Climate Change and the Resilience of Interconnected Infrastructures

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Conference on Climate Change and America's Infrastructures

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

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Infrastructures and Built Environments as Issues for Climate Change Vulnerability, Impact, and Adaptation Assessments (I):

- **Historically, climate change IAV analyses and assessments have tended to emphasize close linkages with *natural* systems obviously sensitive to climate parameters: e.g., ecology, hydrology**

- **Infrastructures and built environments are buffered from direct climate effects by *human* efforts to dominate and control nature by marginalizing its importance in our lives: *earth systems as <u>transformed</u> by human action***

  - **Living and working in settings whose conditions are defined by and within structures, not by conditions external to them (except when we choose otherwise)**

  - **Engineering or replacing natural features to fit human convenience**

- **Therefore, infrastructures have been a focus of emission *mitigation* issues, but often treated as sort of a residual "others" category in categorizing *IAV* issues: e.g., IPCC AR4 – "Industry, Settlement, and Society"**

Infrastructures and Built Environments as Issues for Climate Change IAV Assessments (II):

- **But built infrastructures and environments, especially in an urban context, are emerging as IAV topics of particular interest:**
  - **Anticipated by the US Global Change Research Act of 1990, which mandates attention to such concerns as energy production and use, transportation, health, and human social systems**

  - **Driven by the fact that they are at the heart of the kinds of vulnerabilities and impacts that most people care most about: comfort, convenience, mobility, labor productivity, security….**
  - **Associated with population concentrations and locations in vulnerable areas**
  - **Often threatened by climate change, especially increases in extremes and extreme events: storms, floods, wildfires, droughts, heat waves, …**

Infrastructures and Built Environments as Issues for Climate Change IAV Assessments (III):

- **But built infrastructures and environments are emerging as IAV topics of particular interest (continued):**
  - **Interacting with other kinds of vulnerabilities: e.g., aging infrastructures, rigid structures, high costs of capital investments, risks of terrorism, economic downturns, etc.**
- **The questions are:**
  - **Do built infrastructures and environments make our lives and our country more or less *vulnerable* to impacts of climate change?**
  - **What are the *impacts* likely to be from several scenarios for climate change: e.g., a higher and a lower scenario?**
  - **What are the potentials for built infrastructures and environments to play lead roles in *adapting* to impacts of climate change?**

Infrastructures and Built Environments as Issues for Climate Change IAV Assessments (IV):

- **Built infrastructures include urban areas, energy systems, transportation systems, water systems, sanitation systems, communication systems, and other products of human design and construction to deliver services in support of human quality of life**
- **Climate change impacts and risk management strategies for *infrastructure* are characteristically dominated by big-picture issues:**
  - **Dominated by large-scale events and large-scale decisions that cast long shadows**
  - **Dominated by major players with impressive financial and managerial resources; relatively well-adapted to climate variability; and in many cases already factoring climate change-related risks into their strategic thinking (for example, the oil and gas industry)**
  - **In many cases, already under some stress: e.g. often dealing with aging current infrastructures**
  - **At the margin, not extremely sensitive to climate parameters unless other stresses threaten tipping points – but they often do…**

Infrastructures and Built Environments as Issues for Climate Change IAV Assessments (V):

- **Many of the implications of climate change involve *interactions* among the various kinds of built infrastructures and environments**
- ***Urban areas* are often of special interest for cross-sectoral attention because all of the various kinds of infrastructures are integrated there (and because that is where most of the people live, where the votes are, where the financial centers are, where the media centers are, etc.)**
- **But critical cross-sectoral interactions are also issues for other scales: regional (e.g., electricity infrastructures/communication infrastructures, transportation infrastructures/waste disposal infrastructures) and national (national security)**

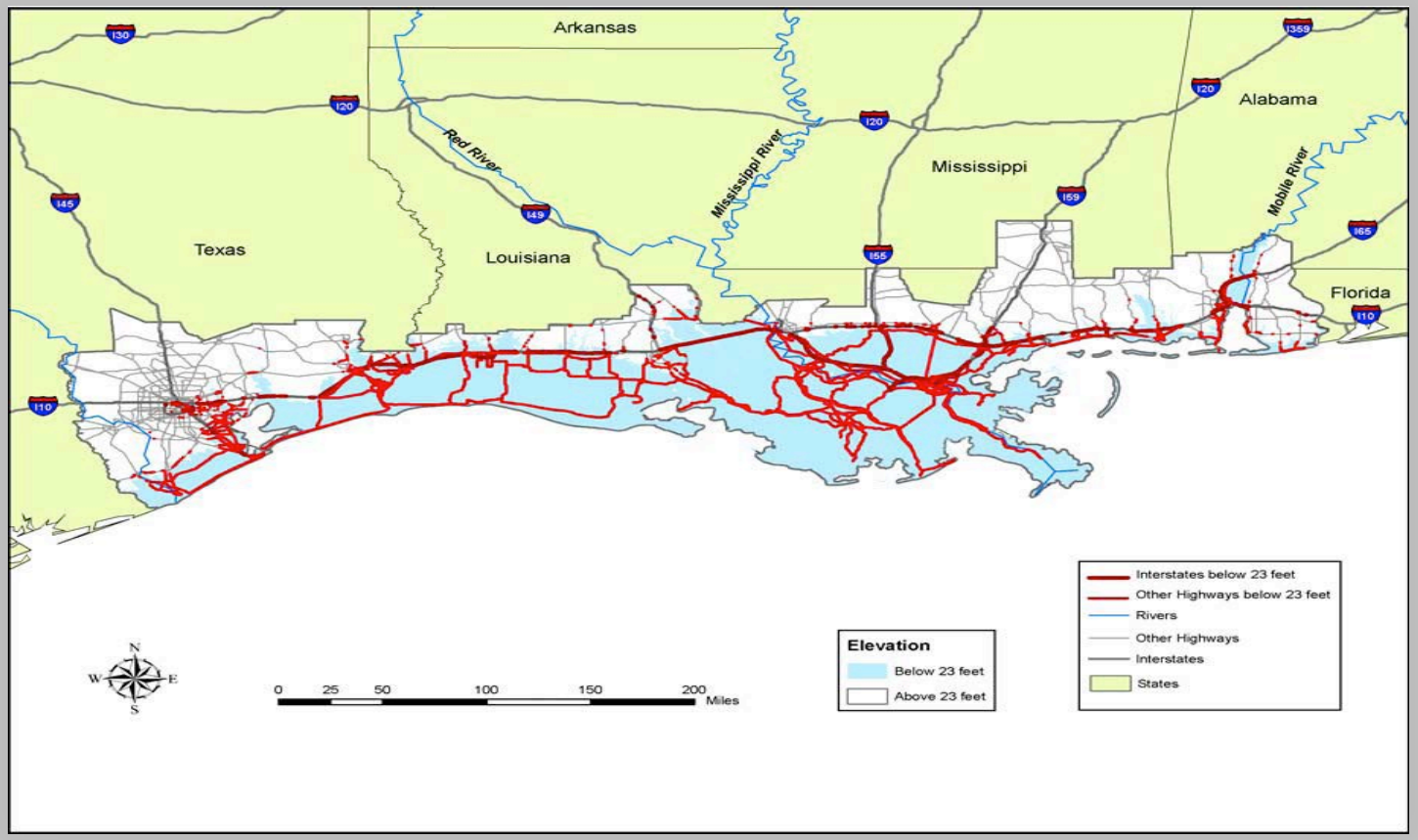
Infrastructures and Built Environments as Issues for Climate Change IAV Assessments (VI):

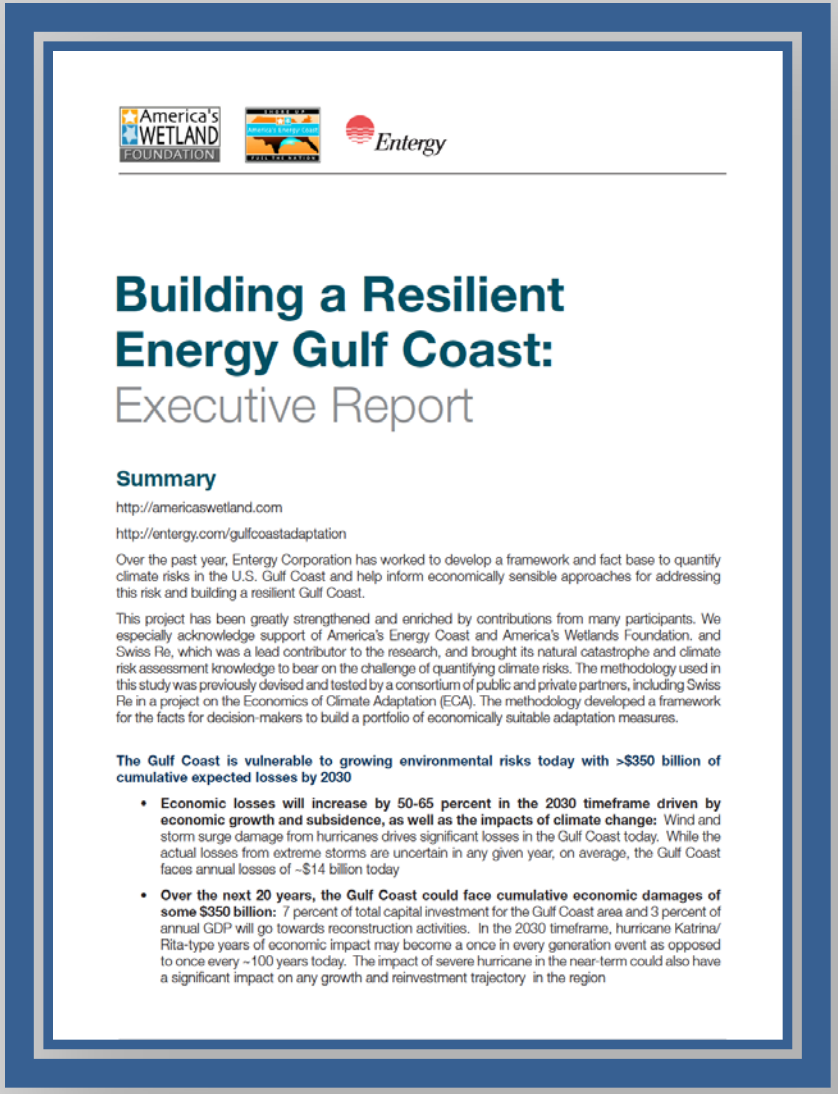
- **We should not minimize the issues regarding adaptive responses:**
  - **Built infrastructures, with their high levels of investment and relatively long lifetimes, are often viewed as among the most rigid of all of our human systems – resistant to adaptation, hard and expensive to change**
  - **Changing or revitalizing built infrastructures tends to be highly dependent on large-scale public investment, when budget deficits at all levels of government are reducing chances of such investment in the foreseeable future**
- **But the resolving the issues is becoming increasingly urgent:**
  - **A matter of national concern: e.g., OSTP's Infrastructure Subcommittee of its Homeland and National Security Committee**
  - **For example, a focus of the American Society of Civil Engineers (ASCE) "water infrastructure" report card, 2011: by 2020 US will have fallen $84 billion short of needed investments in critical water systems, meaning $416 billion in lost GDP and 700,000 lost jobs and increased vulnerability to both flooding and droughts**
  - **And a concern in state governments right now: transportation infrastructures**

