Pacific Northwest
NATIONAL LABORATORY

A Framework for Sub-national Multi-sector Dynamics Scenarios

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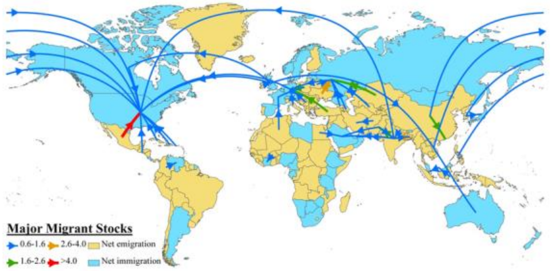
Motivation

- Sub-national and regional planners need to make decisions about long-lived infrastructures that cut across various natural and human systems such as energy, water, and land.
- A key consideration for decision-makers is the resilience of such infrastructures to events of high “stress”.
- Understanding the resilience of infrastructures is challenging because they lie at the intersections of various natural and human systems that are rapidly co-evolving.
- Hence, stressors or external stimuli that cause stresses in individual systems could lead to cascading effects across systems.

Physical Infrastructures
(e.g. transmission lines)

Institutional Infrastructures
(e.g. Intl. immigration laws)



Management systems
(e.g. regulatory authorities)

DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA

Example of cascading effects: California droughts

California Droughts

Surface water Depletion

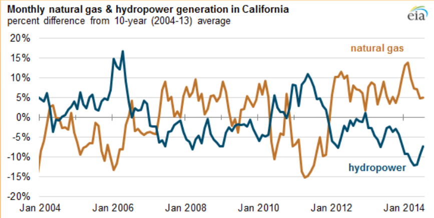
Increased ground water pumping

Drought Insurance programs

Lack of incentives for better adaptive planning

(E.g. switching to drought-resistant crops)

Switch from Hydro to Gas Power



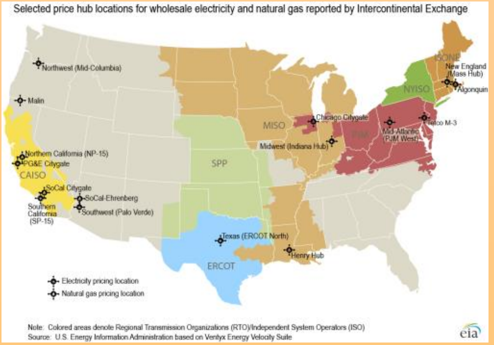
Air Pollutant and Health Impacts

Reduced resilience during times of future stress

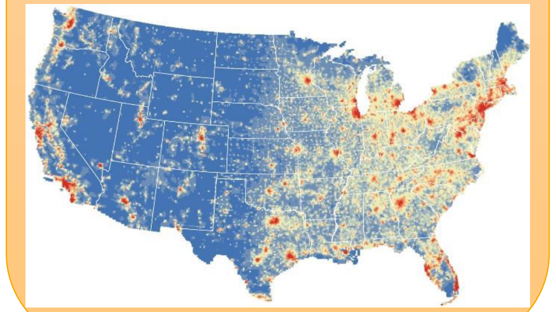
These effects could cut across spatial and temporal scales

