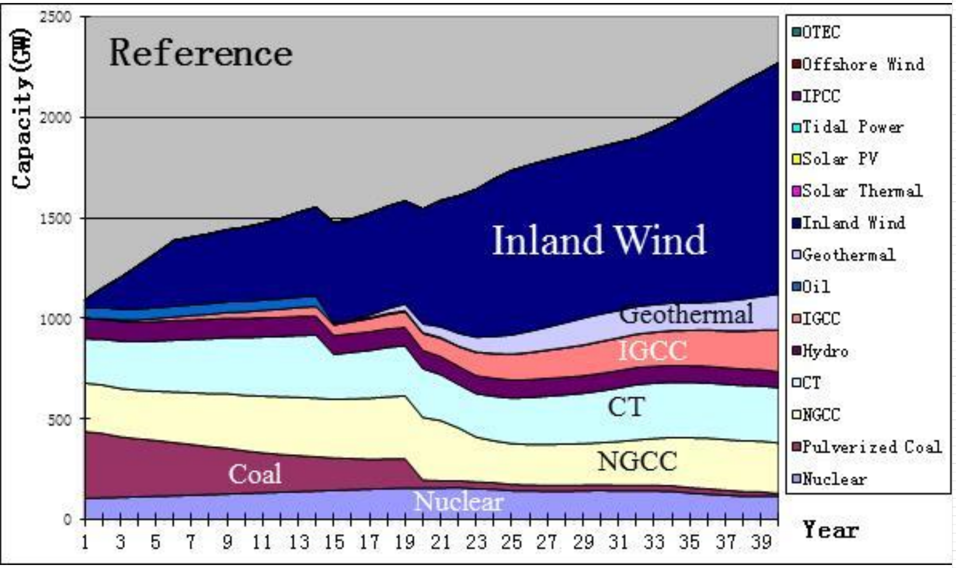
Design: interregional transmission

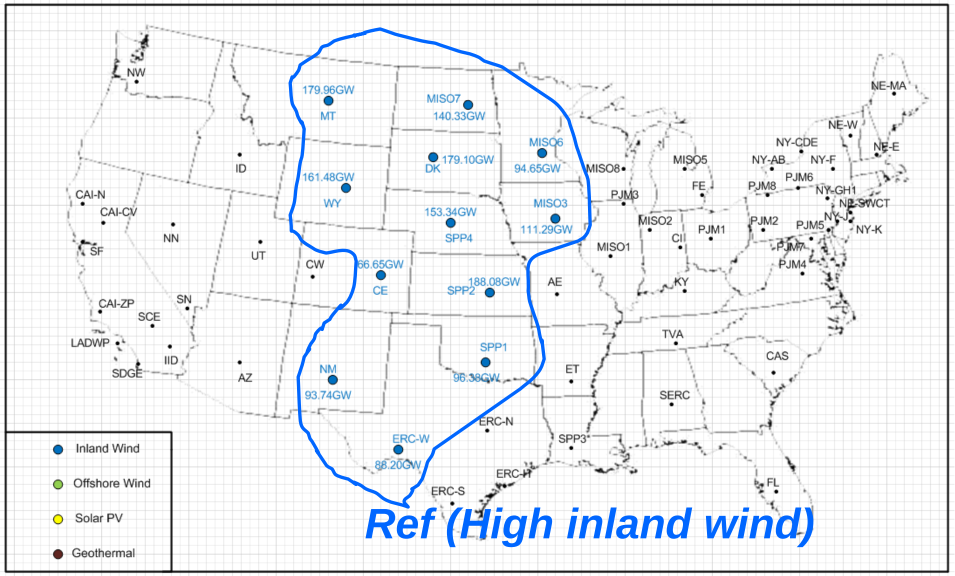
High-capacity interregional transmission is motivated by high renewable penetration because…

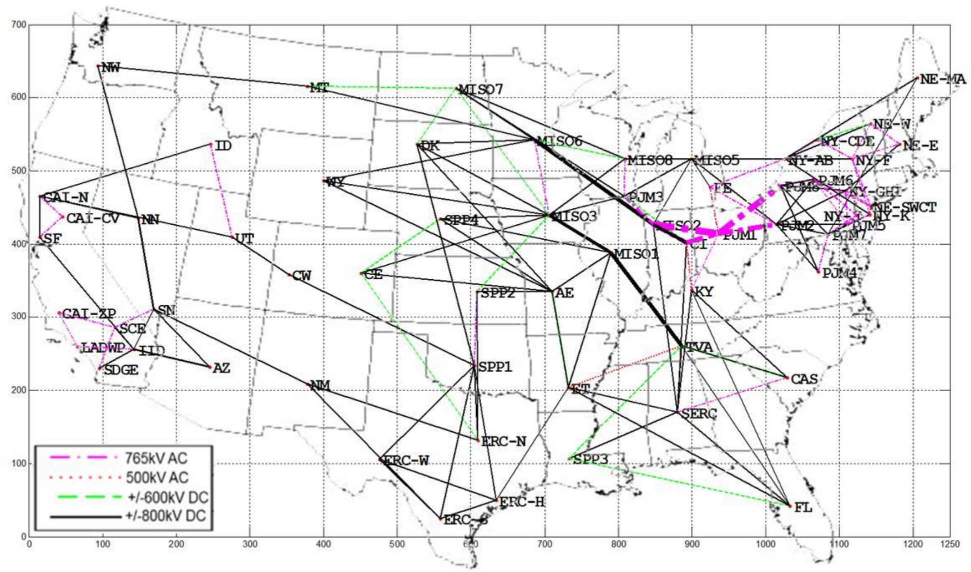
- **Location dependence.**
- **Renewable energy can be moved only by electric transmission.**
- **Transmission costs comprise a relatively small percent of long-term power system cost.**

