

Enhancing the Place of Adaptation in Integrated Climate Change Impact Assessment

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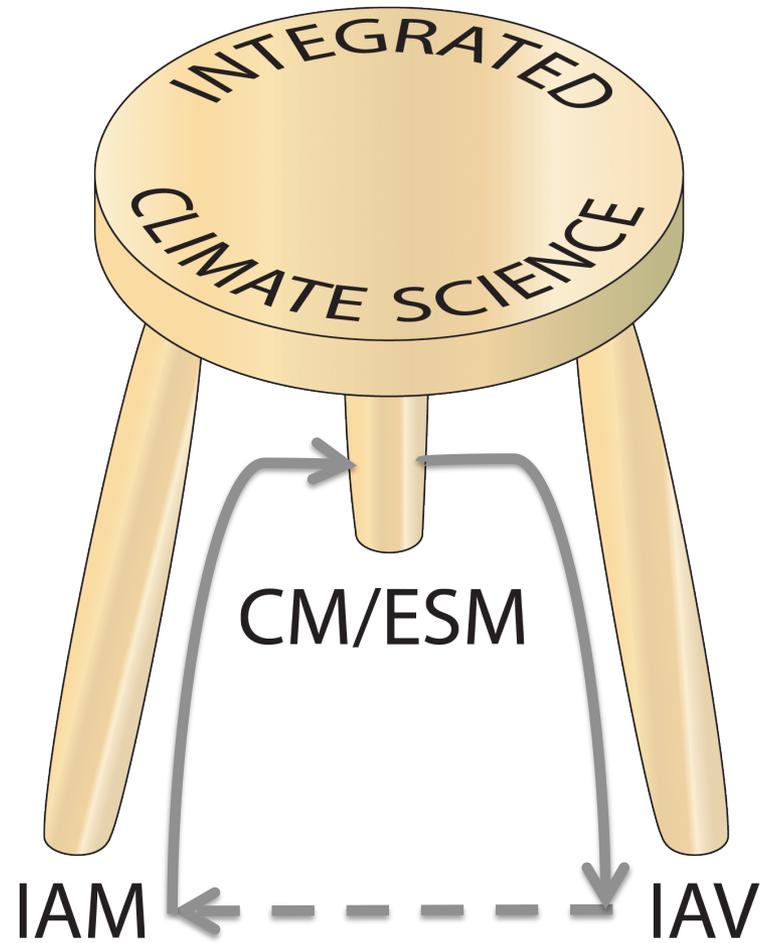
Oak Ridge National Laboratory

Climate Change Impacts and Integrated
Assessment Workshop XIX

Snowmass, CO

25 July 2013





Impacts Are Not Just Defined by Direct Effects of Exposures to Climate Change:

- **Impacts are shaped by multiple drivers of vulnerability to such effects, including sensitivity and coping capacity**
- **Over time, sensitivity and coping capacity are in turn shaped by adaptive risk management: adaptation**
- **Therefore a fully integrated impact assessment – e.g., estimates of impact risks and costs, and analyses their implications for energy policy and technology choices -- must incorporate adaptation**

Incorporating Adaptation in Integrated CC Impact Assessment is Complicated (I):

- Conditions, needs, and payoffs of adaptation options are enormously diverse – e.g., vary by threat, location, affected systems – and often relatively localized: the scales that matter most usually involve fine-grained spatial resolution (and supporting data bases)
- The adaptation research base is relatively limited by a history of scarce funding
 - Evidence is often case-study based, making it difficult to aggregate and generalize
 - Knowledge from practice is often ahead of knowledge from research, but ways of documenting lessons learned are still formative
- Especially true for *built* infrastructures, which are buffered from direct climate effects by *human* efforts to dominate and control nature by marginalizing its importance in our lives and are therefore often treated as sort of a residual, lower-priority “others” category in categorizing *IAV* issues

Incorporating Adaptation in Integrated CC Impact Assessment is Complicated (II):

- **A particular problem for human systems, especially built infrastructures, is that most of the knowledge bases are sector-specific, when many of the important impact and adaptation issues involve cross-sectoral interactions and interdependencies: e.g., energy/water/land**
- **Meanwhile, there is a distinct lack of evidence of *payoffs* from climate change adaptation actions, because we are just beginning to be able to attribute observed impacts to climate change -- which means that we are only beginning to be able to evaluate the effectiveness of adaptations in reducing those impacts**