Consider a Couple of Vivid Examples of Infrastructure Vulnerability:

- **Some examples of infrastructure impacts of extreme events from history:**
  - **The Baltimore tunnel fire of 2001: five days of downtown flooding, 1200 downtown buildings without power, fiber-optic cable destroyed (interrupting Internet service in the NE), transportation systems disrupted**
  - **The Northeast blackout of 2003: 50 million people lost electric power, widespread shutdowns of water pumping stations and loss of water pressure – causing water contamination, loss of power to oil refineries…**
- **Some examples of current US regional vulnerabilities:**
  - **The Gulf Coast, vulnerable to a combination of economic/demographic growth, increasingly strong coastal storms, sea-level rise, and land subsidence: e.g., the experience with Hurricanes Katrina, Rita, Gustav, and Ike**
  - **The coastal Northeast, vulnerable to a combination of dense urban-industrial development, increasingly strong coastal storms, and sea-level rise: e.g., the recent experience with Superstorm Sandy (and Irene before)**

As One Example: Gulf Coast Highways Currently At Risk From Storm Surge At Elevations Currently Below 7.0 M (23 Ft.) – CCSP SAP 4.7, 2009





America's WETLAND FOUNDATION

Entergy

Building a Resilient Energy Gulf Coast:
Executive Report

Summary

http://americaswetland.com

http://entergy.com/gulfcoastadaptation

Over the past year, Entergy Corporation has worked to develop a framework and fact base to quantify climate risks in the U.S. Gulf Coast and help inform economically sensible approaches for addressing this risk and building a resilient Gulf Coast.

This project has been greatly strengthened and enriched by contributions from many participants. We especially acknowledge support of America's Energy Coast and America's Wetlands Foundation. and Swiss Re, which was a lead contributor to the research, and brought its natural catastrophe and climate risk assessment knowledge to bear on the challenge of quantifying climate risks. The methodology used in this study was previously devised and tested by a consortium of public and private partners, including Swiss Re in a project on the Economics of Climate Adaptation (ECA). The methodology developed a framework for the facts for decision-makers to build a portfolio of economically suitable adaptation measures.

The Gulf Coast is vulnerable to growing environmental risks today with >$350 billion of cumulative expected losses by 2030

- **Economic losses will increase by 50-65 percent in the 2030 timeframe driven by economic growth and subsidence, as well as the impacts of climate change:** Wind and storm surge damage from hurricanes drives significant losses in the Gulf Coast today. While the actual losses from extreme storms are uncertain in any given year, on average, the Gulf Coast faces annual losses of ~$14 billion today
- **Over the next 20 years, the Gulf Coast could face cumulative economic damages of some $350 billion:** 7 percent of total capital investment for the Gulf Coast area and 3 percent of annual GDP will go towards reconstruction activities. In the 2030 timeframe, hurricane Katrina/ Rita-type years of economic impact may become a once in every generation event as opposed to once every ~100 years today. The impact of severe hurricane in the near-term could also have a significant impact on any growth and reinvestment trajectory in the region

Key areas examined within 70 miles of the coast

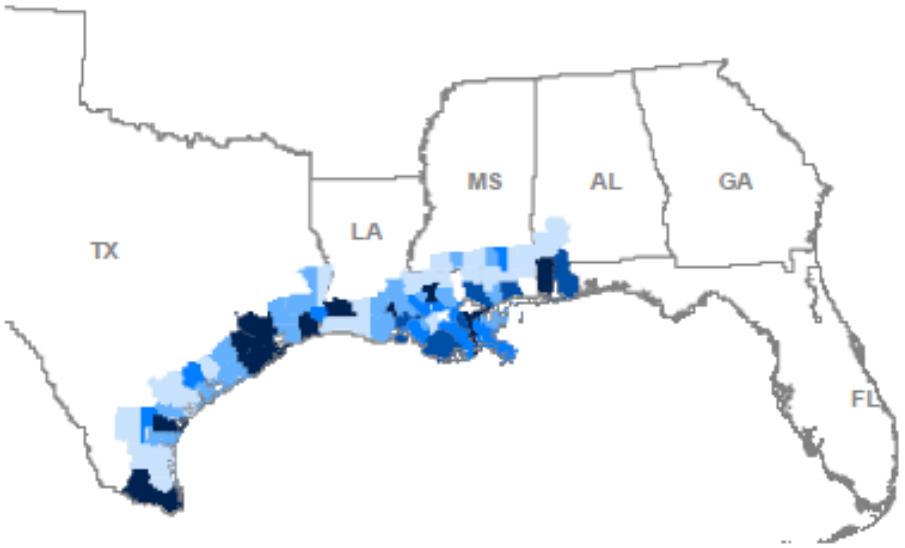
US Gulf Coast region and counties in scope[1]

