Testimony for Senate Energy and Natural Resources Committee, April 19, 2012

To be presented by Benjamin H. Strauss

Good morning, Senator Bingaman and colleagues. Thank you for your attention to this important topic. I am Dr. Ben Strauss, coauthor of two recent peer-reviewed papers making an assessment of sea level risk to the lower 48 states, as well as the summary report submitted with my written testimony. I am also Director of the Program on Sea Level Rise at Climate Central, a nonprofit research organization that conveys scientific information to the public. We take no policy positions.

In my testimony today as in my research, I will address two topics: first, how sea level rise is amplifying the risk from coastal storm surges, and then, what communities and assets are exposed at the lowest elevations.

The nearest-term sea level projections I will share, in inches, may sound small. But they are dangerous. The key problem is that rising seas raise the launch pad for coastal storm surges, and tilt the odds toward disaster. Just a few extra inches could mean the difference to flood a family's basement – or New York City's subway system, disabling it for months. You might think of it this way: raising the floor of a basketball court would mean a lot more dunks.

In the long term, we are likely to see many feet of sea level rise, and be forced to redraw the map of the United States. The high end of projections for this century would be enough to turn Miami-Dade County, Florida into a collection of islands. But in the near term, we will mainly experience sea level rise as more and more coastal floods, reaching higher and higher.

In fact, according to our analysis, sea level rise due to global warming has already doubled the annual risk of extreme coastal flooding across widespread areas of the nation. Global average sea level has risen about 8 inches since 1880. This means that warming is already contributing to the damage caused by any coastal flood today. Diverse studies bracket additional global rise likely this century between 1 and 7 feet.

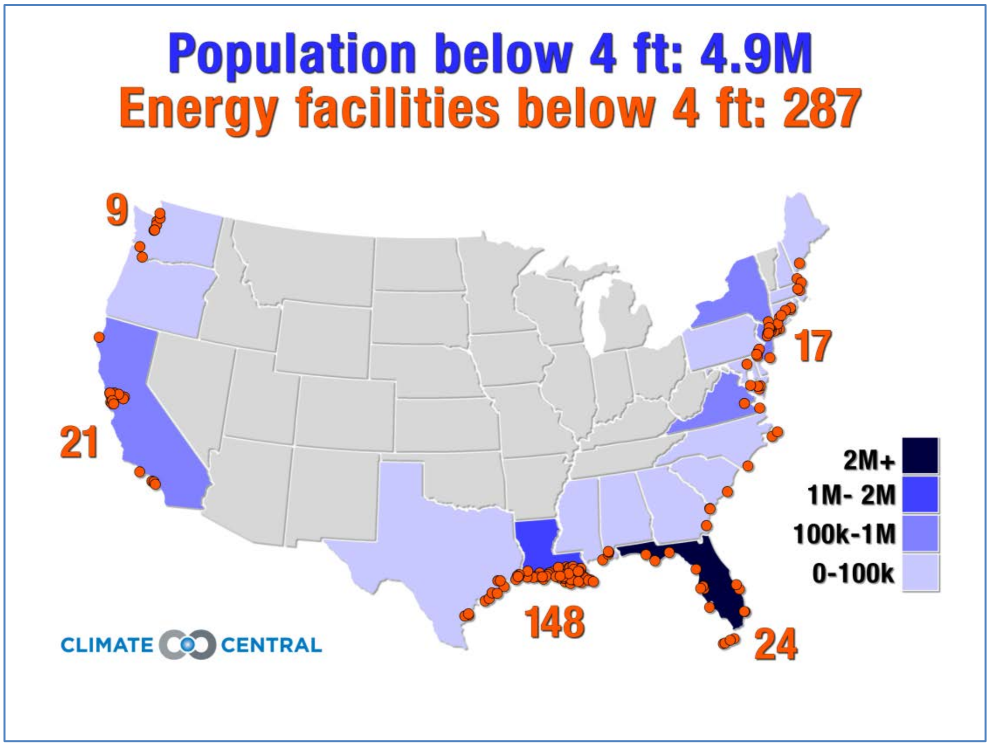
In some areas, especially for Louisiana, Texas, and mid-Atlantic states, sinking land will add to the total effective rise and compound problems. Taking such local factors into account, we made mid-range projections for sites around the lower 48 of 1-8 total inches increase by 2030, and 4-19 by 2050, depending upon location. All along the Pacific, from Seattle to the Oregon coast to San Francisco to Los Angeles, the component of past and projected sea rise from global warming more than triples the odds of "century" floods by 2030 in our analysis, as you can see from the display. The same is true inside the Chesapeake and Delaware Bays, and many sites to the north.