Attention to Impacts on Built Infrastructures Has Grown in Response to Disruptive Effects of Extreme Events:

- **Initially focused on driving forces other than climate and weather: e.g., 9/11 (terrorism...) and the Howard Street Tunnel fire in Baltimore, 2001 (train derailment which started a five-day chemical fire; ruptured a water main – flooding downtown streets; damaged an electric power cable – leaving 1200 downtown buildings without electricity; destroyed a fiber-optic cable passing through the tunnel which carried Internet service to and from the Northeast...)...**
- **But increasingly oriented toward impacts of extreme *weather* events, from Gulf Coast hurricanes in 2005 and 2008 to more recent Hurricanes Irene and Sandy, major droughts in Texas and the south-central US, flooding in the Missouri and Mississippi River valleys, wildfires in the west, etc.**
- **Vulnerabilities of energy system facilities and infrastructures to impacts – and their linkages with other infrastructures, such as water, communication, transportation, commerce, waste management, and health – have become a central issue and a growing concern at DOE**

A Few Examples of Recent Attention to the Magnitude of Infrastructure Vulnerabilities:

- **A Munich Re study, October 2012: showed that weather-related economic losses nearly quintupled in North America between 1980 and 2011, with climate change a significant contributor**
- **A regional vulnerability assessment by Entergy: estimated losses to all sectors in 77 Gulf Coast counties of nearly \$40 billion by 2050 due to a combination of coastal storms, sea-level rise, land subsidence, and projected patterns of economic and demographic change**
- **The ASCE “water infrastructure report card” in 2011: estimated that by 2020 the US will have fallen \$84 billion short of needed investments in critical water systems, meaning \$416 billion in lost GDP, 700,000 lost jobs, and increased vulnerability to both flooding and droughts**

DOE's Integrated Assessment Research Program Has Been Exploring a New Approach for Overcoming Some of These Obstacles in Incorporating Adaptation by Built Infrastructures in Integrated Climate Change Impact Assessments :

- **Critical infrastructure simulation and analysis approaches developed by DOE national laboratories for DHS through NISAC are designed specifically to meet a number of these needs**
- **They are focused on impacts of extreme events on infrastructures (not just weather) at relatively local scales: cities, small regions**
- **They include very detailed facility/asset-specific GIS data bases for each infrastructure: e.g., every power plant and oil refinery in the US**
- **They are explicitly concerned with interactions and interdependencies, not only among different infrastructures but among components of different infrastructures**
- **Although developed to simulate impacts of possible terrorist acts, they have mainly been applied to decision support during extreme weather events – and have been fine-tuned based on learning from these events**

These Tools Are Intriguing:

- **Being applied for a variety of sponsoring agencies, including DOE: NISAC for DHS, electricity delivery and energy reliability for DOE, National Geospatial-Intelligence Agency, and others**
 - **Attention to 18 critical infrastructure sectors, along with dynamic infrastructure interdependencies**
 - **Virtually unique as impact assessment modeling approaches that work at a very fine scale, with data bases to support analyses at that scale for the entire United States**
 - **Especially useful for IAV applications related to extreme events**
 - **Utilizing advanced modeling and visualization approaches**
 - **Capable of fast turnaround analysis: e.g., infrastructure implications of Hurricane Irene and Sandy and the recent San Diego blackout**

Interdependencies: a Complex System-of-Systems Problem

Agriculture & Food
 Banking & Finance
 Chemical
 Commercial Facilities
 Dams
 Defense Industrial Base
 Emergency Services
 Energy
 Government Facilities
 Manufacturing
 Nuclear Reactors, Materials & Waste
 Information Technology
 National Monuments & Icons
 Postal & Shipping
 Public Health & Healthcare
 Telecommunications
 Transportation
 Water