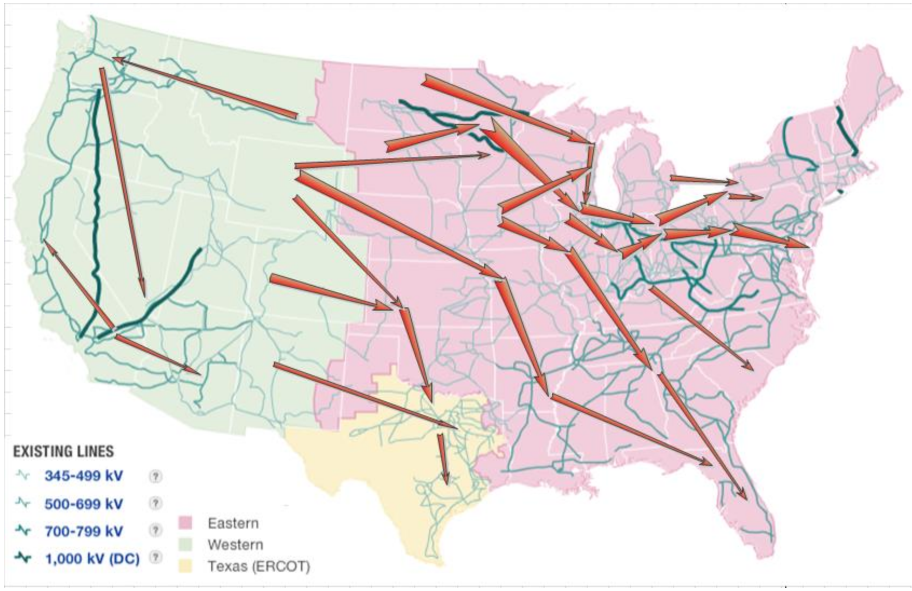


Design: interregional transmission



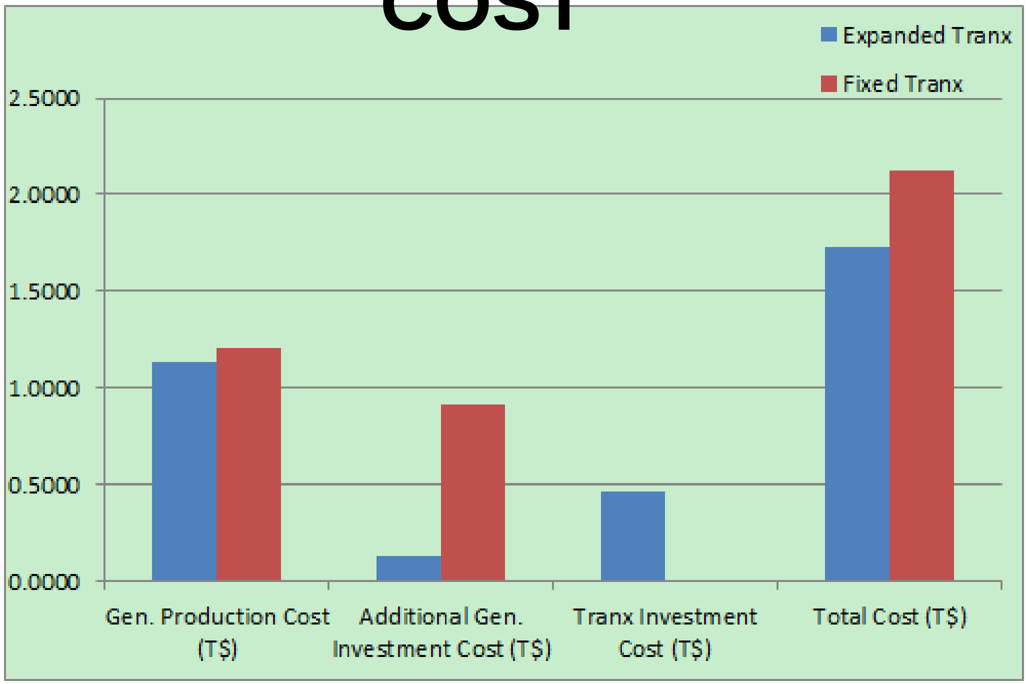




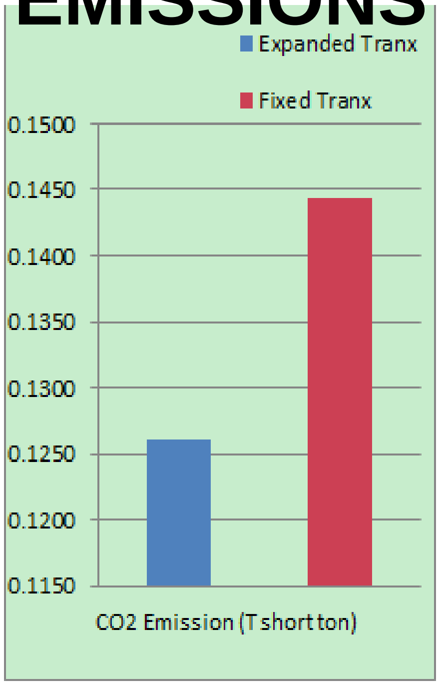


Design: interregional transmission

COST



EMISSIONS