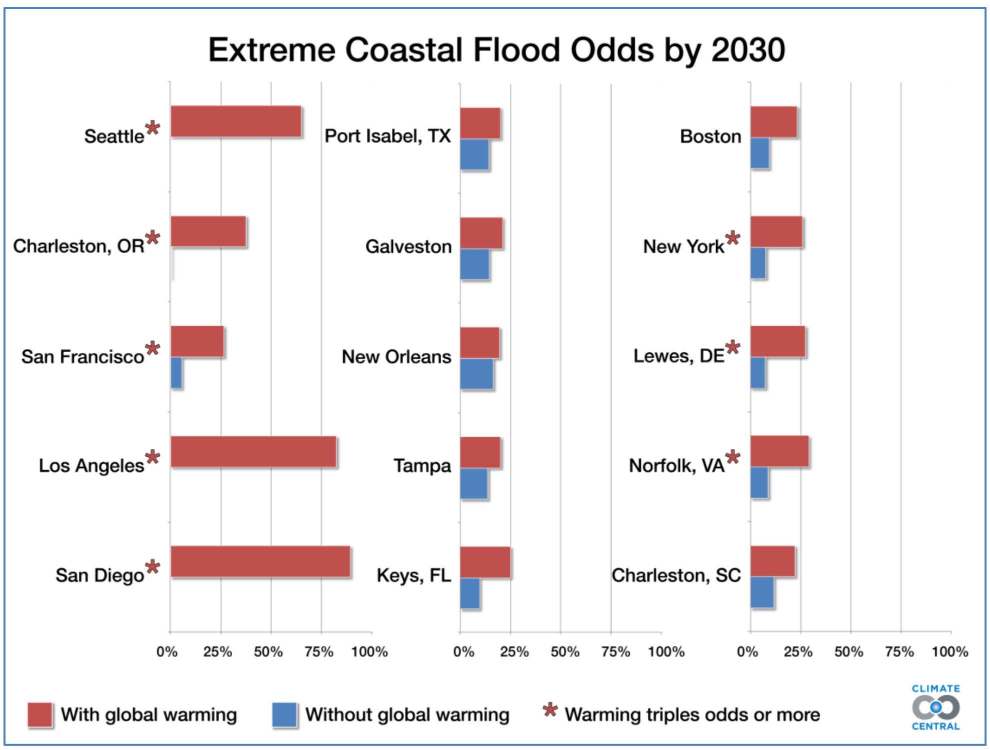
These increases are likely to cause a great deal of damage. At over half the 55 sites where we studied flood risk, storm surges on top of sea rise have better than even chances to reach more than 4 feet above the high tide line by 2030. Yet nearly 5 million U.S. residents live in 2.6 million homes on land below this level. Multiplied by the national average sales price of existing homes in 2010, this stock comes to more than $500 billion of residential real estate, in a rough estimate. An enormous amount of infrastructure also lies in the same zone, from airports to wastewater treatment plants, and including almost 300 energy facilities – as you can see in the second display, along with population figures. The facilities shown are mainly natural gas, oil and gas, and electric facilities. More than half are in Louisiana, the vast majority there unprotected by levees.