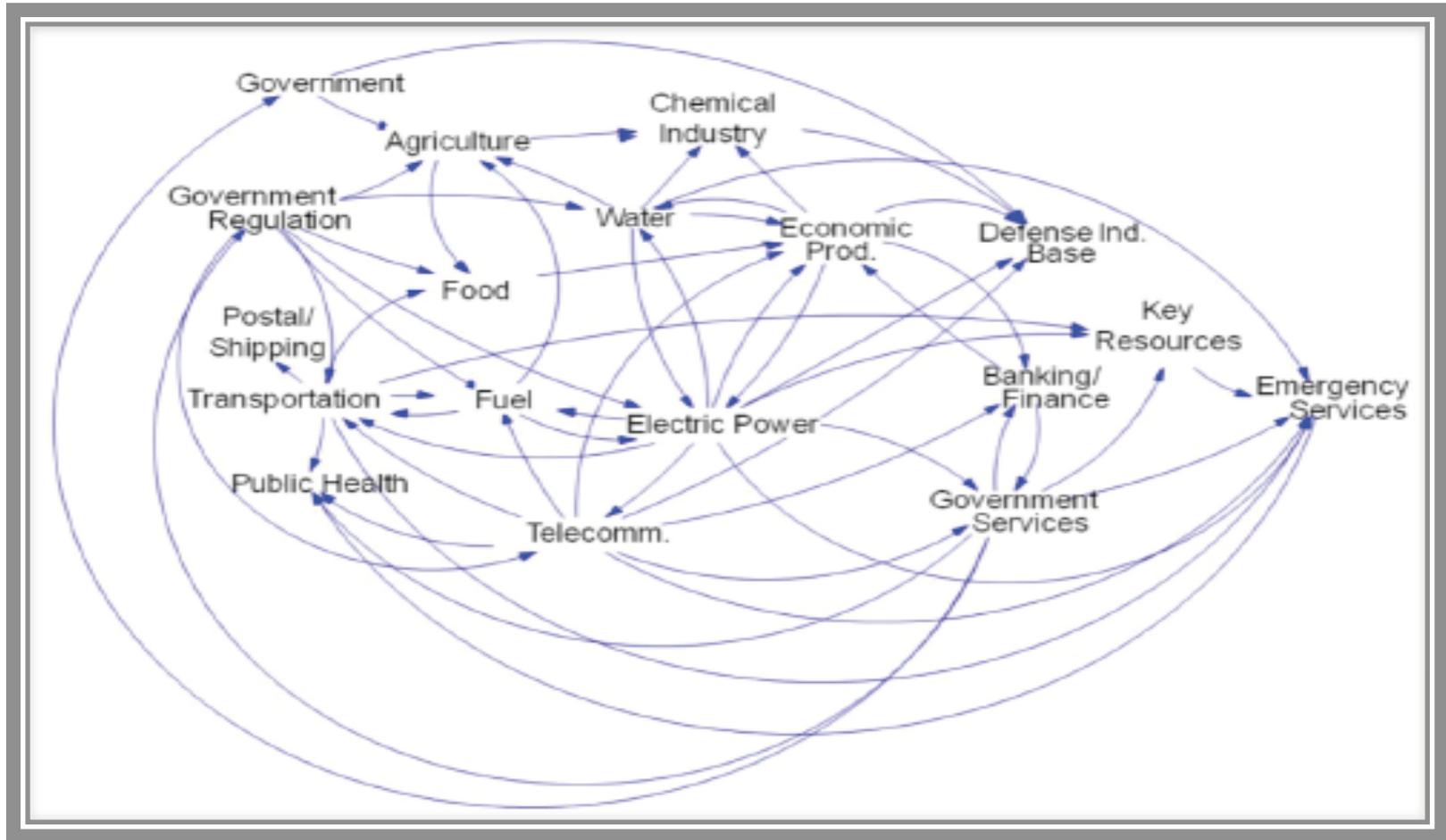
5. ENERGY	
5.1	ELECTRICITY
5.1.1	Electricity Generation
5.1.1.1	Hydroelectric Generation
5.1.1.1.1	Hydroelectric Dams
5.1.1.1.2	Pumped Storage Facilities
5.1.1.1.3	Run-of-River Generators
5.1.1.2	Fossil Fuel Electric Power Generation
5.1.1.2.1	Coal-fired Generators
5.1.1.2.2	Natural-gas-fired Generators
5.1.1.2.3	Oil-fired Generators
5.1.1.3	Nuclear Electric Power Generation
5.1.1.3.1	Light Water Reactor Power Plants
5.1.1.3.2	Other Reactor Power Plants
5.1.1.4	Other Electric Power Generation
5.1.2	Electricity Transmission
5.1.2.1	Transmission Lines
5.1.2.2	Transmission Substations
5.1.2.3	DC Converter Stations
5.1.2.4	Generation Dispatch and Transmission Control Center
5.1.3	Electricity Distribution
5.1.3.1	Distribution Lines
5.1.3.2	Distribution Substations
5.1.3.3	Distribution Control and Dispatch Centers
5.1.4	Electricity Markets
5.1.4.1	Generation Markets
5.1.4.2	Transmission Markets
5.1.5	Other Electricity Facilities
5.2	PETROLEUM
5.2.1	Crude Oil Supply
5.2.1.1	On-shore Wells
5.2.1.2	Off-shore Wells
5.2.1.3	Crude Oil Production from Other Sources
5.2.1.4	Gas-Oil Separation Plants