2010 GDP ($M)

- ≤1,000
- 1,000-2,500
- 2,500-5,000
- 5,000-10,000
- >10,000

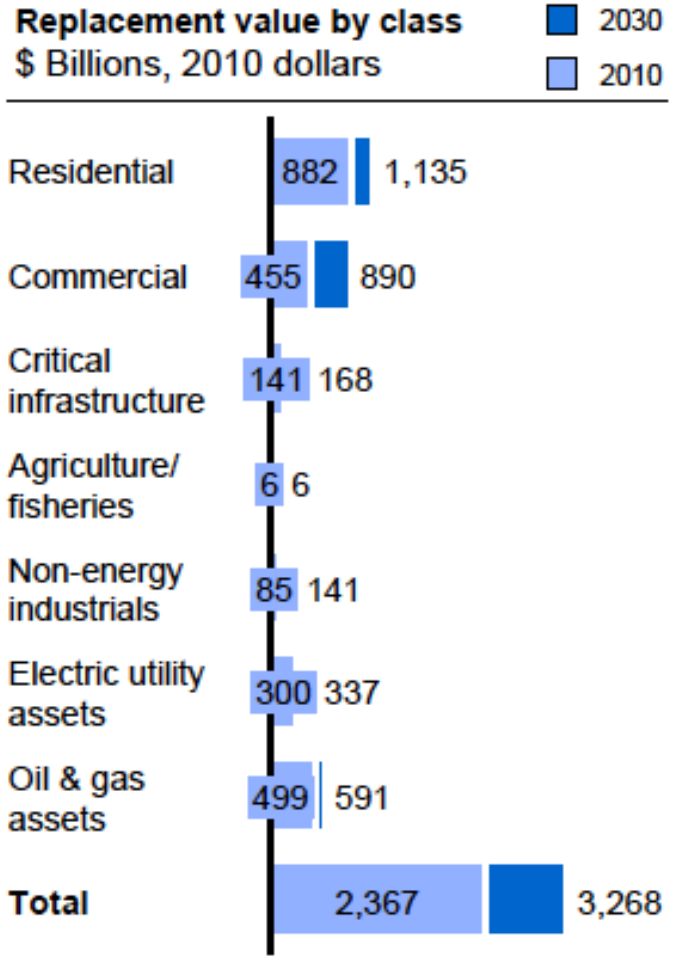
Basic metrics

Counties	77
Area	61,685 sq. mi
GDP	$634 B
Population	11.7 million



Asset values by class

Replacement value by class
$ Billions, 2010 dollars



1 Includes 30 Louisiana parishes

Source: ESRI; Energy Velocity

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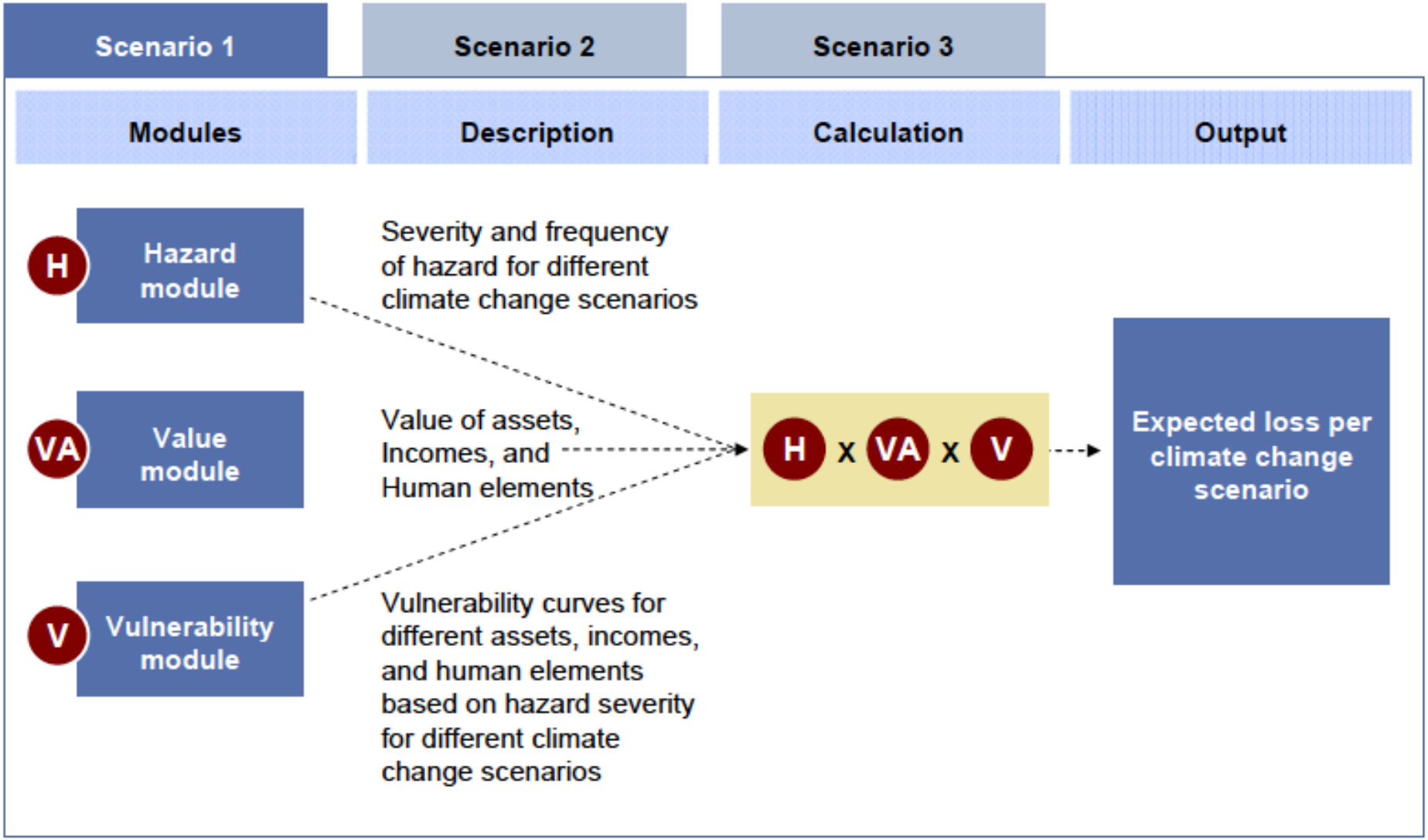

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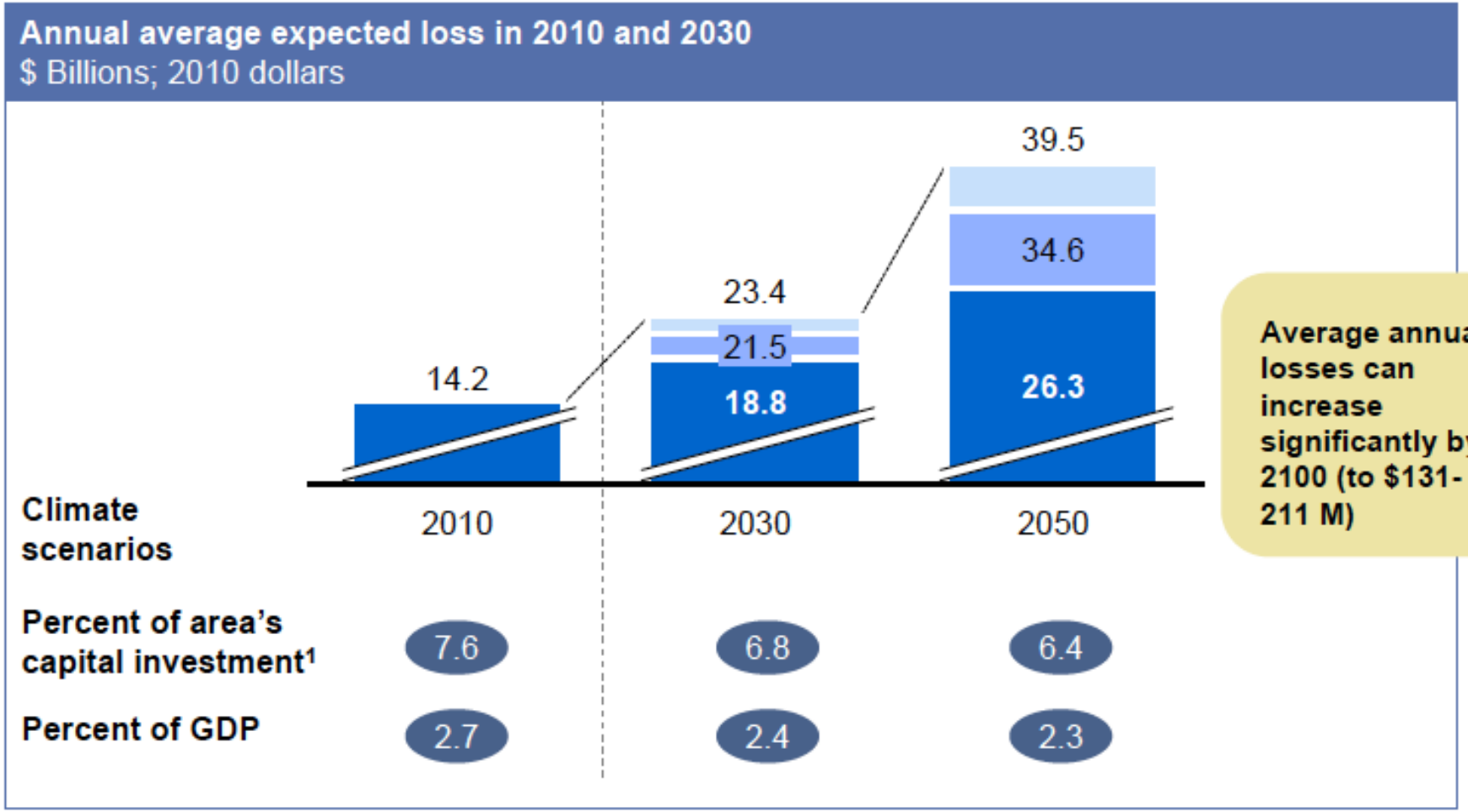
3 Extreme storms drive significant economic damage with losses increasing going forward

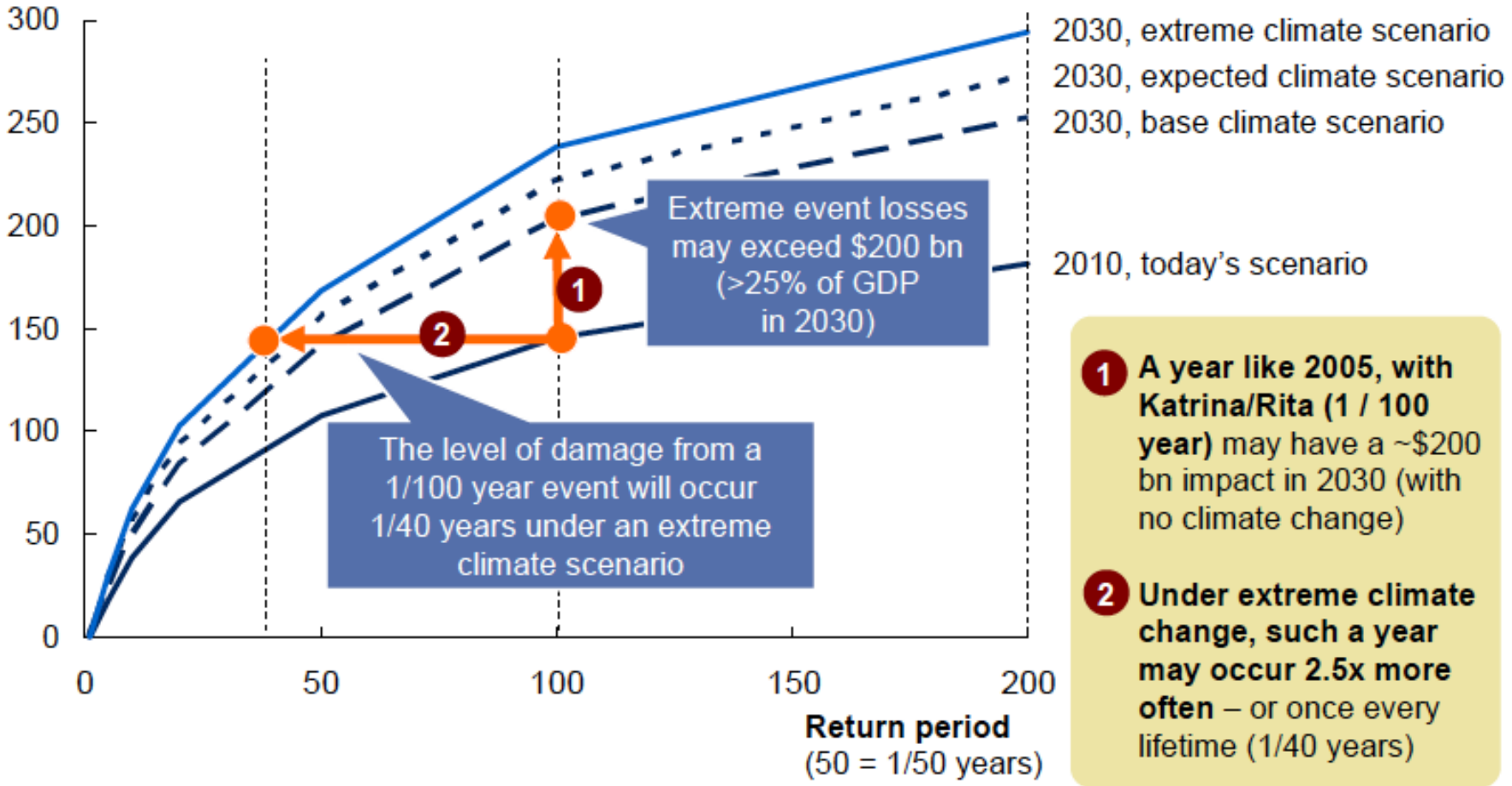


1 No climate change; includes impact of subsidence
2 Based on BEA historical average of capital investment (private and total government expenditures) as a percentage of GDP