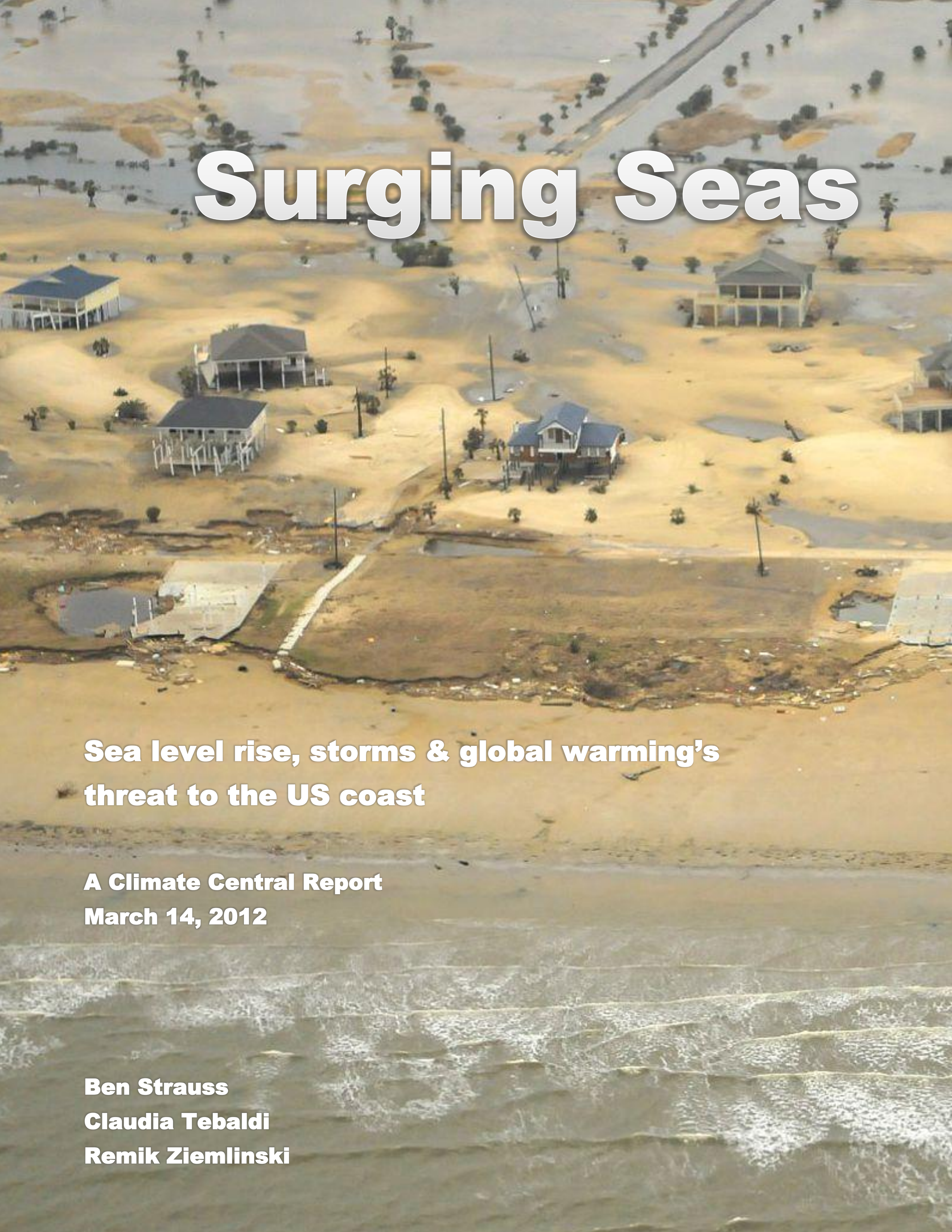
In 285 municipalities, more than half the population lives on land below the 4-foot mark. One hundred and six of these places are in Florida and 65 are in Louisiana. In 676 towns and cities spread across every coastal state in the lower 48 except Maine and Pennsylvania, more than 10% of the population lives below the 4-foot mark. Maps and statistics for 3,000 coastal towns, cities, counties and states are name- and ZIP-searchable at sealevel.climatecentral.org, and I urge you and your colleagues and staff members to explore the places important to you.

In conclusion, the risks from sea level rise are imminent and serious; this is not a distant problem only of concern for our children. Escalating floods from sea level rise will affect millions of Americans, and threaten countless billions of dollars of damage to buildings and infrastructure.

Thank you for your attention.


Population below 4 ft: 4.9M
Energy facilities below 4 ft: 287
9
17
21
148
24
2M+
1M- 2M
100k-1M
0-100k
CLIMATE CENTRAL


Extreme Coastal Flood Odds by 2030
Seattle*
Charleston, OR*
San Francisco*
Los Angeles*
San Diego*
Port Isabel, TX
Galveston
New Orleans
Tampa
Keys, FL
Boston
New York*
Lewes, DE*
Norfolk, VA*
Charleston, SC
0%
25%
50%
75%
100%
With global warming
Without global warming
* Warming triples odds or more
CLIMATE CENTRAL



Surging Seas

Sea level rise, storms & global warming's threat to the US coast

A Climate Central Report
March 14, 2012

Ben Strauss
Claudia Tebaldi
Remik Ziemlinski

Executive Summary

Global warming has raised sea level about 8 inches since 1880, and the rate of rise is accelerating. Scientists expect 20 to 80 more inches this century, a lot depending upon how much more heat-trapping pollution humanity puts into the sky. This study makes mid-range projections of 1-8 inches by 2030, and 4-19 inches by 2050, depending upon location across the contiguous 48 states.