Defined in the NIPP*

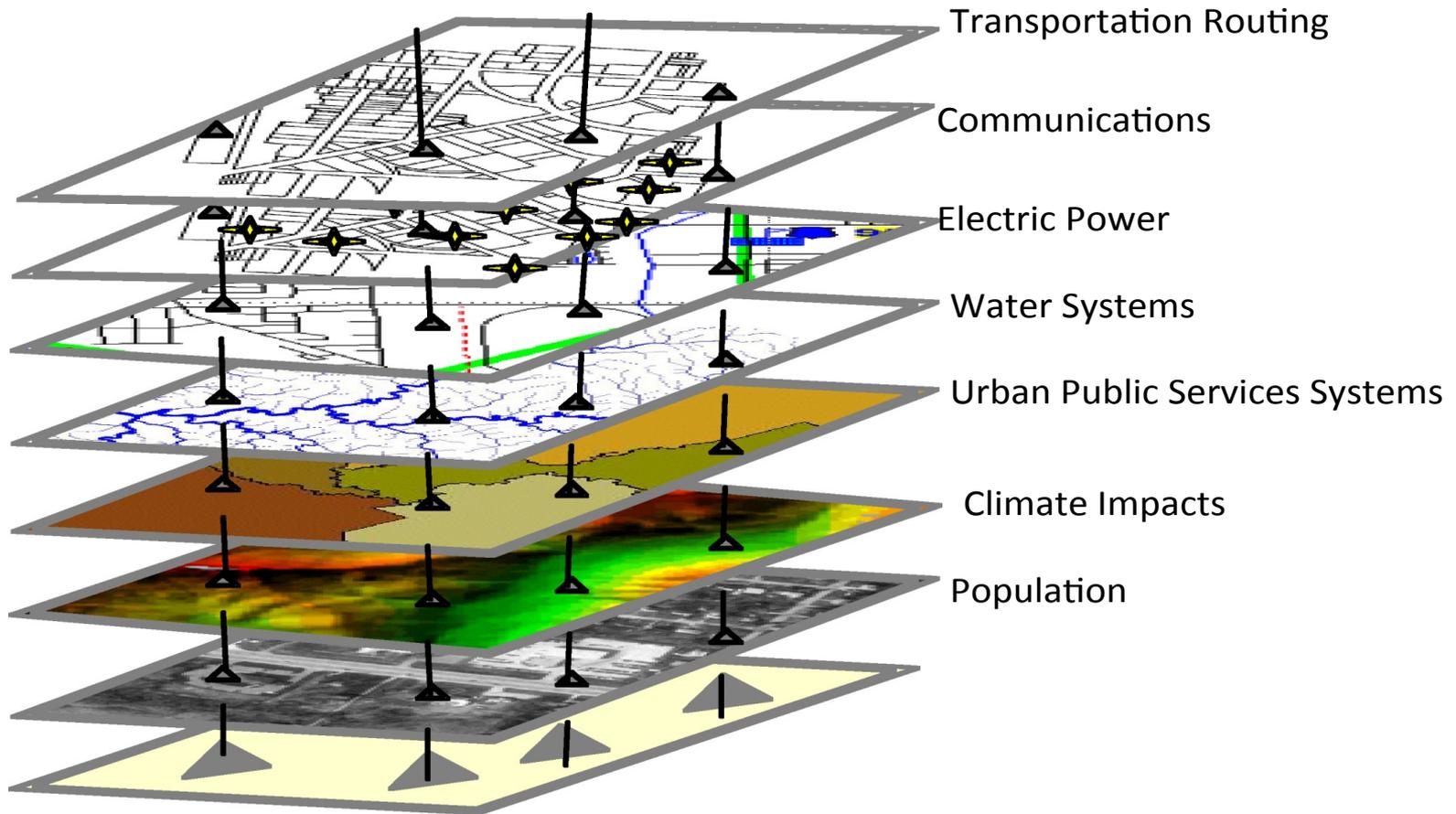


*National Infrastructure Protection Plan