Short-term climate variability in some regions

Electricity trade

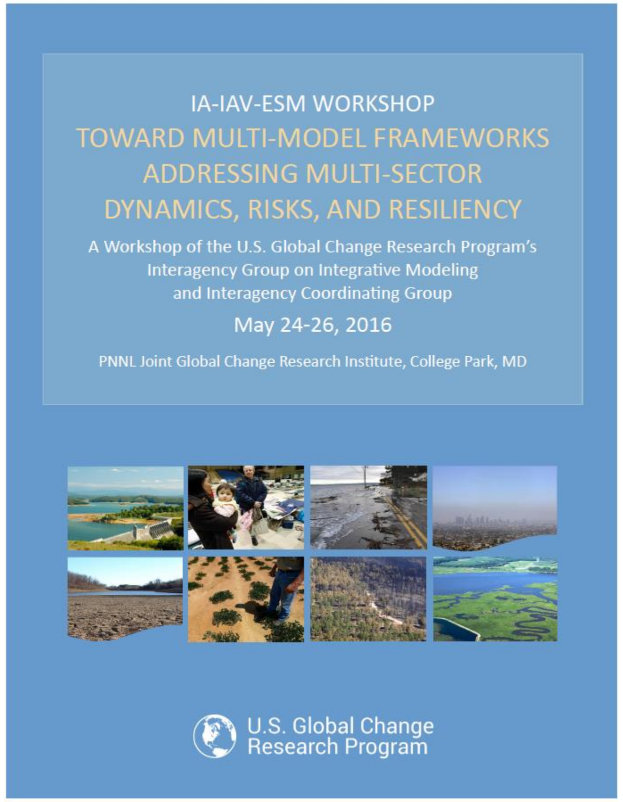


Long-term demographic shifts



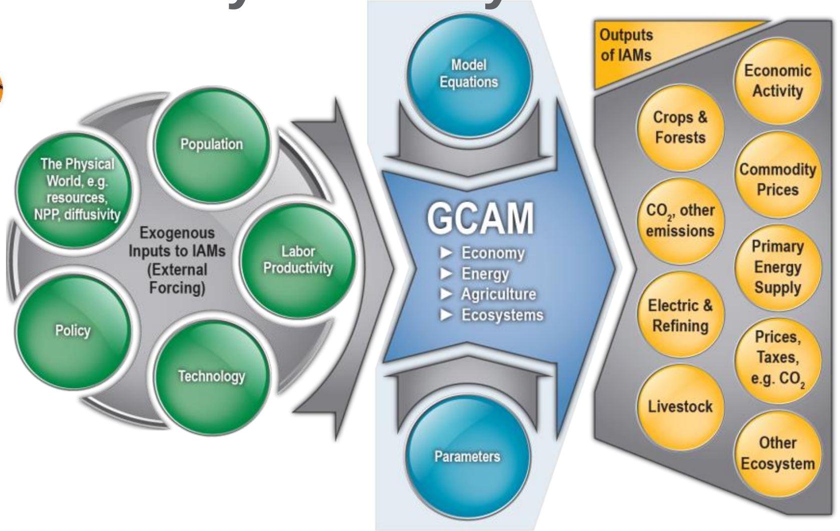
Transmission infrastructure throughout U.S.

A number of studies are looking into multi-sector multi-scale feedbacks and interactions

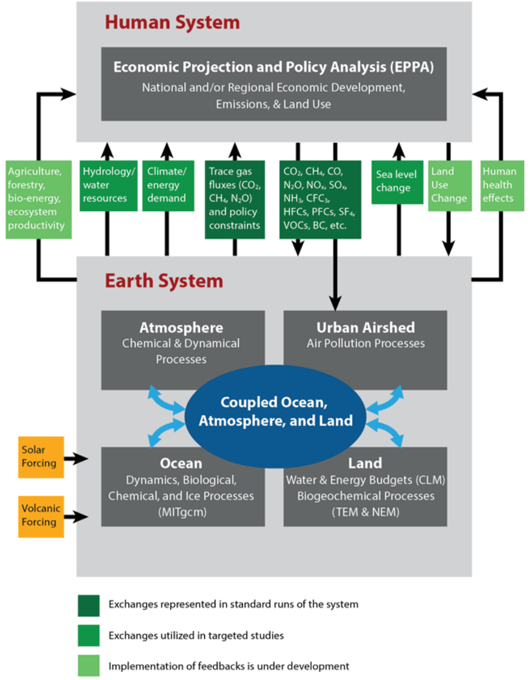


PCHES
Program on Coupled Human and Earth Systems

Integrated Human-Earth Systems Dynamics



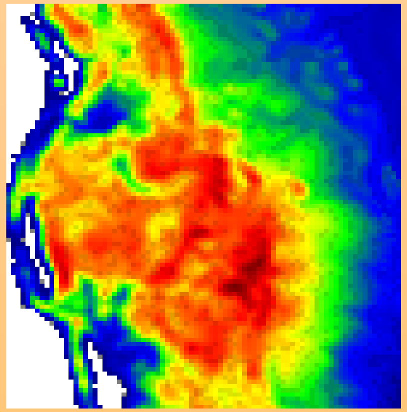
Integrated Global System Modeling



How might various stressors that drive changes across multiple systems at various spatial and temporal scales interact to influence the resilience of infrastructures that cut across systems?