Rising seas dramatically increase the odds of damaging floods from storm surges. For over two-thirds of the locations analyzed (and for 85% of sites outside the Gulf of Mexico), past and future global warming more than doubles the estimated odds of "century" or worse floods occurring within the next 18 years—meaning floods so high they would historically be expected just once per century. For over half the locations analyzed, warming at least triples the odds of century-plus floods over the same period. And for two-thirds the locations, sea level rise from warming has already more than doubled the odds of such a flood even this year.

These increases are likely to cause an enormous amount of damage. At three quarters of the 55 sites analyzed in this report, century levels are higher than 4 feet above the high tide line. Yet across the country, nearly 5 million people live in 2.6 million homes at *less* than 4 feet above high tide. In 285 cities and towns, more than half the population lives on land below this line, potential victims of increasingly likely climate-induced coastal flooding. 3.7 million live less than 1 meter above the tide.

About half of this exposed population, and eight of the top ten cities, are in the state of Florida. A preliminary independent analysis suggests about $30 billion in taxable property is vulnerable below the *three*-foot line in just three counties in southeast Florida, not including the county with the most homes at risk in the state and the nation, Miami-Dade. Small pockets or wide areas of vulnerability, however, exist in almost every other coastal state.

The population and homes exposed are just part of the story. Flooding to four feet would reach higher than a huge amount of dry land, covering some 3.0 million acres of roads, bridges, commercial buildings, military bases, agricultural lands, toxic waste dumps, schools, hospitals, and more. Coastal flooding made worse by global warming and rising seas promises to cause many billions of dollars of damage over the coming decades.

This report and its associated materials, based on two just-published peer-reviewed studies, is the first major national analysis of sea level rise in 20 years, and the first one ever to include:

- Estimates of land, population and housing at risk;
- Evaluations of every low-lying coastal town, city, county and state in the contiguous US;

- Localized timelines of storm surge threats integrating local sea level rise projections; and
- A freely available interactive map and data to download online (see SurgingSeas.org).

Summaries of these findings at a state-by-state level are available in fact sheets at SurgingSeas.org/factsheets. The original peer-reviewed studies can be found via SurgingSeas.org/papers. All findings reflect best estimates from the research; actual values may vary.

This report focuses on new research and analysis, not recommendations; but it is clear from the findings here that in order to avoid the worst impacts, the United States must work to slow sea level rise by reducing emissions of heat-trapping gases, and work to diminish the remaining danger by preparing for higher seas in coastal cities and counties everywhere. SurgingSeas.org/plans lists a selection of existing resources, plans and efforts to prepare, from local to national levels.

Sea level rising

Background

Global average sea level has increased over 8 inches since 1880,[1] and global warming has caused the great majority, if not all, of that rise.[2] Warming has acted in two main ways: by heating up and thus expanding the global ocean; and by attacking glaciers and polar ice sheets, pouring meltwater and icebergs into the sea.[3] The planet has heated by more than one degree Fahrenheit over the last century, rising faster as we have burned coal, oil and gas faster, and so sent ever more heat-trapping gases into the air.[4] Scientists overwhelmingly agree that these building gases are responsible for most of the warming observed thus far.[5]

Warming and sea level rise[6] are both accelerating, as is the rate of decay of ice sheets on Greenland and Antarctica.[7] Loss of ice from these sources has the potential to raise sea level by many tens of feet over centuries. In the warm period before the last Ice Age – when the planet was as warm as we expect it to become by 2100 or sooner, at least without deep and immediate cuts to pollution – global sea level very likely reached over 20 feet higher than it is today,[8] an eventual sea level we could be *committing* to within decades[9] if not already.[10] That rise would be enough to drown many major coastal metropolises.