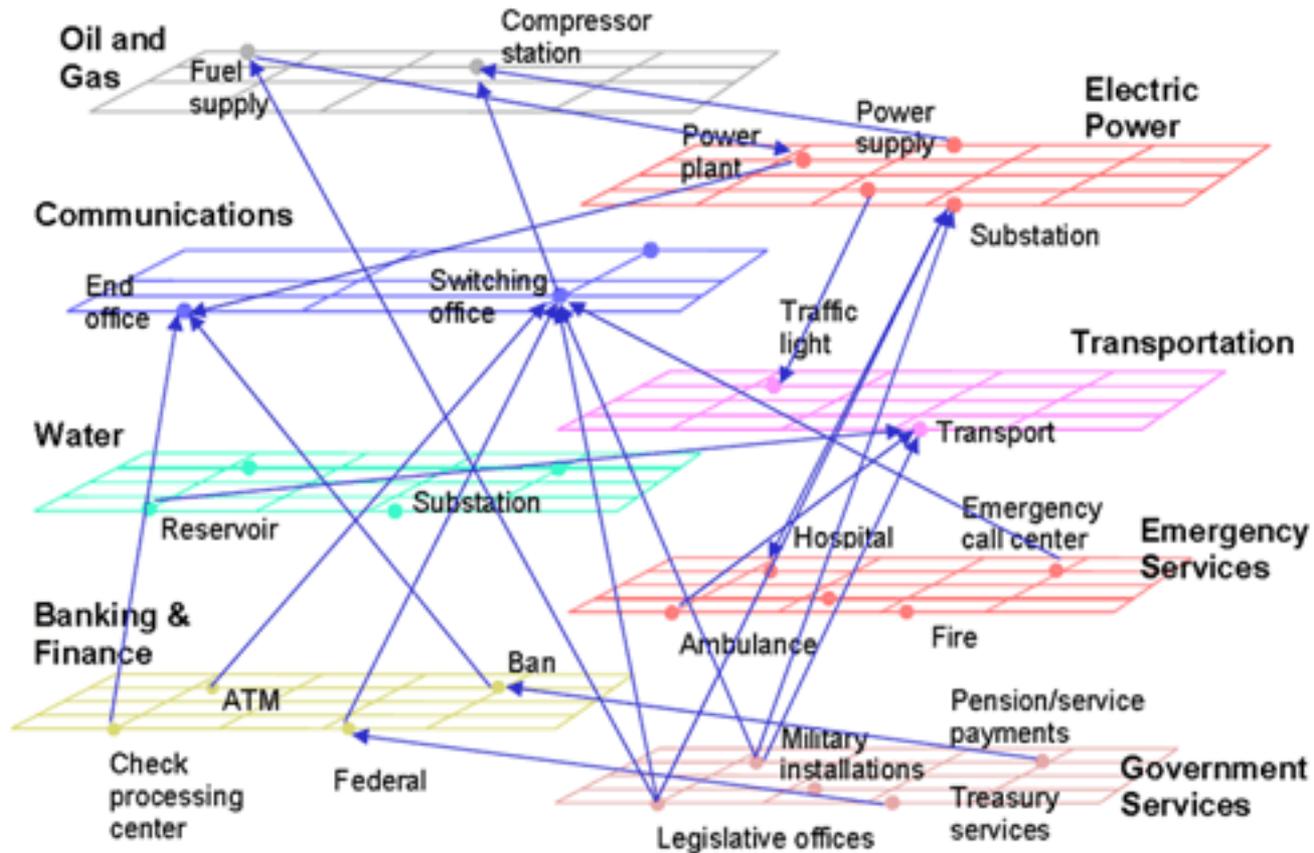
An Interdependent System of Systems Approach (I)