An important consideration for studies is uncertainty about future stressors

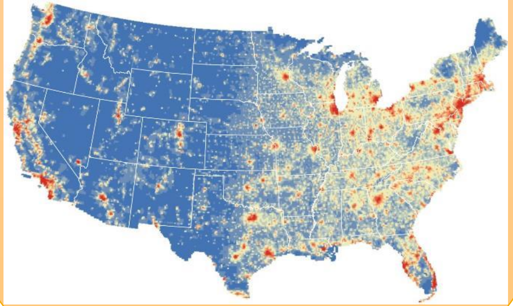
Regional climatic conditions



Extreme events

E.g. Droughts/ Heat waves/ Cold waves

Long-term demographic shifts

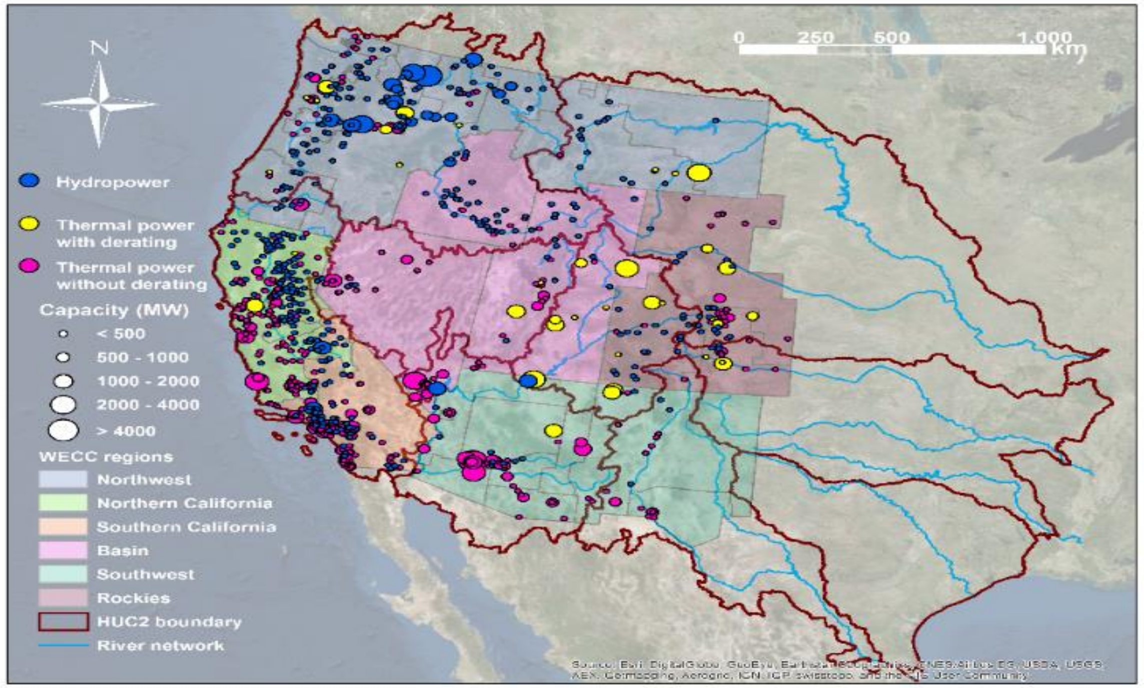


Technological change

A common approach to treat uncertainty in modeling studies is to use a handful (3-5) of scenarios

The focus of previous community-scale scenarios such as the Shared Socioeconomic Pathways (SSPs) is global and national