Projections

This century, scientists expect about 20 to 80 more inches of global sea level rise, depending significantly on how much more heat-trapping pollution humankind puts into the sky.[11] The amount also depends on just how strongly pollution translates into warming, and just how strongly warming translates into sea rise. The analysis presented in this report, based on a paper by Tebaldi and others,[12] takes a wide range of possibilities into account. It also factors in the gradual sinking or rising of coastal land around much of the U.S., which leads to faster or slower rates of local sea level rise, compared to global rates.

This study's middle-of-the-road projections for 2030 range from one inch of local sea level rise in the northwest corner of Washington State, where the land is slowly rising, to 8 inches near New Orleans, where it is sinking. By 2050, these projections increase to 4 and 19 inches, respectively. Best- and worst-case projections range from lower to considerably higher values. Table 1 shows findings for all 55 locations studied, plus regional and national summaries.

Storm surge: The risk multiplier

Rising seas dramatically increase the odds of damaging floods from storm surges. For over two-thirds of the 55 locations analyzed (and for 85% of sites outside the Gulf of Mexico), past and future global warming more than doubles the estimated odds of "century" (or worse) floods occurring by 2030—meaning floods so high they would historically be seen with only a one percent (or less) chance per year. For over half the locations analyzed, warming at least triples the odds of century-plus floods. Figure 1 illustrates these changes around the nation, and Table 2 shows results at all flood study sites. Additionally, for two-thirds of the locations, sea level rise from warming has *already* at least doubled the annual risk of century-plus floods (see Table 2 and footnote 18). These calculations all incorporate the assumption that 90% of historic sea level rise has stemmed from warming.

The increases in odds come despite the fact that sea level rise from warming, over the next two decades and over the last century, is better measured in inches than in feet. In many places, only inches separate the once-a-decade flood from the once-a-century one; and separate the water level communities have prepared for, from the one no one has seen. Critically, a small change can make a big difference, like the last inch of water that overflows a tub. Sea level rise is raising the launch pad for storms and high tides, and being experienced by the ever-more frequent occurrence of extreme high water levels during these events – long before the ocean reaches damaging heights permanently.

Flood waters will reach different levels in different places on different schedules. Part of these differences will come from uneven local rates of sea level rise, part will come from chance, and part will come from how big local storm surges tend to be, which can vary a lot. Mostly because of this last factor, expected heights above high tide are generally about a foot higher than the national average in the Gulf of Mexico, and a foot lower than average in southern California and the southern Atlantic coast. But lower heights do not necessarily imply lower risk. For example, two feet of sea level rise should make an enormous difference in places where two-foot surges are rare extremes, and relatively less in places where ten-foot surges are sometimes seen.

This study found that at over half the sites examined, there is a one-in-two or better chance of water reaching at least 4 feet higher than the average local high tide by 2030, at least once. 85 percent of stations have at least one-in-six odds. By 2050, many locations should experience 5-foot or higher floods, with at least one-in-two odds at nearly half of stations, and at least one-in-six odds at nearly two-thirds. In all cases, sea level rise caused by global warming increases the odds, usually doubling or tripling them or more. Table 2 provides details for each site studied.

U.S. vulnerability

Floods exceeding these levels are likely to cause an enormous amount of damage. Across the country, nearly 5 million people live in 2.6 million homes on land less than 4 feet above high tide. In 285 cities and towns, more than half the population lives below this line, potential victims of increasingly likely climate-induced coastal flooding. And nationwide, over 6 million people live on land less than 5 feet above average high tide. Based on a paper by Strauss and others,[13] this study estimated the land, housing and population less than 1-10 feet above local high tide levels, for every coastal town, city, county and state in the contiguous 48 states. SurgingSeas.org presents full results in a searchable, interactive map and in tables. 3.7 million live on land less than 1 meter above the local high tide.

About half of the exposed population under 4 feet, and eight of the top ten cities, are in the state of Florida. A preliminary independent analysis suggests about $30 billion in taxable property lies below the *three*-foot line in just three counties in southeast Florida, not including the county with the most homes at risk in the state and the nation, Miami-Dade.[14]

Small pockets or wide areas of vulnerability, however, exist in almost every other coastal state, as Figure 2 makes clear. Table 3 shows the top ten states, counties and cities by total population living less than 4 feet above local high tide. State fact sheets at SurgingSeas.org/factsheets provide more summary information at a state level. The map at SurgingSeas.org links each city displayed with the nearest flood analysis site used in this study, as an indicator for when and with what chances a given water height might be achieved in the area. Actual odds may vary over even small distances.