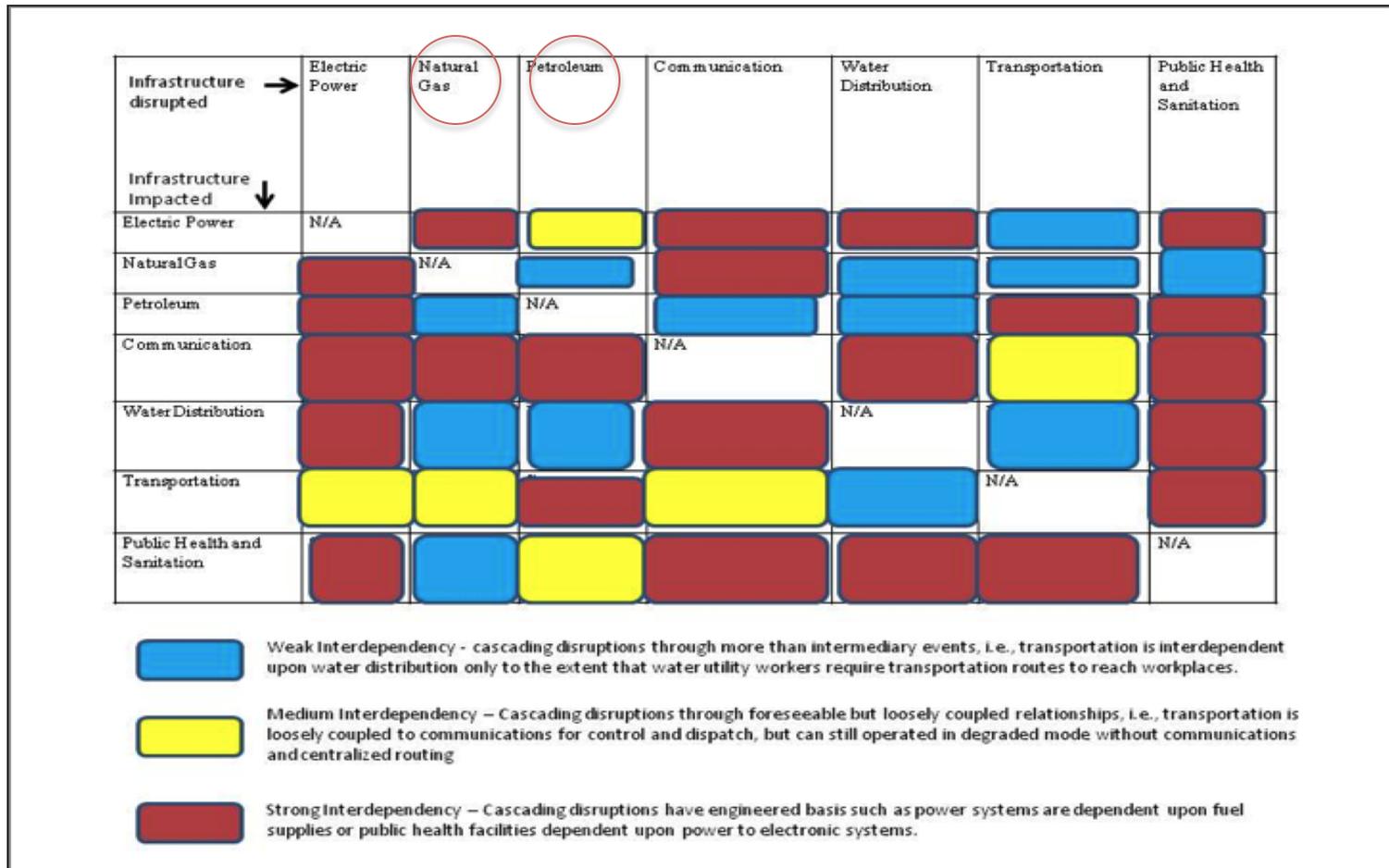
An Interdependent System of Systems Approach