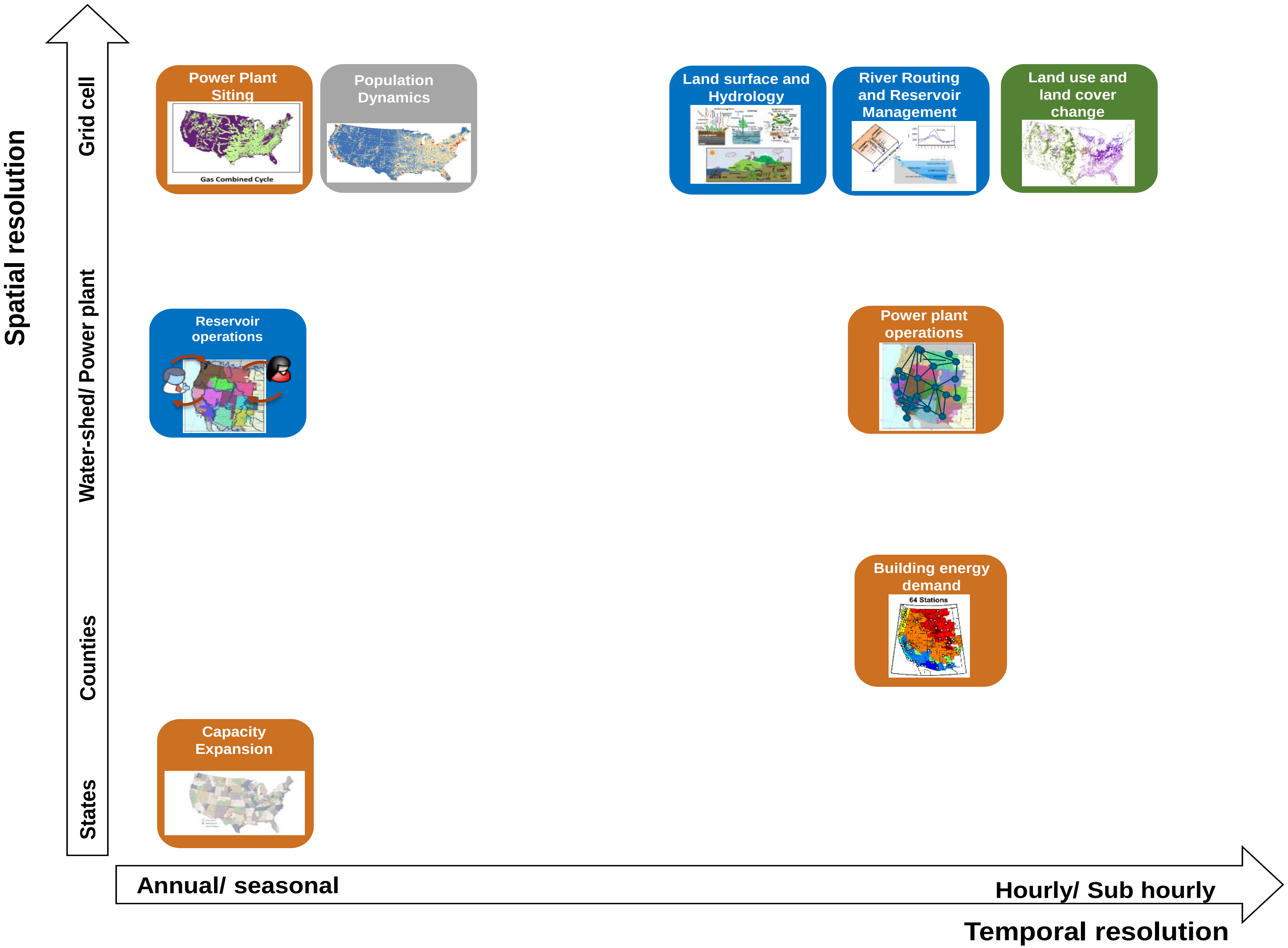
- Some studies have “downscaled” and extended the SSPs for regional and sub-national contexts.
- However, the applicability of the SSPs for multi-sector studies at sub-national levels interested in resilience outcomes is not clear.
- For example, assessments of resilience of grid operations and power systems in the western U.S. region would require scenarios looking at alternative assumptions of stressors such as water availability and air temperature.
- These assumptions need to be consistent with assumptions made for other regions to develop proper combined understanding at the national level.



We provide an initial framework to construct sub-national scenarios for the U.S. Energy-Water-Land Systems

- Since scenarios are context specific, we use the Integrated Multi-sector Multi-scale Modeling (IM3) project as the “test-case”.
  - IM3 is a good choice because the focus is pretty broad encompassing a range of complex energy-water-land dynamics at multiple spatial and temporal scales.
  - Initial focus is to develop a general scenario logic/framework of high/low stresses for the IM3 project.
  - With the objective that the framework will be more broadly applicable to other projects.
- We interview individual IM3 experiment leads to help define the content of the scenarios:
  - What “stress” means in the context of the coupled systems they are studying and how they would measure it.
  - What inputs the teams would need from a scenario framework.
- Develop a matrix of stressors most common to multiple areas of the IM3 project and story-lines describing “high” stress conditions.
  - We keep the matrix flexible to make sure that it is broadly applicable beyond the IM3 project.

Overview of experiments in IM3



Drivers across experiments in IM3

- Inputs for many drivers are available within the scope of models in IM3.
- However, some experiments depend on external sources of information to construct their scenarios because some model couplings do not yet exist within the scope of experiments that were surveyed.
- Scenario needs for energy-water-land experiments are really focused on demographic, climate, economic, technology and institutional drivers.