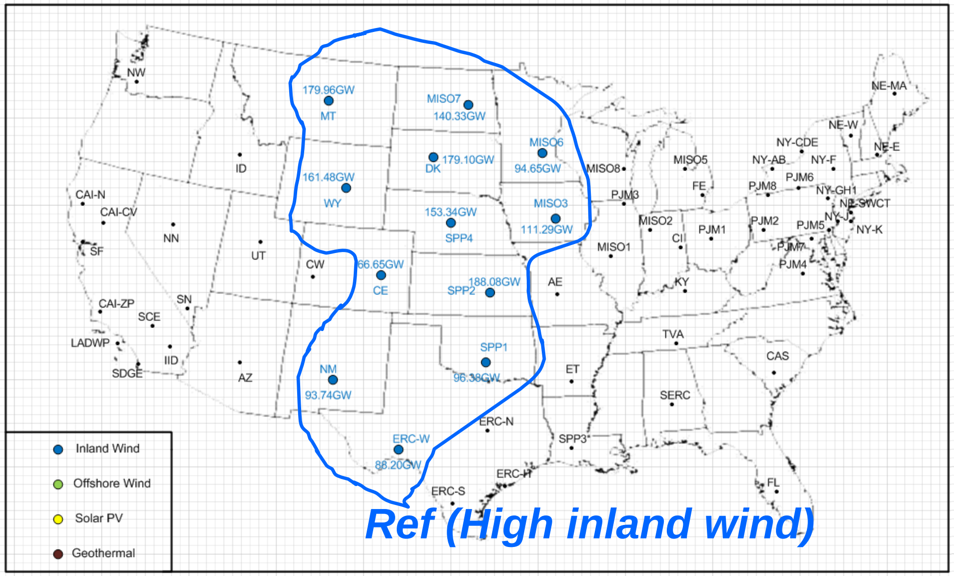


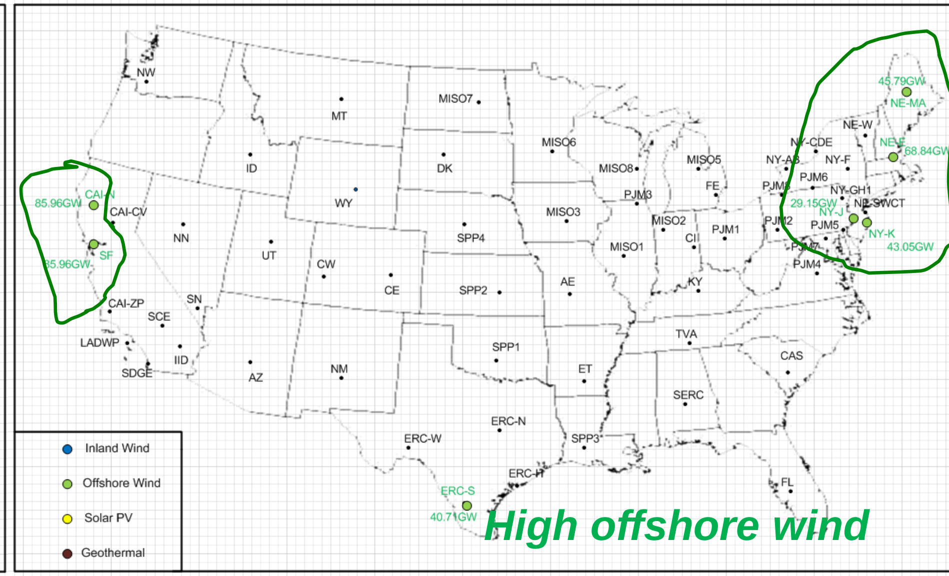
BLUE: EXPANDED TRANSMISSION
RED: FIXED TRANSMISSION
➔ For a high-renewable generation portfolio, interregional transmission investment lowers cost and lowers emissions.