The population and homes exposed are just part of the story. Flooding to four feet would reach higher than a huge amount of dry land, covering some 3 million acres of roads, bridges, commercial buildings, military bases, agricultural lands, toxic waste dumps, schools, hospitals, and more. Coastal flooding made worse by global warming and rising seas promises to cause many billions of dollars of damage over the coming decades. This report focuses on population, housing and land, but future analyses will address infrastructure, landmarks, and property threatened.

A number of state and local governments are beginning to plan or even take action against the challenge of sea level rise. SurgingSeas.org/plans presents a list and further resources.

Research methods

To make maps of low and vulnerable coastal land, this study used the highest-resolution nationwide coastal elevation data publicly available, from the National Elevation Dataset (US Geological Survey; cells ca. 30 feet on a side). We adjusted elevations to indicate heights compared to the nearest average high tide levels, because these can vary by several feet from place to place. Tidal information came from VDatum, a tool created by the National Oceanic and Atmospheric Administration. We then removed from consideration all wetland area as defined by the National Wetlands Inventory, and overlaid the remaining map elevation zones against high-resolution data from the 2010 Census to extract population and housing estimates. SurgingSeas.org/LandAnalysis provides more detail.

To analyze future high water levels from sea level rise plus storm surge and tides, we studied 55 water level gauges around the US. We combined local factors, such as sinking land, and global future sea level rise estimates, to make local sea level rise projections at each site. We then used historic patterns of local extreme water levels to forecast future probabilities of extremes assuming the same patterns continue, but augmented by the projected local sea level rise. Our analysis also included developing confidence intervals around best estimates. SurgingSeas.org/FloodAnalysis provides more detail.

To estimate how global warming shifts the odds of high storm surges, we computed extreme event probabilities in a hypothetical world with no warming-induced sea level rise, past or future, and then compared the results with our first calculations including warming. We retained local sea level change from vertical land movement in the no-warming scenario. Based on a review of scientific literature, we assumed that 10% of the global average sea level rise observed since 1880 came from factors other than warming, and so also retained this 10% of global rise in the no-warming scenario.

For more detail, visit SurgingSeas.org/research, which includes links to fuller descriptions of our methods, and the two core scientific papers upon which this report is based:

Tebaldi C, Strauss B H and Zervas C E 2012. Modelling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters*.

Strauss B H, Ziemlinski R, Weiss J L, and Overpeck J T 2012. Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. *Environmental Research Letters*.

Limitations

The results presented here should be interpreted with certain limits in mind. One set of limits comes from the elevation data used. Like almost any dataset, it includes errors – so any point classified as below a given height, may in fact be above it; and any point classified as above a height, may be below it. These potential errors should cancel out when evaluating the totals of what is affected over larger areas like towns, cities and counties. However, elevation error should be kept in mind when looking at any individual point on the map that accompanies this analysis (SurgingSeas.org/map).

Another issue from the elevation data concerns their horizontal resolution. Cells 30 feet on a side are too large to completely capture fine features like levees or seawalls, which may protect land even when it is below the water level, such as in the New Orleans area. Therefore, this analysis quantifies the land, housing and population *below* different threshold elevations – amounts not affected by built protection – but does not evaluate how much would be *inundated*, given each water level. Of course, many areas are not protected; protected areas are protected only to limited heights; and being below water level poses challenges for storm water drainage, increasing the risk of rain-driven flooding.

The analysis of flood odds and timing applies strictly only at the 55 water level gauge sites studied, and can only be considered general indicators for the surrounding areas. This is mainly because storm surge patterns can vary from place to place, even over short distances, due to geography and storm directions. Statistics among gauges sometimes correspond well over wide areas, suggesting wide applicability. But they also sometimes vary greatly over short distances, suggesting the opposite.

This report assumes that recent historic storm patterns do not change in the future. However, global warming may change the frequency or intensity of storms that affect coastal flooding. This analysis also leaves out projected changes in Atlantic circulation expected to add several extra inches of sea level rise along the Northeast Corridor by mid-century;[15] and projected changes in the "gravity fingerprint" of global oceans,[16] which may partly counteract the first change.[17]

Most broadly, this report presents our best estimates for the quantities analyzed, given the underlying data and our assumptions. True values are likely to fall above or below our estimates.

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Table 1. Projected sea level rise with 90% confidence intervals.