Source: Swiss Re

4 The risk profile of the region will also shift going forward

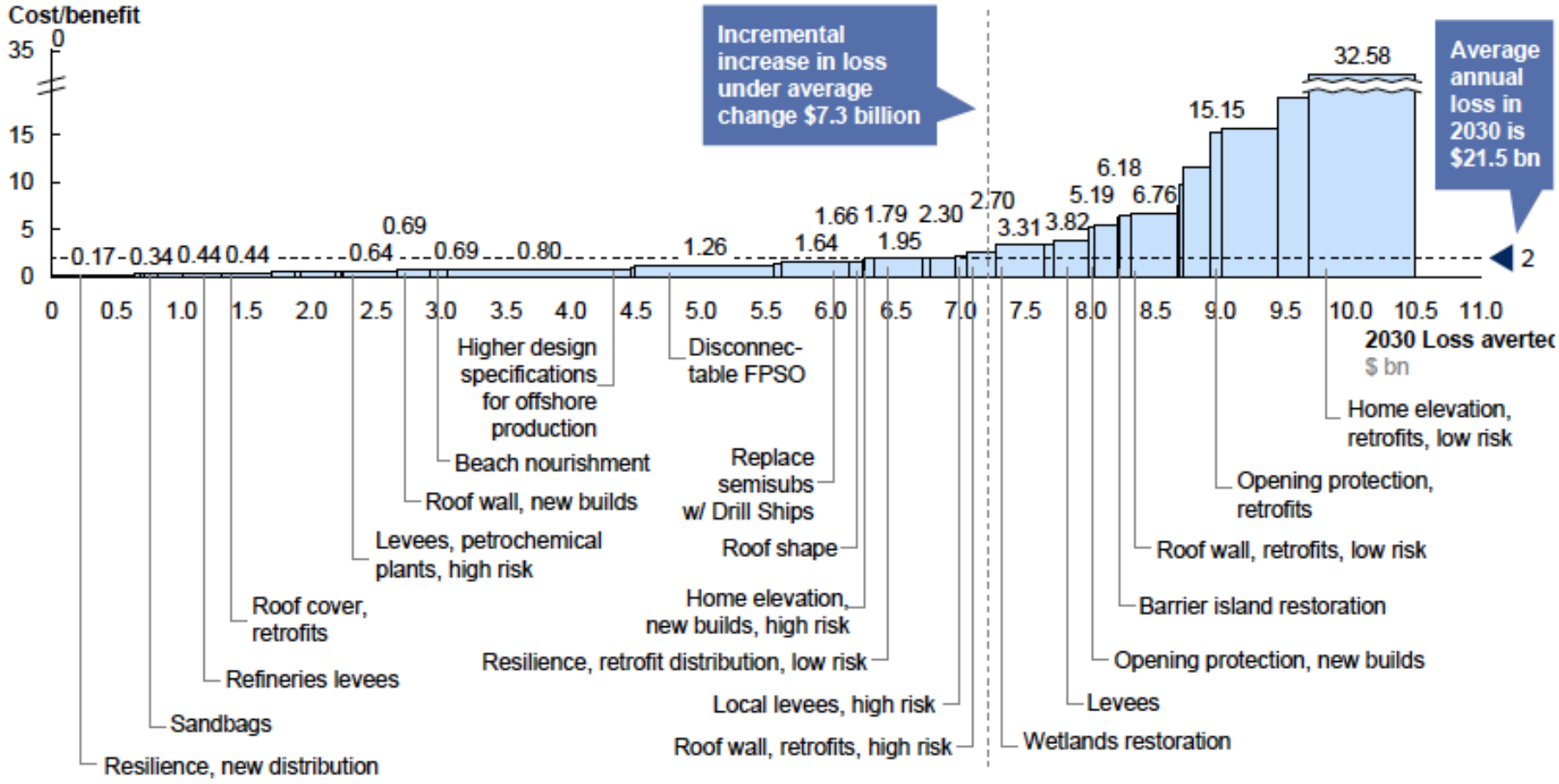
Loss frequency curve for annual loss
$ Billions; 2010 dollars



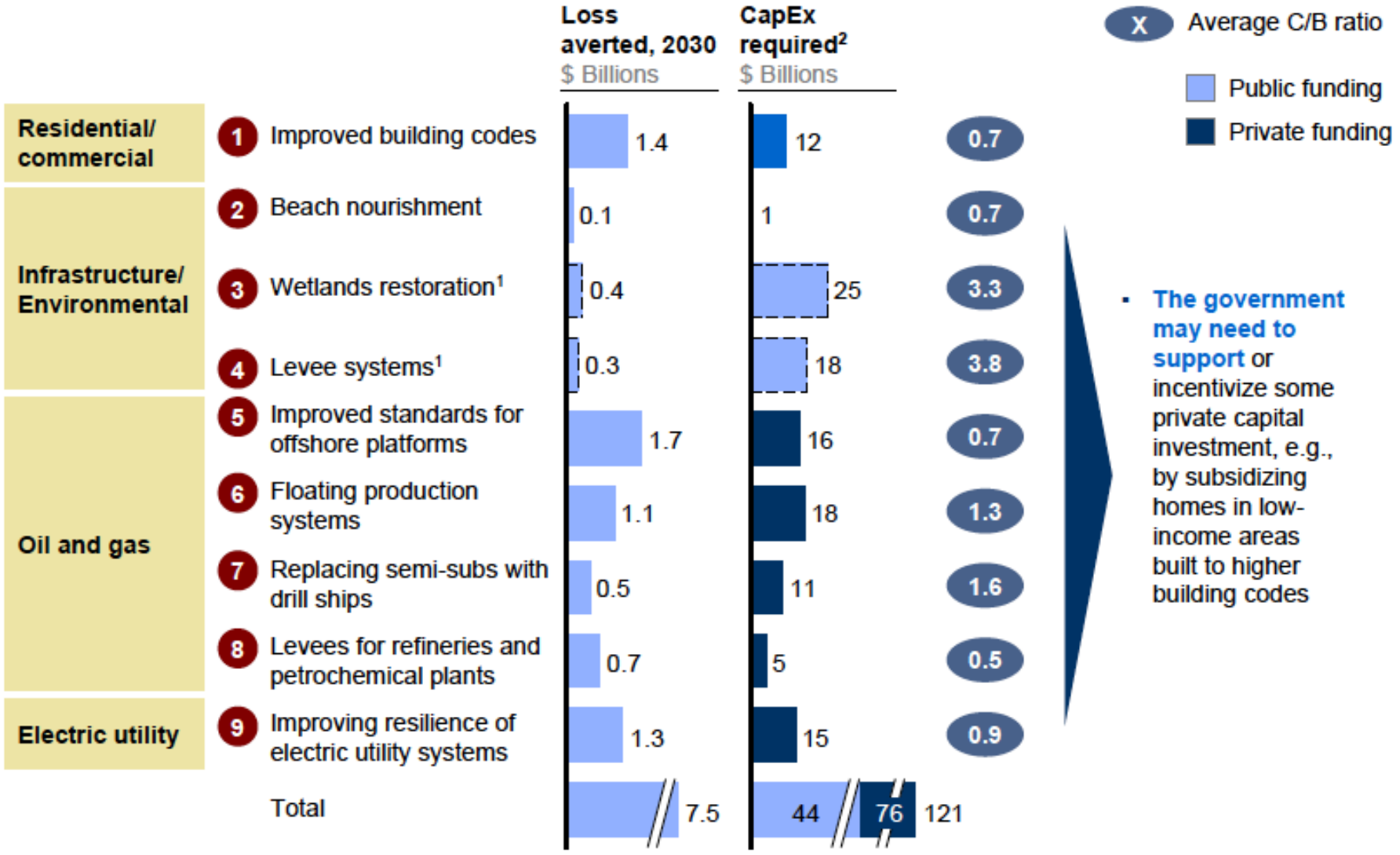
1. **A year like 2005, with Katrina/Rita (1 / 100 year)** may have a ~$200 bn impact in 2030 (with no climate change)
2. **Under extreme climate change, such a year may occur 2.5x more often** – or once every lifetime (1/40 years)

Source: Swiss Re; Press searches

5 A range of attractive measures can address the increase in annual loss between today and 2030 and keep the risk profile of the region constant



6 Measures can translate into broad near-term actions to protect our region – that are cost effective and will help our economy and our environment