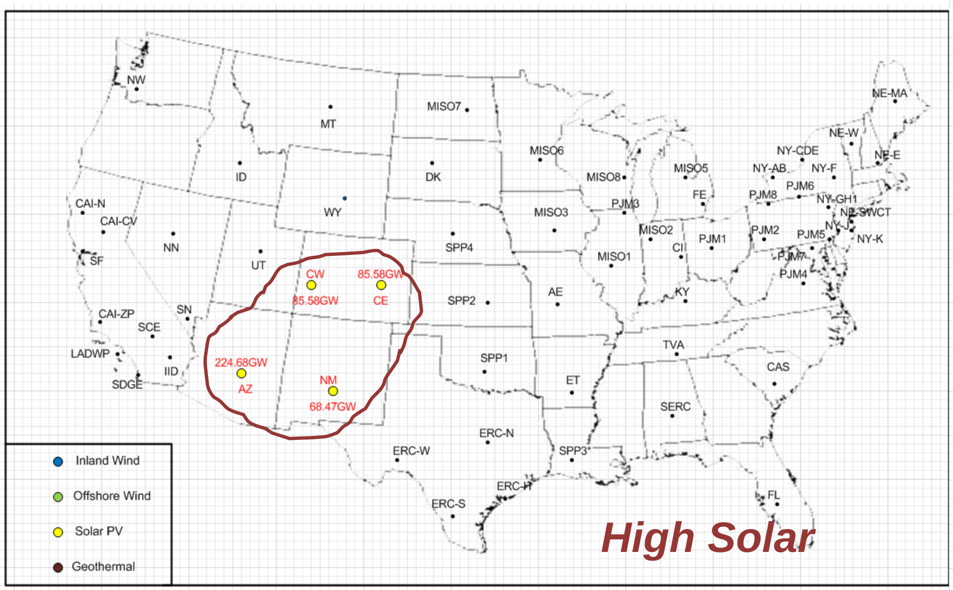
Other benefits:

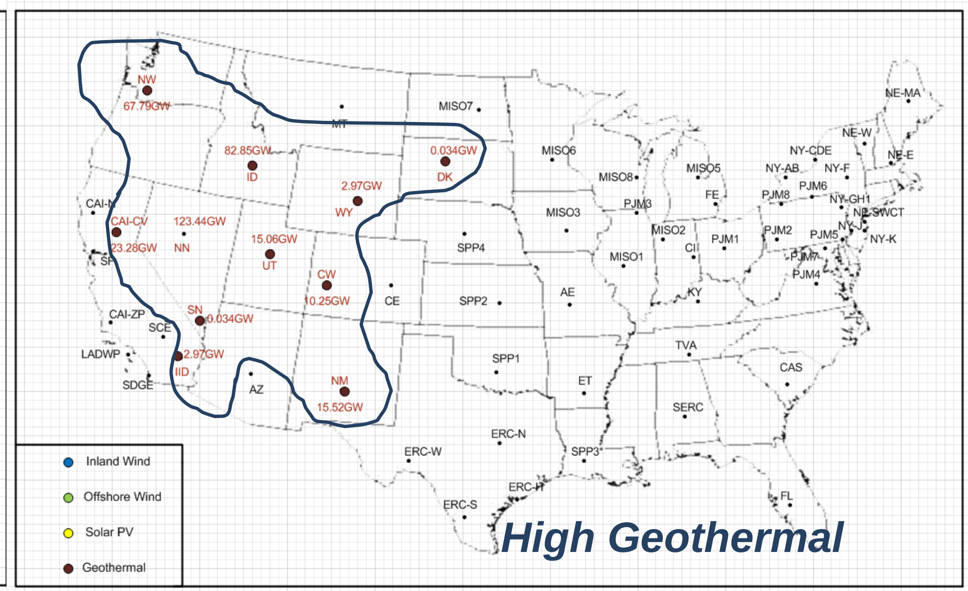
- **resilience of energy prices to large-scale events;**
- **energy system flexibility.**