Driver	Experiments within IM3 and Models					
	Population dynamics	Capacity Expansion	Power Plant Siting	Power Plant Operations	Reservoir Operations	LULCC dynamics
		GCAM-USA, ReEDS	GCAM-USA, CERF	MOSART-WM, PLEXOS	RiverWare, ABM	GCAM-USA, CLM
Total population	Blue	Orange	Orange			Orange
Urbanization	Blue		Orange			Orange
Population gender	Blue					
Population age	Blue					
Migration	Orange					
Fertility rate (aggregate)	Orange					
Mortality rate (aggregate)	Orange					
Fertility rate (gender)	Orange					
Mortality rate (gender)	Orange					
Income or Income growth	Orange	Orange	Orange			Orange
Labor wages						
Average Energy prices						
Electricity demand		Green	Green		Orange	
Fossil fuel resources		Orange	Orange			
Renewable resources		Green	Green			
Natural gas prices		Orange	Orange	Orange		
Location marginal pricing			Green	Blue		
Transmission infrastructure		Orange	Blue	Orange		
Capacity Expansion		Blue	Green	Orange		
Water availability		Orange	Green	Green	Blue	Green
Runoff				Green	Green	
Water demand		Blue		Orange	Orange	Orange
Water scarcity						Orange
Land-use patterns						Blue
Land area for power plant siting			Orange	Orange		
Urban planning						Orange
Global mean temperature						
GHG emissions		Blue		Blue		Orange
Regional Climate		Orange	Orange	Orange	Orange	Orange
Precipitation				Orange	Orange	Orange
Technological advance		Orange	Orange	Orange		
Environmental regulations		Orange	Orange	Orange		Orange
Energy supply policies		Orange	Orange			
Energy Efficiency Policies		Orange	Orange			
Land Regulations						Orange
Forest management						Orange
Water rights			Orange	Orange	Orange	Orange
International migration laws	Orange					

Legend:

Green	Input, Currently being taken from within IM3
Orange	Input, Currently Need Scenario
Blue	Output

Example story-lines for a subset of stressors: Synthesis of Interviews

Drivers	Story-lines for stressors or assumptions leading to high stress in individual or combined energy, water, and land systems
Per capita income growth	Higher per-capita economic growth in the Western and Southern U.S. driven by improved labor productivity due to favorable conditions (e.g. average climate, education, health systems).
Temperature, Precipitation	Frequent and sustained heat and cold waves in the Western and Southern U.S. In addition, frequent and sustained drought conditions in the Western U.S. accompanied by frequent and sustained flooding in Northeast and South.
Population growth, Urbanization, Migration	High in-migration into the Western and Southern U.S. from other regions, increased international in-flows into these regions, and high urbanization rates in these regions driven by favorable economic, average climate, lifestyle and social conditions.
Technological advance	Environmental regulations and technological breakthroughs in energy supply and demand technologies result in increased electrification of buildings, industry, and transport; rapid deployment of renewables, carbon capture and storage (CCS), biofuels, and energy efficiency. In addition, farmers follow best irrigation and agricultural practices and there is a shift from once-through to recirculating cooling systems.
Water availability	Severely limited water availability in the Western U.S. due to frequent drought conditions, and stringent water institutions.

How to construct scenarios using our framework

- Our framework is intended to be flexible, so users designing their experiments could pick individual or combinations of story-lines in our matrix that would result in high stress for individual or combined energy, water, and land systems.
- For example, an experiment on grid operations could combine capacity expansion outputs from a high stress population scenario from GCAM-USA with high stress water availability outputs from a river routing model driven by severe drought and inflexible water rights assumptions to explore a high stress scenario.
- Constructing meaningful scenarios would ultimately depend on the degree of internal consistency and the focus of the experiment.
  - Consistency across elements of our matrix
  - Consistency across regions within the U.S.
  - Consistency with international trends

Concluding thoughts

- A framework such the one proposed here serves as a useful “reasonably consistent” organizing tool for multi-sector, multi-scale sub-national studies.
    - A perfectly internally consistent set of scenarios might not be practical.
    - For example, a rapid transition towards low-carbon technologies in the energy system driven by institutions pertaining to the energy system could result in reduced long-term temperature increases and also reduced variability over the long run.
- Our study also raises several technical considerations for future studies and areas of research:
    - Need for tools that span sectors, spatial, temporal, and process resolutions.
    - Need for the development of community practice for “down-scaling” and “upscaling” procedures.
    - In the case of “competing” tools, there is a need to conduct experiments that explore consistency systematically.

Thank you

Example interview questions

- **Drivers:** What are direct and indirect drivers of change that influence the systems and science questions that you are studying?

- **Background on model:** How are these drivers accounted for in your model and analysis? Explicitly resolved in the model or implicitly accounted for?

- **Existing scenarios:** What scenarios, or input data/parameters/assumptions are you already using or planning to use? (e.g., any assumptions regarding configurations of infrastructure, land use, and other factors)

- **Stressors:** What constitutes “high-stress” conditions for the systems being studied? Can system-failure threshold or tipping-point values be identified?