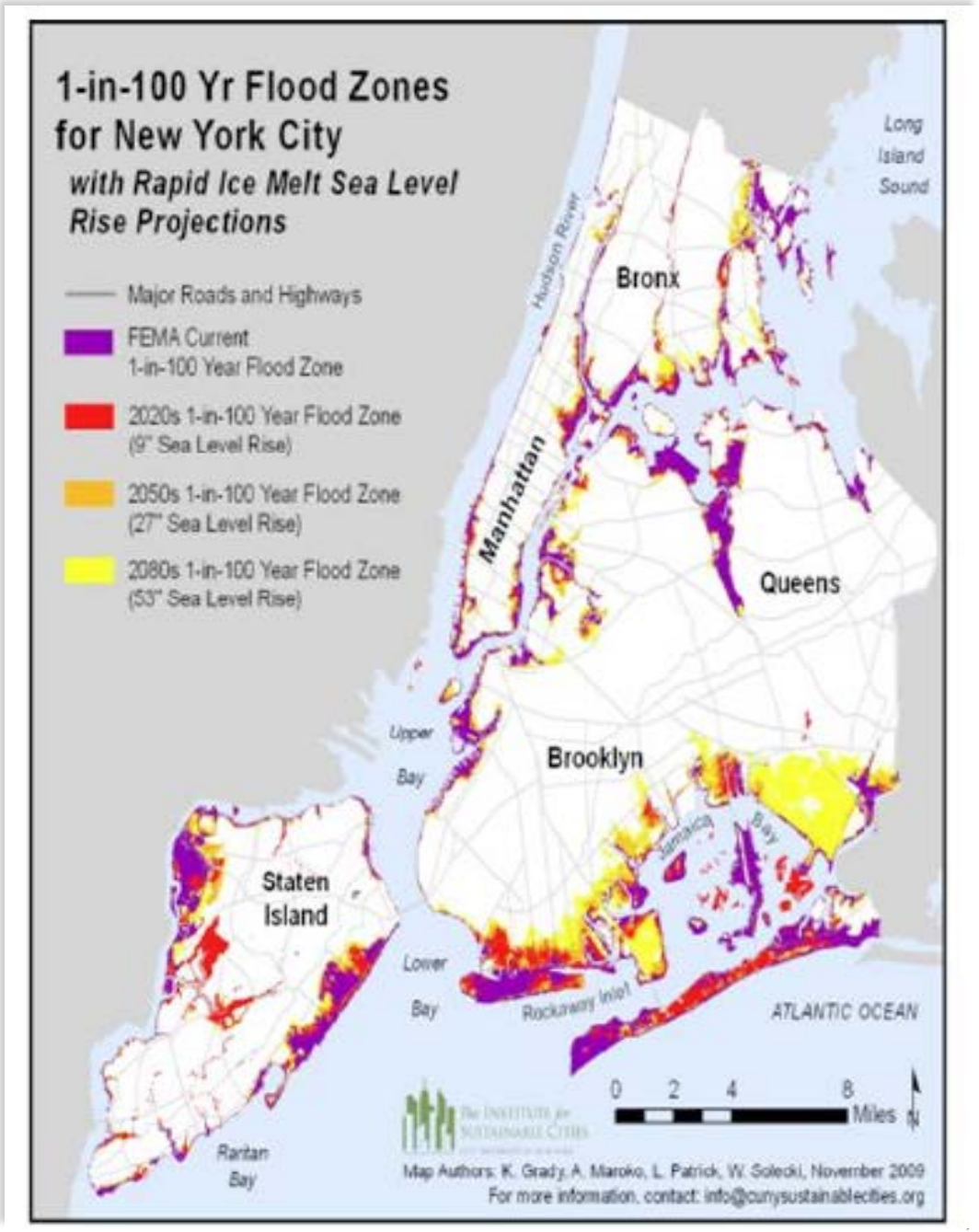


1 Included despite high C/B ratios due to strong co-benefits, risk aversion
2 Total capital investment, non-discounted, across 20 years

Atlantic City: Today's 100-Year Flood Could Become a Two-Year Flood by 2100

The top image shows the location of Atlantic City, NJ, on Absecon Island. The light blue area in the bottom image depicts today's FEMA 100-year flood zone (which extends beyond the area shown). Currently, this area has a 1 percent chance of being flooded in a given year. By 2100, this approximate area is projected to flood, on average, once every year or two under either emissions scenario, inundating high-tourist-value hotels and casinos. Under the higher-emissions scenario, the new 100-year flood height would be roughly four feet greater in 2100 than today, flooding a far greater area than the current FEMA flood zone.

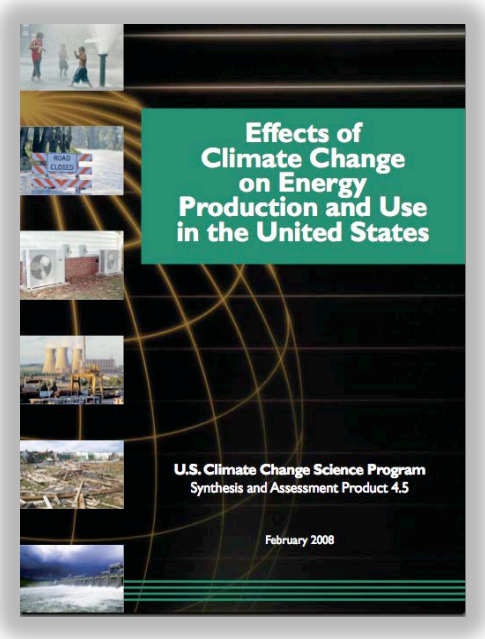
In the Most Severe of the Climate Change Scenarios, Current Land Uses in Some Coastal Parts of the NYC Metropolitan Area May Be Difficult to Sustain



Locations in New York City Power Plants Relative to 10-foot Elevation Contour

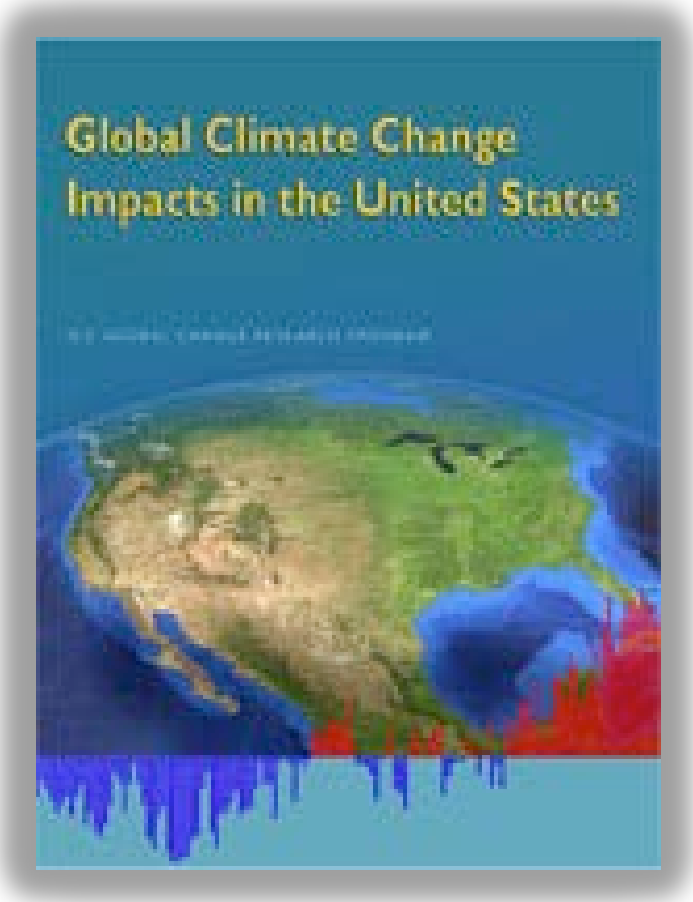
How Infrastructures and Built Environments Have Been Dealt with in Assessments Over the Past Decade:

- **During the CCSP era, in Synthesis and Assessment Products (SAPs):**
  - **Several specifically relevant: 4.5 (energy production and use), 4.6 (human health and welfare/human systems – including human settlements), 4.7 (transportation/Gulf Coast)**
  - **Several others partially relevant: 2.2 (carbon cycle), 4.1 (coastal sensitivities/Mid-Atlantic), 4.3 (agriculture, land, water)**



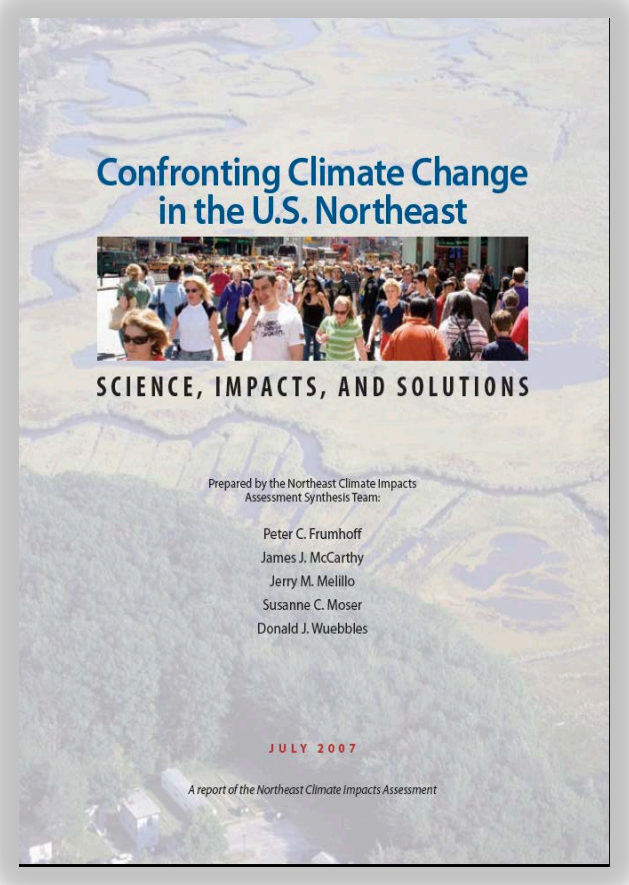
How Infrastructures and Built Environments Have Been Dealt with in Assessments Over the Past Decade:

- **Followed by US GCRP's *Global Climate Change Impacts in the US* (2009):**
  - **Sectoral characterizations for water resources, energy supply and use, transportation, agriculture, health, and "society"**
  - **Included as one of four recommendations: "expand our understanding of climate change impacts," including the cross-cutting item "economic systems, human health, and the built environment"**



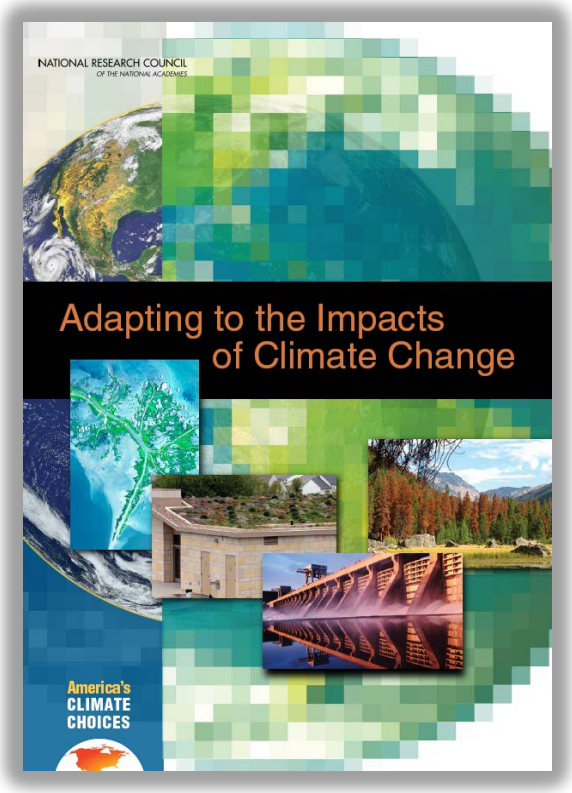
How Infrastructures and Built Environments Have Been Dealt with in Assessments Over the Past Decade:

- **Also notable have been:**
  - **A number of regional assessments, including the Northeast (2008)**
  - **Several major urban assessments, including New York City and Chicago**
  - **California Energy Commission's PIER program**



How Infrastructures and Built Environments Have Been Dealt with in Assessments Over the Past Decade:

- **Also notable are:**
  - **Three recent NAS/NRC reports:**
    - **Restructuring Federal Climate Research to Meet the Challenges of Climate Change, 2009**
    - **NAS/NRC/TRB report on climate change implications for transportation infrastructures, 2008**
    - **America's Climate Choices: panel reports on limiting emissions, adapting to impacts, advancing the science, and informing decisions, 2010; overview report, 2011**



  - **IPCC: periodic assessment reports, e.g., AR4, 2007; AR5, now under way; plus special reports such as on climate extremes and potentials for adaptation, 2012**

Analyses of Cross-sectoral Infrastructure Interdependencies to Determine Vulnerabilities to Cascading Disruptions Have Been Harder to Find:

- **Although little of the work has been published, however, there is an important base of knowledge available**

- **DOE and its Laboratories – LANL, Sandia, and ORNL – are deeply involved in developing tools for modeling and analyzing cross-sectoral vulnerabilities of critical infrastructures as a national security issue, e.g., NISAC for DHS, electricity delivery and energy reliability for DOE, and others**

  - **Attention to 18 critical infrastructure sectors, along with dynamic infrastructure interdependencies**
  - **Utilizing advanced modeling and visualization approaches**
  - **Capable of fast turnaround analysis: e.g., infrastructure implications of Hurricane Irene and the recent San Diego blackout**

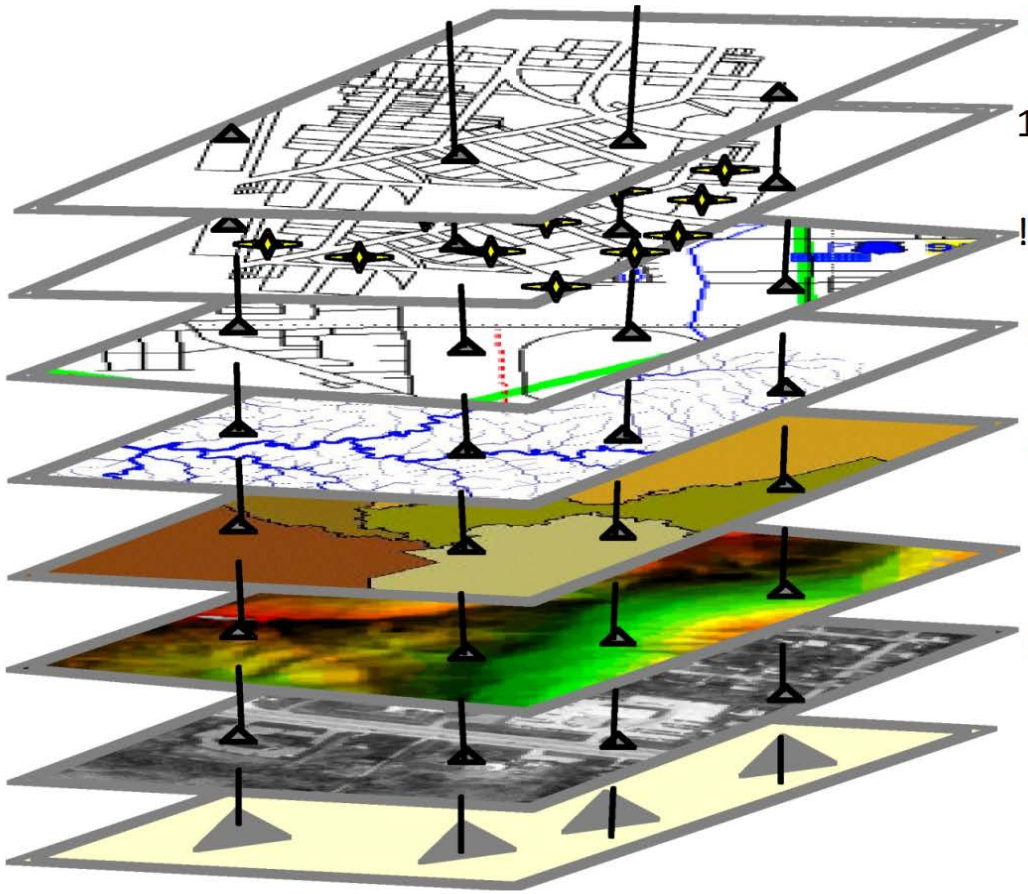
Interdependencies: a Complex System-of-Systems Problem

riculture & Food
nking & Finance
emical
mmercial Facilities
ms
fense Industrial Base
nergency Services
ergy
overnment Facilities
anufacturing
clear Reactors, Materials & aste
ormation Technology
tional Monuments & Icons
stal & Shipping
blic Health & Healthcare
lecommunications

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
5.2.2	Crude Oil Storage
5.2.2.1	Strategic Petroleum Reserve
5.2.2.2	Crude Oil Bulk Storage
5.2.2.2.1	*Crude Oil Land-Based Terminals*
5.2.2.2.2	*Crude Oil Marine Terminals*
5.2.3	Crude Oil Transport
5.2.3.1	Crude Oil Pipelines
5.2.3.1.1	*Crude Oil Pipeline Segments*
5.2.3.1.2	*Crude Oil Pipeline Pumping Stations*
5.2.3.1.3	*Crude Oil Pipeline Control Centers*