Major Renewable Investments



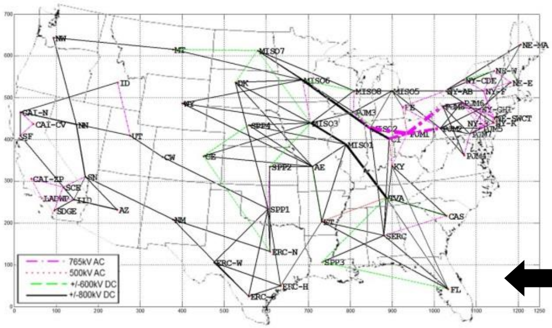


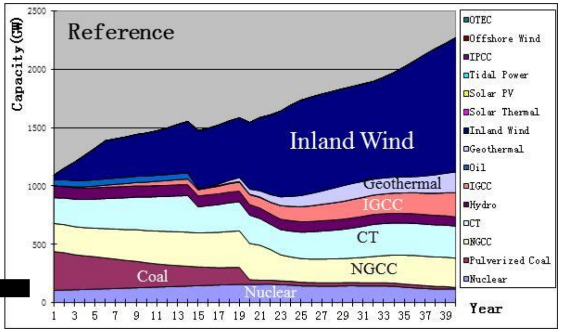




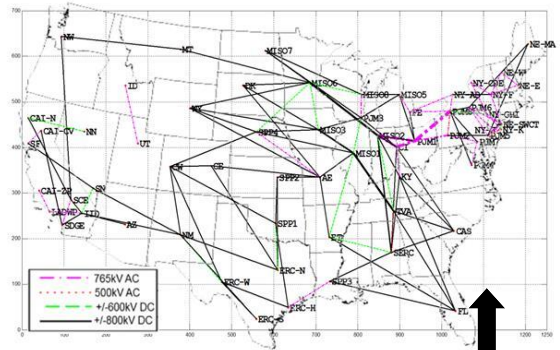
Design: interregional transmission

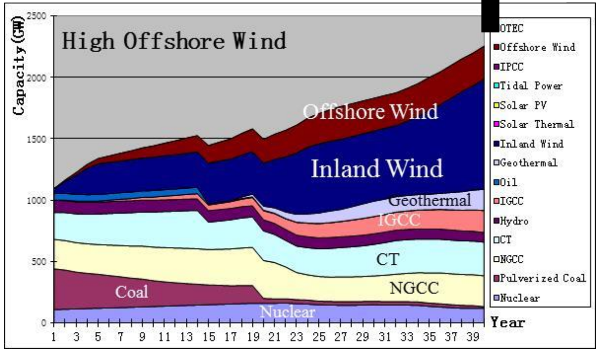
Ref (high inland wind)

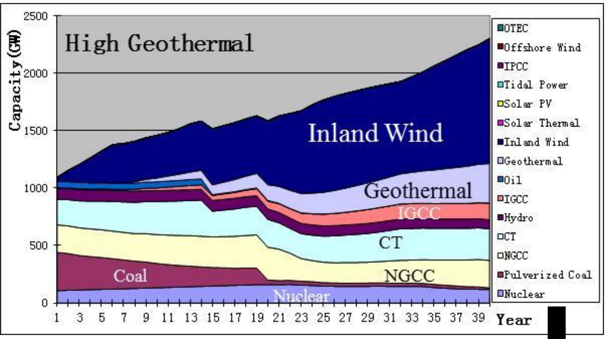




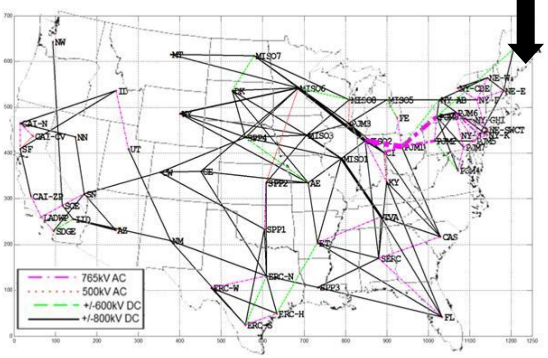
High Offshore Wind



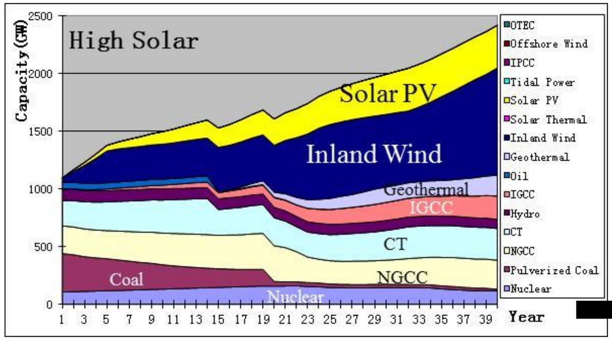


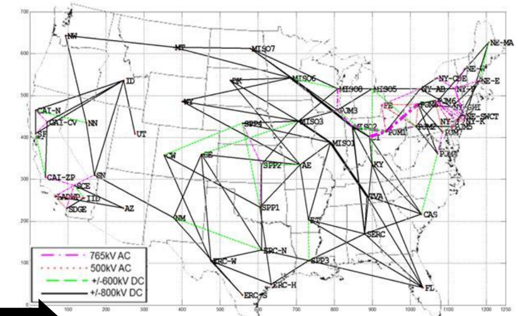


Designs selected to minimize 40yr investment+operational costs, accounting for existing transmission, terrain, population density, forest areas, elevation, wind, ice-loading, right-of-way.



High Geothermal





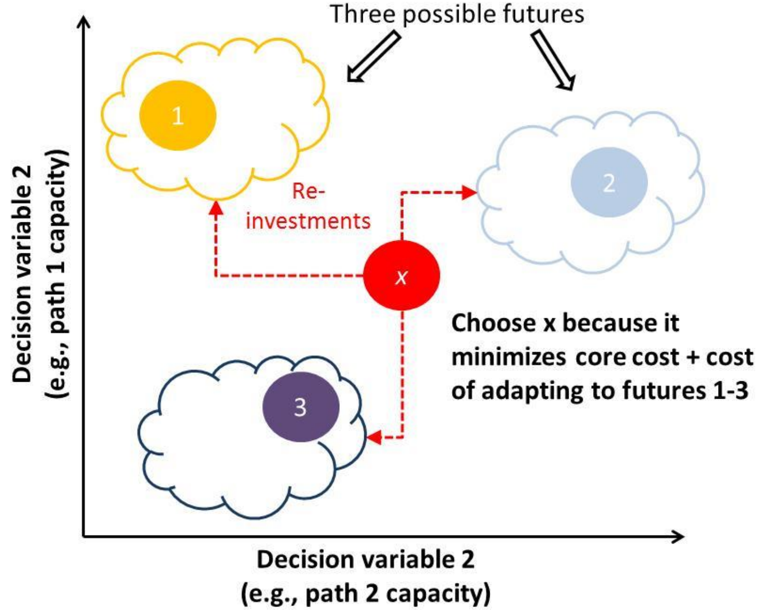
High Solar

Two Questions

1. **<u>Uncertainty</u>**: Given that the future is uncertain, but we have to decide before we know the future, which transmission system do we actually build?