Infrastructure Systems Can Be Modeled as Interconnected Infrastructure Layers

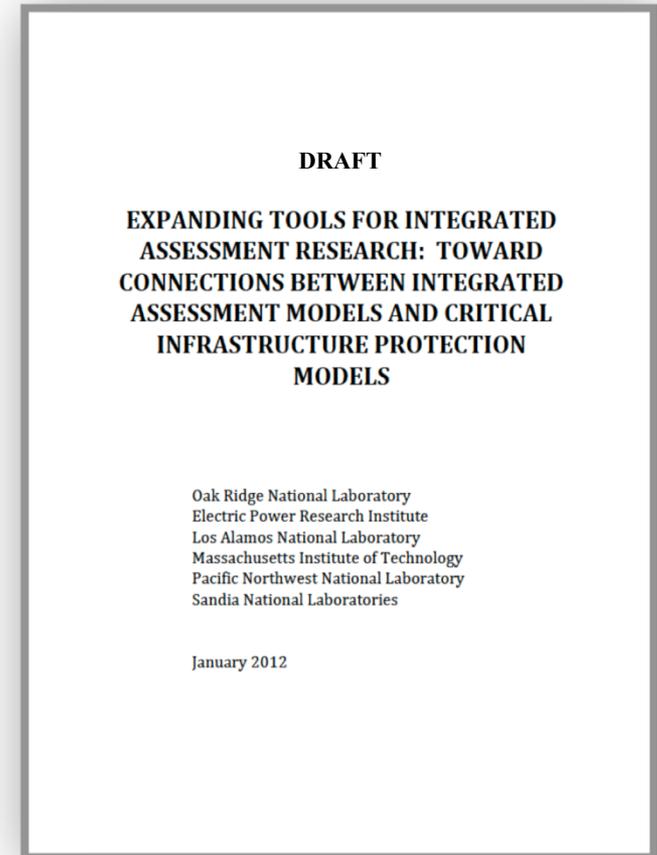


A Number of Years of Experience in Applying These Tools Is Telling Us about Infrastructure Interdependencies:



The Challenges Facing Integration of These Tools with Other Integrated Assessment Tools Are Considerable:

- **Modeling frameworks developed to address very different issues: energy/economic systems vs. emergency impacts and cascading inter-dependencies**
- **Very different in model structure, data, and representation of interactions**
- **Very different in spatial scale: continental/national vs. local**
- **Very different in time scale: decadal and well beyond vs. days and weeks**
- **But some recent experiences may be showing us ways to benefit from some kinds of connections**



Examples of Some Recent and Current Experiences with Connections:

- **Without DOE support, analyses of vulnerabilities of electricity systems to wildfires (LANL), issues in international conflict/stability and global supply chain analysis that can be related to climate change (Sandia), and issues related to long-term population resettlement dynamics related to climate change vulnerabilities (ORNL)**
- **With DOE support, connecting components of IAM and CIP models in the Regional Integrated Assessment Modeling (RIAM) project, led by PNNL and supported by ORNL and others: combining location-specific energy facility data with climate change scenarios and sensitivity coefficients to estimate impacts of climate change and potentials for adaptation at a regional scale, linked to a regional IAM and to the national-scale GCAM**
- **With support from a variety of sources, Sandia/MIT collaboration in (a) exploring climate change implications for water systems and their linkages with energy and other infrastructures and (b) exploring linkages between localized and regional impacts and the broader macroeconomy**

At a Relatively Modest Level of Effort, IARP Is Seeking to Enhance Capacities for Incorporating a Connected Infrastructure Dynamics Modeling (CIDM) Approach in Integrated CC Impact and Adaptation Assessment:

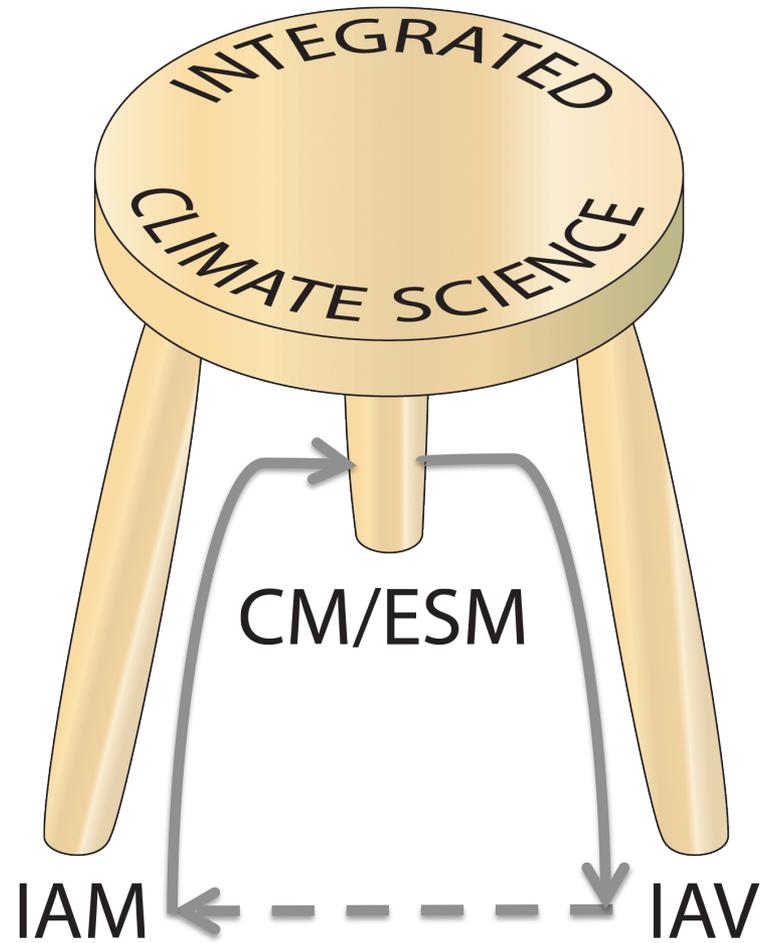
- **Adding climate and weather-related parameters to CIDM beyond extreme events alone**
- **Adding richness to the energy layers of CIDM to add capacities to analyze interactions among components of energy systems as well as between energy and other infrastructures**
- **Adding capacities for CIDM to address infrastructure changes in the future, related to technological change and other drivers – *an essential step in being able to assess infrastructure adaptation options in order to increase resilience***
- **Using energy/water infrastructure interactions as a case study of how CIDM tools and perspectives can be combined with IAM and other integrated CC impact assessment tools and perspectives**
- **Identifying some possible targeted experiments with connecting IAM and CIDM tool sets and expertise**

A First Cut at Targeted Experiments:

- **Examining near-term climate effects on existing critical infrastructures and possible near-term adaptation approaches to reduce impacts: connecting emission scenarios and other projections of near-term extremes and extreme weather events with vulnerabilities of energy and other infrastructures to extremes and extreme events, now and over time**
- **Examining effects of driving forces shaping the character and deployment of critical infrastructure over medium to long term time horizons, e.g., socioeconomic and technological change, using IAMs and RCPs to frame the evolution of critical infrastructures and CIDM to estimate bottom-up impacts and adaptive potentials**
- **Combining these examinations of climate change and other key driving forces (e.g., socioeconomic and technological) over the near, medium, and long terms to help guide the evolution of critical infrastructures to be robust to both forces**

Of Course, Structural Adaptation in Built Infrastructures Is Not the Only Challenge in Enhancing Adaptation's Place in CCIA:

- **Other key issues include:**
 - **Institutional and community adaptations**
 - **Adaptation capacity-building**
 - **Possible needs for transformational adaptations in especially vulnerable regions and/or sectors, especially if progress with mitigation continues to be slow**
- **But we need to start somewhere in figuring out how to link the bottom-up character of adaptation planning and action with the larger national and regional framing of integrated climate change assessment, and this appears to be a target of opportunity – with some unique bottom-up data sources and analytical tools, related to DOE's science agendas**
- **One challenge is to be thinking about how the new kinds of model-based integration that we pursue in this case could be adapted to incorporating *other* kinds of emerging data bases about localized climate change vulnerabilities and adaptations as well**



The Final Challenge Is Linking Emerging Knowledge about Impacts and Adaptation Back with Emission/Mitigation Modeling and Analysis:

- **We need to begin to discuss ways to connect (a) assumptions about (and eventually observations of) climate change adaptation in the energy sector and other infrastructures with which it is linked, working up from a facility scale, with (b) projections of energy supply and use technologies and the GHG emissions associated with them, working at regional, national, and potentially global scales – reflecting impact vulnerabilities and adaptation needs, potentials, and possible strategies**
- **Might start with some impact and adaptation scenarios:**
 - **Impacts associated with several CMIP-5 scenarios at a fine-grained scale (especially for energy technology choices), combined with**
 - **Representative adaptation scenarios, e.g., substantial, mixed, minimal -- to see how IAM projections of GHG emissions and consequences of mitigation policy options are affected by these additional impact and adaptation drivers**