*Defined in the NIPP**

An Interdependent System of Systems Approach



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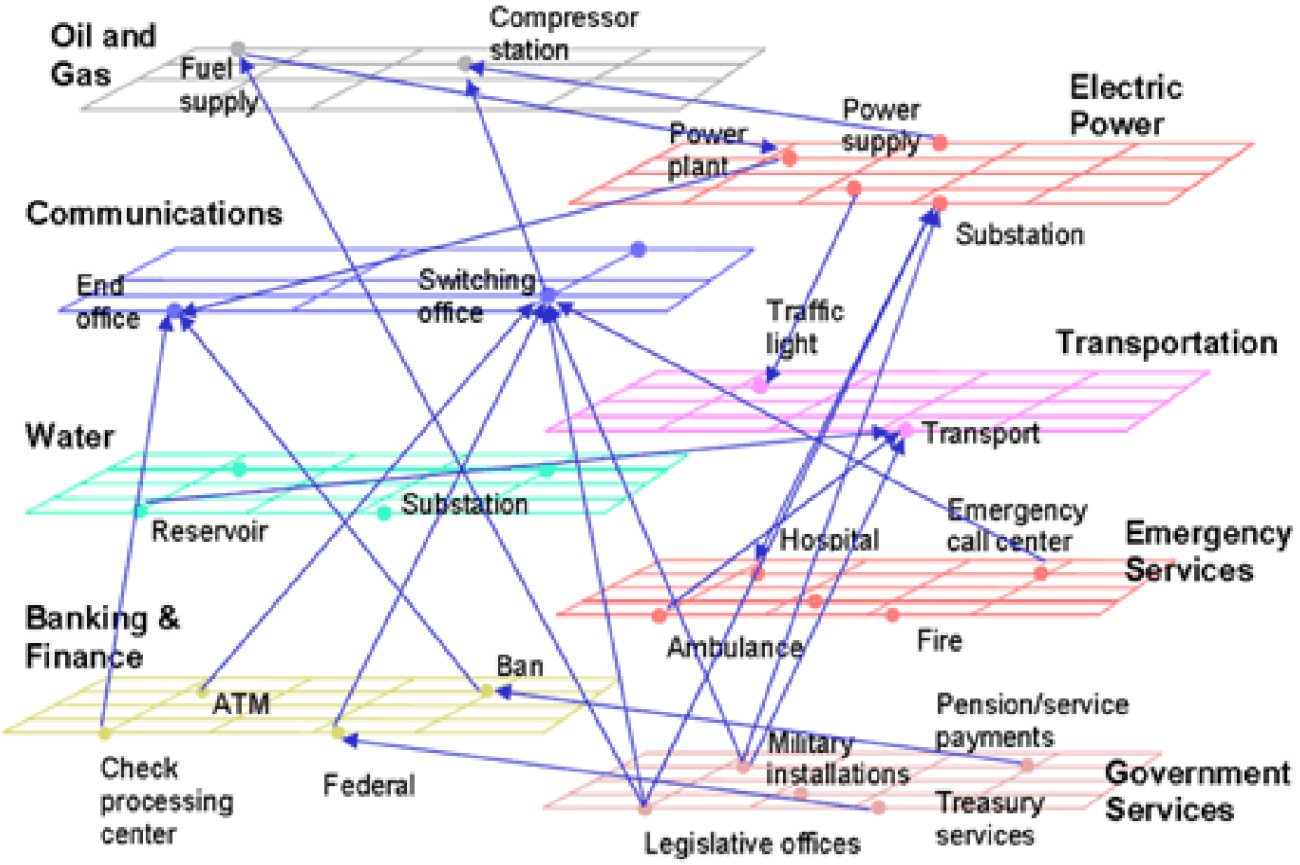
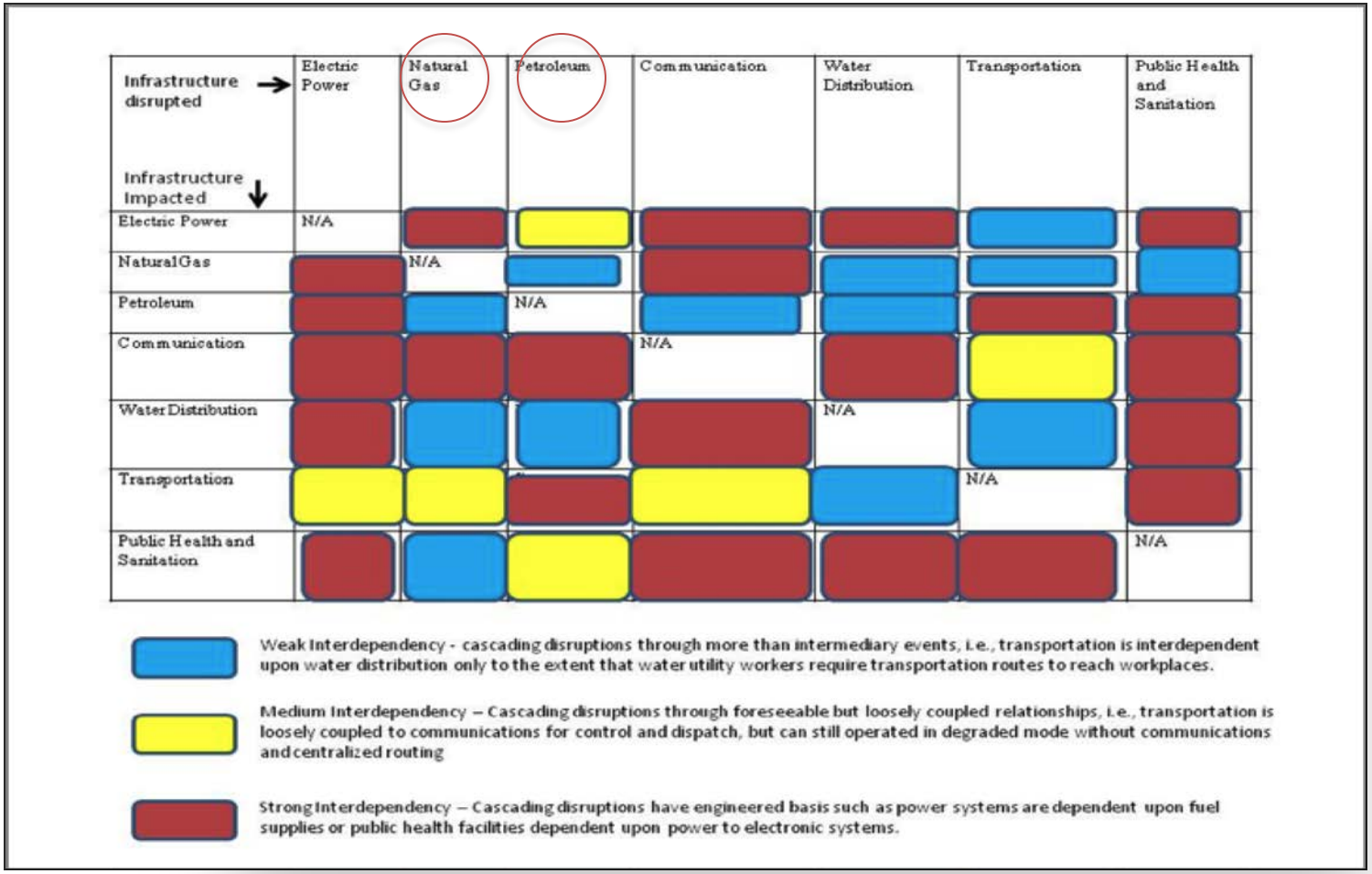

Oil and Gas
Fuel supply
Compressor station
Power plant
Power supply
Electric Power
Substation
Communications
End office
Switching office
Traffic light
Transportation
Transport
Water
Reservoir
Substation
Emergency call center
Hospital
Emergency Services
Ambulance
Fire
Banking & Finance
ATM
Ban
Pension/service payments
Military installations
Government Services
Check processing center
Federal
Treasury services
Legislative offices

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



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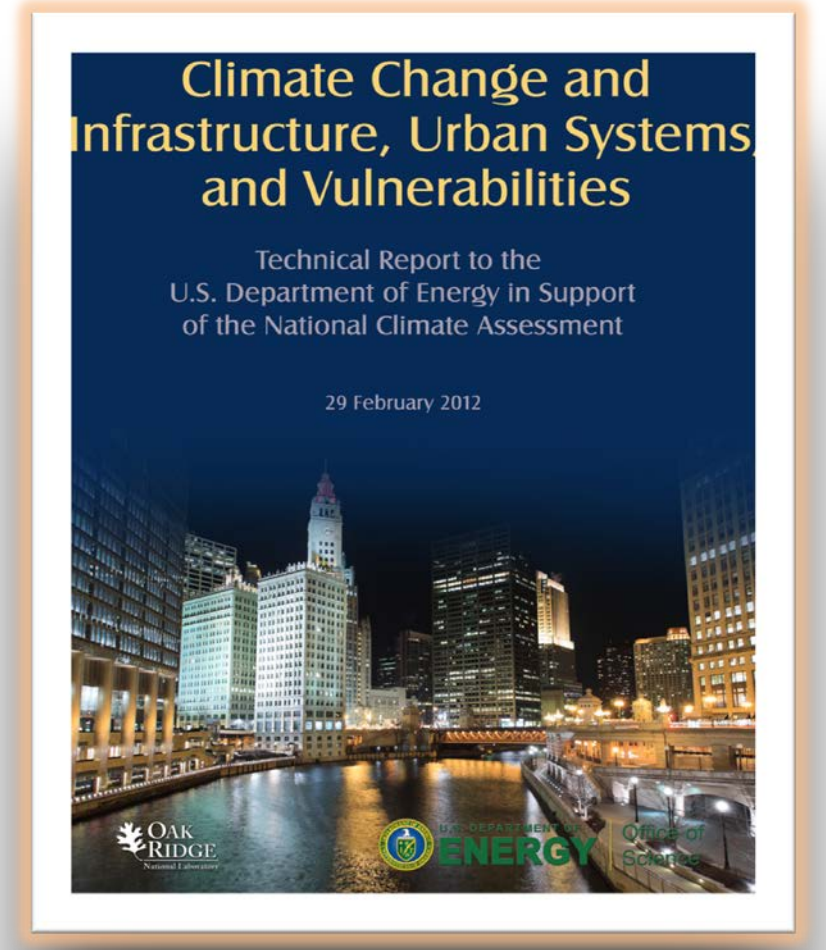
A Recent Report in Support of the US National Climate Assessment Summarizes What We Know:



The Draft Report on Climate Change and Infrastructures and Built/Urban Environments Includes the Following General Findings (I):

- **About climate change and US infrastructures:**
  - **The dominant concern is with climate-related extreme events: extreme weather events associated with climate change will increase disruptions of infrastructure services in some locations**
  - **Disruptions of services in one infrastructure will almost always result in disruptions in one or more other infrastructures, especially in urban areas**
  - **Such linkages will trigger serious cross-sectoral cascading infrastructure system failures in some locations, at least for periods of days or weeks**

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The Draft Report on Climate Change and Infrastructures and Built/Urban Environments Includes the Following General Findings (II):

- **About climate change and US infrastructures:**
  - **These risks are greater for infrastructures that are:**
    - **Located in areas vulnerable to extreme weather events**
    - **Located at or near particularly climate-sensitive environmental features, such as coastlines, rivers, storm tracks, and vegetation in arid areas**
    - **Already stressed by age and/or by demand levels that exceed what they were designed to deliver**
  - **These risks are significantly greater if climate change is substantial rather than moderate**

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The Draft Report on Climate Change and Infrastructures and Built/Urban Environments Includes the Following General Findings (III):