2. Balkanized authority: With so many decision-makers, many with conflicting preferences, what are possible paths forward to build such geographically expansive infrastructure?

Designing under global uncertainties



Identifies an investment that is "core" in that the total "CoreCost" plus the cost of adapting it to the set of envisioned futures is minimum.

Minimize:

$\mathrm{CoreCosts}(\underline{x}^f)+\beta[\ \Sigma_i\ \mathrm{AdaptationCost}(\Delta\underline{x}_i)]$

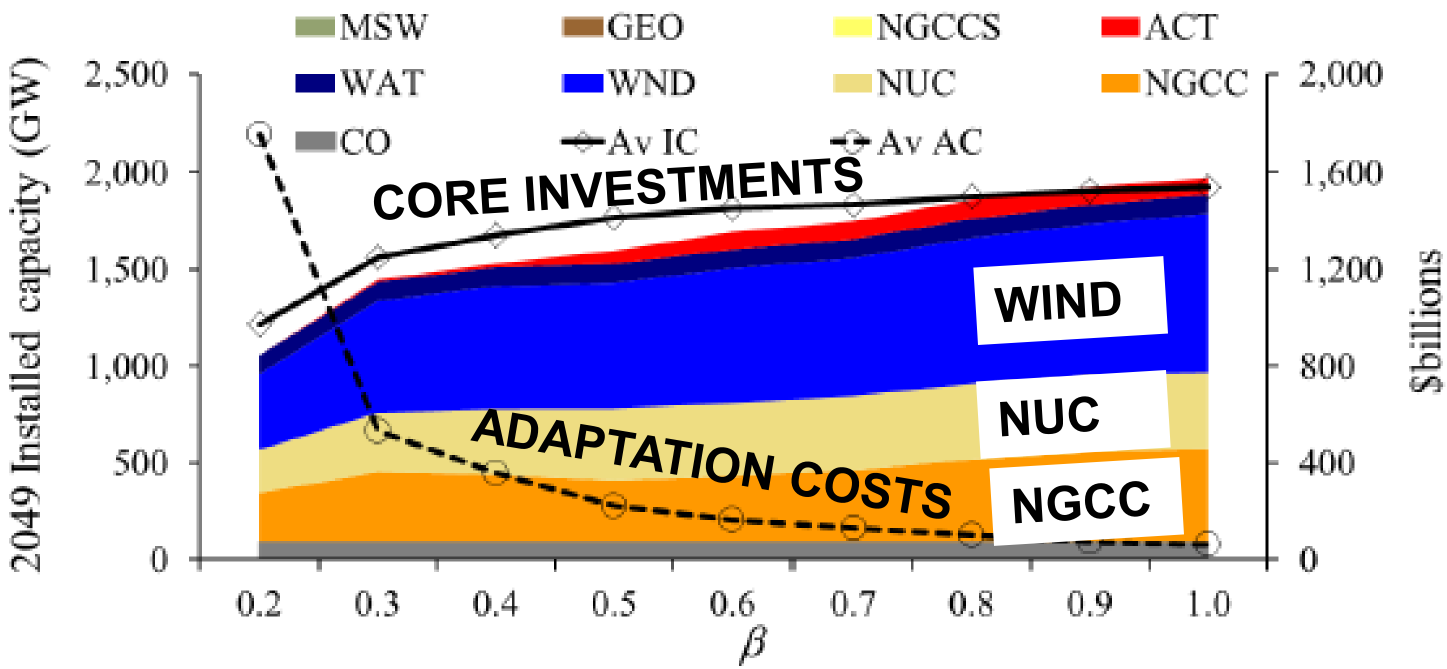
Subject to:

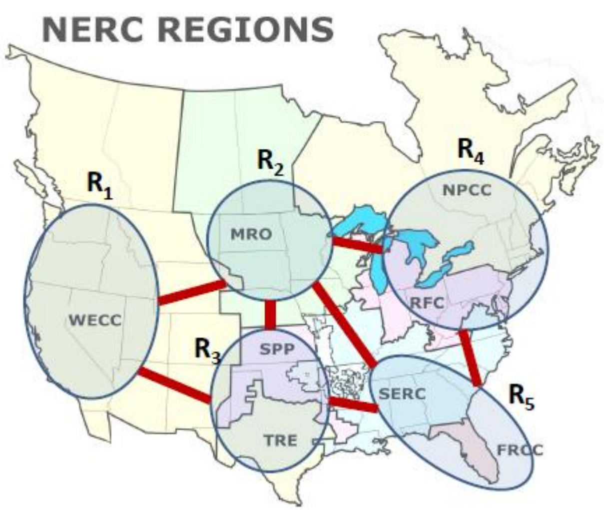
Constraints for scenario i=1,…N: $\underline{g}_i(\underline{x}^f+\Delta\underline{x}_i)\leq\underline{b}_i$

$\underline{\mathbf{x}}^{\mathbf{f}}$: Core investments, to be used by all scenarios i

$\mathbf{\Delta\underline{x}_i}$: Additional investments needed to adapt to scenario i

Designing under global uncertainties





Minimize:

CoreCosts($\underline{x}^f$)+β[Σ_i AdaptationCost($\Delta\underline{x}_i$)]

Subject to:

Constraints for scenario i=1,…N: $\underline{g}_i(\underline{x}^f+\Delta\underline{x}_i)\leq\underline{b}_i$

$\underline{\mathbf{x}}^f$: Core investments, to be used by all scenarios i

$\Delta\underline{\mathbf{x}}_i$: Additional investments needed to adapt to scenario i

Two Questions

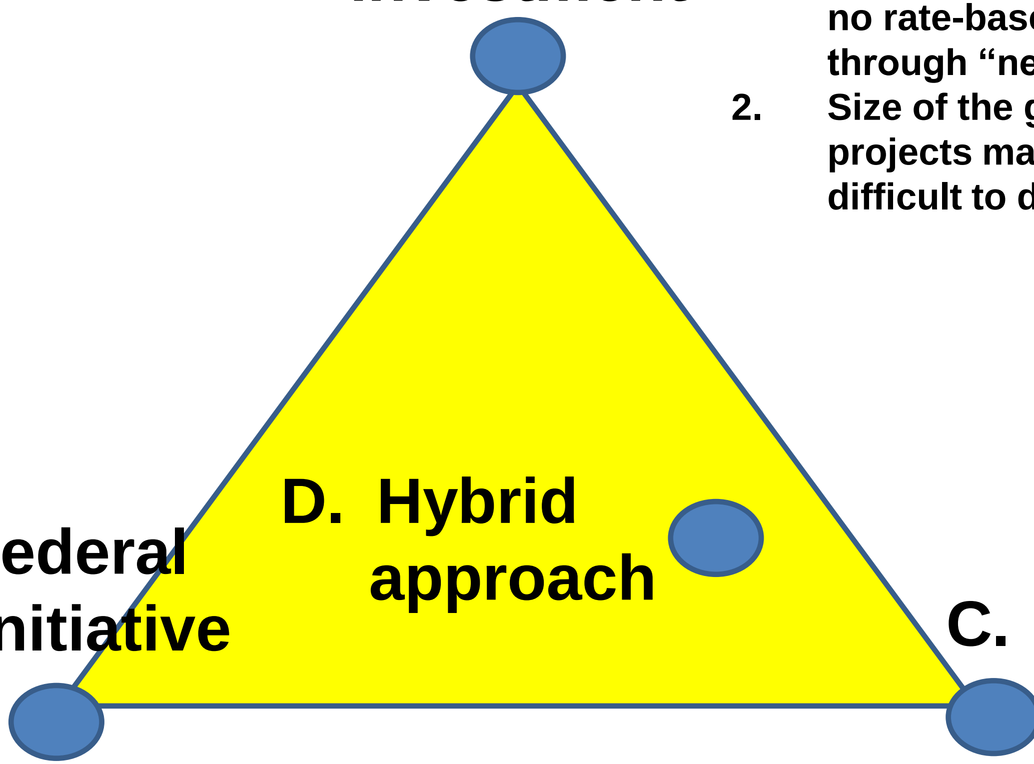
1. **Uncertainty**: Given that the future is uncertain, but we have to decide before we know the future, which transmission system do we actually build?

2. **Balkanized authority**: With so many decision-makers, many with conflicting preferences, what are possible paths forward to build such geographically expansive infrastructure?

Possible paths forward

A. Market-driven investment

1. Market (merchant)-driven investment: no rate-base recovery, costs recovered through “negotiated rates.”
2. Size of the groups to form for overlay projects may need to be very large and difficult to develop/manage.



B. Federal initiative

1. Similar to interstate highway system, Feds paid 90% via gasoline tax, states 10%. States managed program for location, design, ROW acquisition, construction, O&M.
2. Not clear that the interstate highway system had a “pass-through” feature like an overlay may have.

C. Multiregional coordination

1. Establish permanent multiregional stakeholder group consisting of industry, state governments, advocacy groups to address:
2. States need to see benefit for taking multiregional view.
3. The above is evolving.

Possible paths forward: D. Hybrid approach

1. **Design it using multiregional collaborative stakeholder group of industry, states, advocacy, DOE, supported by Governors Associations. Impasses addressed by federally-appointed arbiters.**
2. **Incentivize merchant transmission developers to build consistent with design.**
3. **Federalize what merchant developers will not or cannot build, but with careful Fed-State coordination and cooperation.**

Public Education and Policy

*2006 survey:

What is the impact of nuclear power plants on CO_2 emissions?

80% got it wrong

**2008 survey:

Which costs more today: electricity from wind turbines or electricity from coal-fired plants?