- **About potentials for risk management strategies:**
  - **Risks of disruptive impacts of climate change can be substantially reduced by developing and implementing appropriate adaptation strategies, recognizing a diversity of contexts**
  - **Many of the elements of such strategies can be identified based on existing knowledge, such as:**
    - **Attention to standards, codes, certification programs and other practices that set rules for infrastructure design and construction**
    - **Partnerships between the public and private sector**
    - **Special attention to classes of infrastructure that are toward the end of their lifetimes or performing poorly under growing demands**
    - **Leadership and effective governance**

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The Draft Report on Climate Change and Infrastructures and Built/Urban Environments Includes the Following General Findings (IV):

- **About potentials for risk management strategies:**
  - **Other elements of adaptation strategies will often include:**
    - **Bundling climate change responses with other development/sustainability issues**
    - **Addressing issues regarding financing**
    - **Actively seeking to spur innovation**
  - **Meanwhile, there are some encouraging signs of progress:**
    - **A number of bottom-up initiatives by US cities**
    - **Attention to adaptation research needs for infrastructures**

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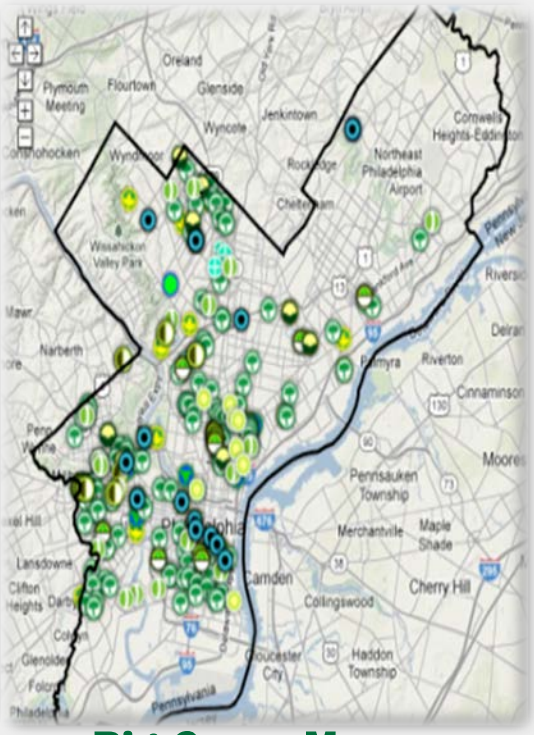
A Few Examples of Innovative Bottom-up Initiatives in the US:

- **In urban areas, often in response to growing concerns about stormwater and wastewater handling; e.g., Philadelphia's "Green City, Clean Waters" program:**
  - **A 25-year commitment to convert more than 1/3 of the city's impervious land cover to green facilities, along with stream corridor restoration and preservation**
  - **Being implemented through leveraged funding from the development community as a part of every new development project**
  - **Has catalyzed a Model Neighborhood program to encourage community participation in greening the city**



Big Green Map

- **A number of comprehensive assessments of climate change vulnerabilities and responses, such as New York City and Chicago, along with a commitment by more than 1,000 mayors to join the U.S. Conference of Mayor's Climate Protection Agreement**

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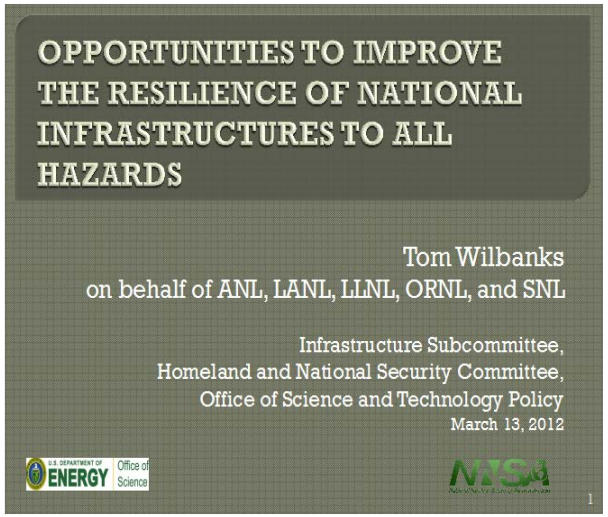
Examples of Adaptation Science Initiatives Focused on US Infrastructure Resilience:

- **A focus on improving the resilience of national built infrastructures to all hazards through research opportunities and priorities: Infrastructure Subcommittee, Homeland and National Security Committee, OSTP, e.g.:**
  - **Improved indicators of resilience**
  - **Innovative materials**
  - **Improved sensors**
  - **Rethinking "optimization" in a risk management context**



- **An interest on the part of ASCE in rethinking codes and standards for built infrastructure design, construction, and operation**
  - **To remove assumptions of "stationarity" of climatic and other parameters**
  - **To encourage flexibility as an objective for infrastructure capital stock**

A Few Final Points about Climate Change Risk Management Strategies for US Infrastructures:

- **In most cases, climate-resilient pathways for adaptation will require greater flexibility than has been the general practice, along with selective redundancy where particular interdependencies threaten cascading system failures in the event of disruptions – designing with *flexibility as an objective* is likely to become a growing challenge**
- **In some cases, especially if climate change is substantial, climate-resilient pathways will require *transformational* changes, beyond incremental changes – how do we begin to imagine the unimaginable… and promote participative contingency planning for big changes?**
- **Focal events (such as extreme storms or floods) can create "policy windows" for getting decisions made that are difficult under normal circumstances: the challenge is to be ready when the window opens, before it closes…**

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The Draft Report from the Third US National Climate Assessment, Now Out for Public Review, Includes Relevant Information:

- **Includes a number of chapters of interest regarding infrastructures:**
  - **3: Water Resources**
  - **4: Energy Supply and Use**
  - **5: Transportation**
  - **10: Water, Energy, and Land Use**
  - **11: Urban Systems, Infrastructure, and Vulnerability**
  - **+ decision support, regions, mitigation, adaptation, and research agenda**
- **To review (and comment) go to:**
  - **http://www.globalchange.gov/what-we-do/assessment/draft-report-information/public-review**

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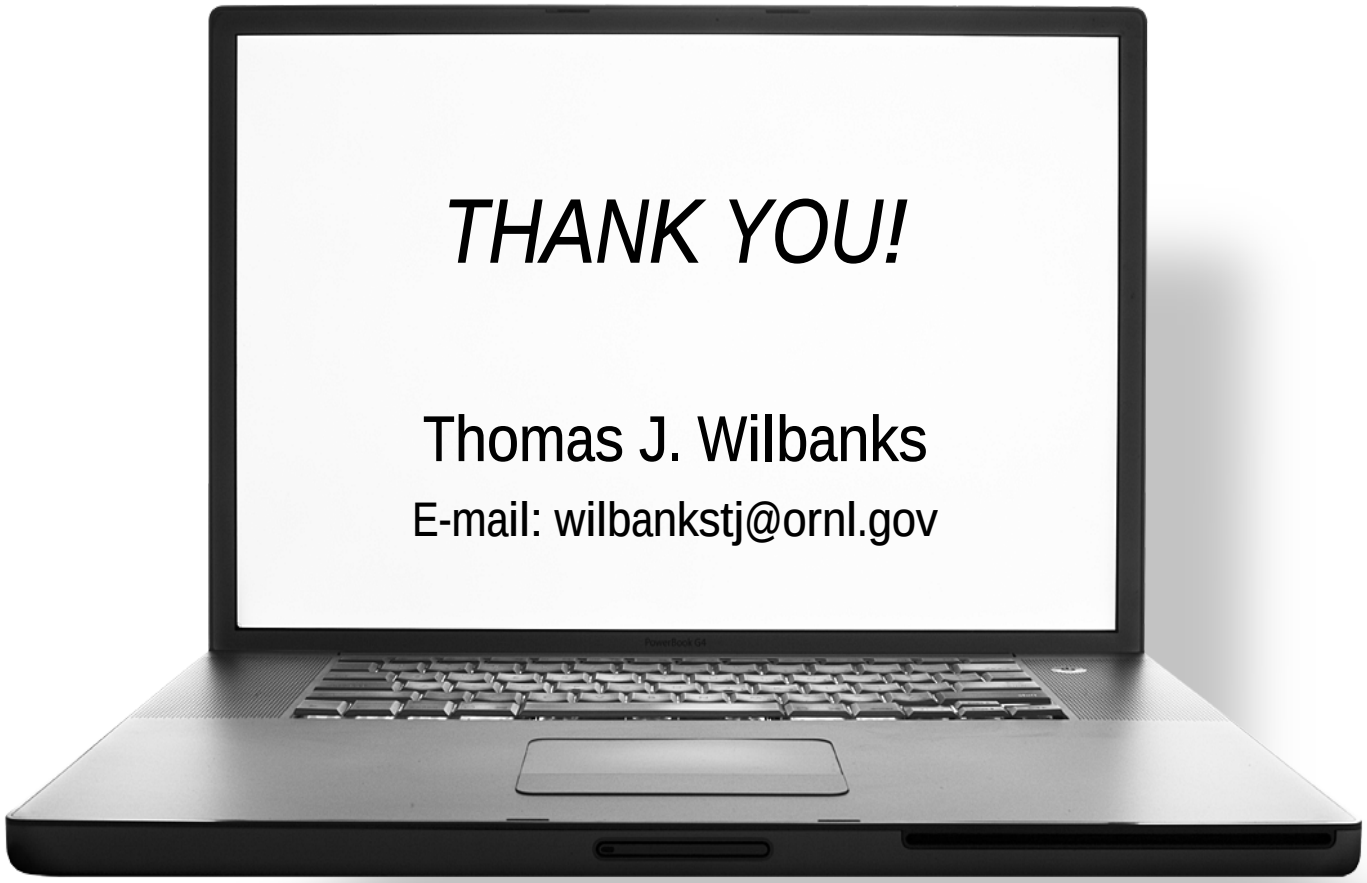

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