82% got it wrong

#2009 survey (women):

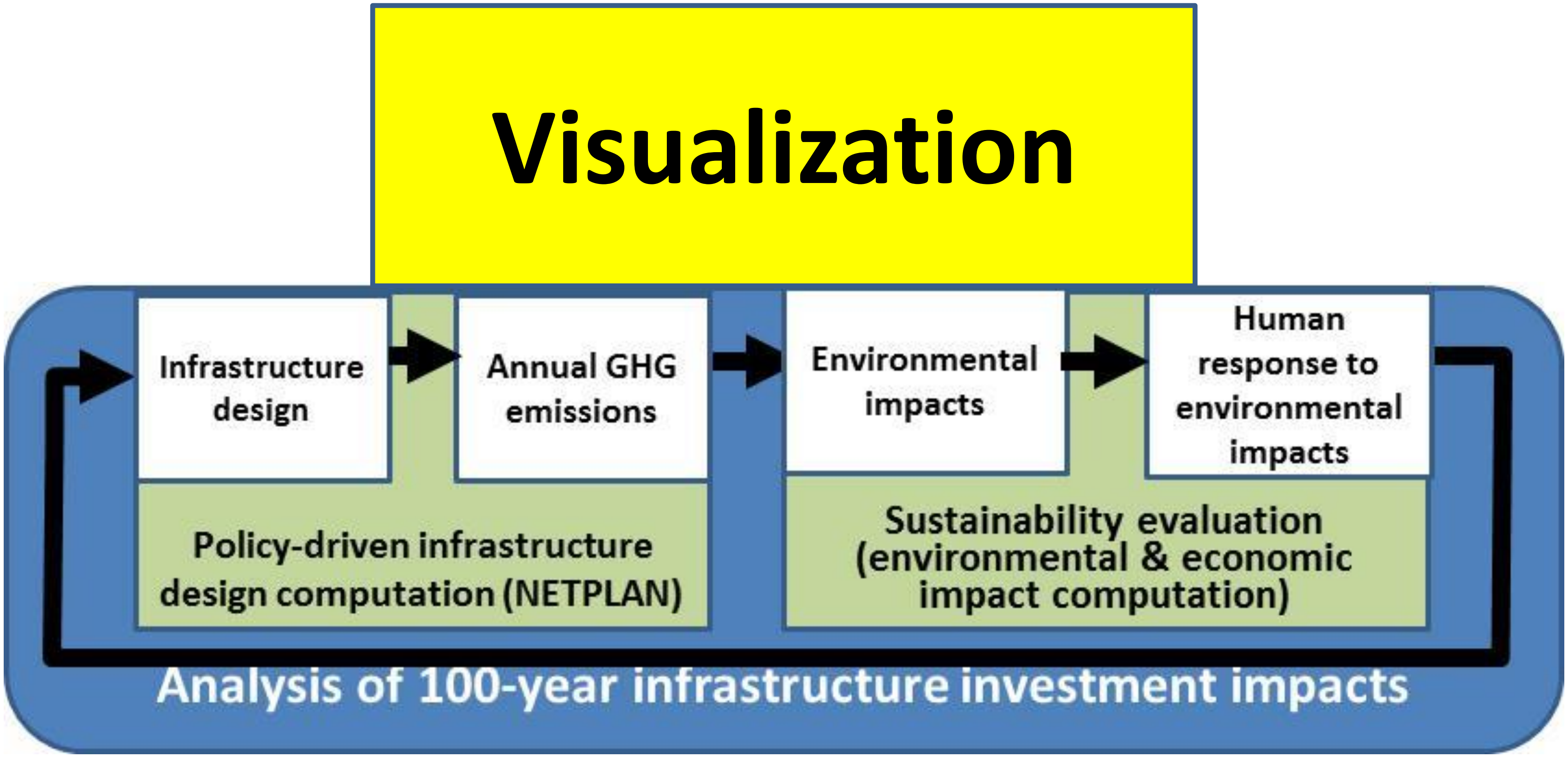
67% identify coal power plants as a big cause or somewhat of a cause of global warming, 54% think the same about nuclear energy;
43% don't know that coal is the largest source of US electricity.

##2003, 2007 survey:

For both survey years, "People see alternative fuels (hydro, solar, wind) as cheap and conventional fuels as expensive."

*T. Curry, et al., "A survey of public attitudes towards climate change and climate change mitigation technologies in the United States: Analyses of 2006 Results," Publication LFEE 2007-01-WP, MIT Laboratory for Energy and the Environment.
#M. D;Estries, "Survey: Women fail on energy knowledge," July 3, 2009, report on a survey commissioned by Women Impacting Public Policy and Women's Council on Energy and the Environment.
**H. Klick and E. Smith, "Public understanding of and support for wind power in the United States,"Renewable Energy, Vol. 35, July 2010, pp. 1585-1591.
S. Ansolabehere, "Public attitudes toward America's energy options," MIT-NES-TR-008, June 2007.

Developing and communicating sustainable infrastructure pathways



Intent is that this system will be publicly available via internet.

Concluding comment

There is need to centrally ***design***, at the national level, interdependent infrastructure systems. This need is driven by two attributes of these infrastructure systems:

- Economies of scale motivate centralized designs to avoid inefficient infrastructure investment;
- Infrastructure lives for 50 years or more, and climate impacts take decades to turn;

  ➔free markets appear too short-term to adequately respond to these issues, and the consequences of getting it wrong are potentially severe.