NOAA water level station	State	Projected sea level rise (inches) By 2030 Best estimate	By 2030 90% range	By 2050 Best estimate	By 2050 90% range
National average		5	2-9	12	6-22
Atlantic average		6	2-10	13	6-23
Gulf average		6	3-9	13	8-23
Pacific average		4	0-8	9	2-20
Eastport - Passamaquoddy Bay	ME	4	1-8	9	2-20
Portland - Casco Bay	ME	4	1-8	10	3-20
Boston - Boston Harbor	MA	5	2-9	12	5-22
Woods Hole - Buzzards Bay	MA	5	2-9	12	5-22
Nantucket Island, Nantucket Sound	MA	5	2-10	13	6-23
Newport - Narragansett Bay	RI	5	2-9	12	5-22
Providence - Providence River	RI	5	2-9	11	4-22
New London - Thames River	CT	5	2-9	12	5-22
Bridgeport - Bridgeport Harbor	CT	5	2-9	12	5-22
Montauk - Fort Pond Bay	NY	6	2-10	13	6-23
The Battery - New York Harbor	NY	5	2-9	13	6-23
Atlantic City - Atlantic Ocean	NJ	7	4-11	15	8-25
Cape May - Cape May Canal	NJ	6	3-10	15	8-25
Reedy Point - C&D Canal	DE	6	3-10	14	7-24
Lewes - Ft. Miles	DE	6	3-10	13	6-24
Cambridge, Choptank River	MD	6	2-10	13	6-23
Baltimore - Fort McHenry	MD	5	2-10	13	6-23
U.S. Naval Academy - Severn R.	MD	6	2-10	13	6-23
Solomons Island - Patuxent River	MD	6	3-10	14	7-25
Washington - Potomac River	DC	6	2-10	13	6-23
Kiptopeke - Chesapeake Bay	VA	6	3-10	14	7-24
Lewisetta - Potomac River	VA	7	4-11	16	9-26
Sewells Point - Hampton Roads	VA	7	4-11	16	9-26
Chesapeake Bay Bridge Tunnel	VA	8	5-12	17	10-28
Beaufort, Duke Marine Lab	NC	6	2-10	13	6-23
Wilmington - Cape Fear River	NC	5	2-9	11	4-22
Springmaid Pier - Atlantic Ocean	SC	6	3-10	14	7-25
Charleston - Cooper River Entrance	SC	5	2-10	13	6-23
Fort Pulaski - Savannah River	GA	6	3-10	13	6-24
Fernandina Beach - Amelia River	FL	5	2-9	12	5-22
Vaca Key - Florida Bay	FL	5	2-10	13	6-23
Key West	FL	5	2-9	12	5-22
Naples - Gulf Of Mexico	FL	5	1-9	11	4-22
St. Petersburg, Tampa Bay	FL	5	2-9	12	5-23
Clearwater Beach - Gulf Of Mexico	FL	5	2-9	12	5-22
Apalachicola - Apalachicola River	FL	4	1-8	10	3-20
Pensacola - Pensacola Bay	FL	5	1-9	11	4-21
Grand Isle, East Point	LA	8	7-12	19	14-27
Sabine Pass North	TX	5	3-8	11	7-20
Galveston Pier 21 - Galveston Channel	TX	7	5-10	16	12-24
Galveston Pleasure Pier - Gulf Of Mexico	TX	8	6-11	18	14-26
Freeport, Dow Barge Canal	TX	6	4-9	14	9-22
Rockport - Aransas Bay	TX	6	4-9	14	10-22
Port Isabel - Laguna Madre	TX	6	4-9	13	9-21
La Jolla - Pacific Ocean	CA	5	2-9	11	4-22
Los Angeles - Outer Harbor	CA	4	1-8	10	3-20
Port San Luis - Pacific Ocean	CA	3	0-7	9	2-19
Monterey - Monterey Harbor	CA	4	1-8	10	3-20
San Francisco - San Francisco Bay	CA	4	1-9	11	4-21
Charleston - Coos Bay	OR	4	0-8	9	2-20
South Beach - Yaquina River	OR	5	2-9	12	5-22
Astoria - Tongue Point	OR	3	-1-7	7	0-18
Toke Point - Willapa Bay	WA	4	1-8	10	3-20
Neah Bay - Strait of Juan De Fuca	WA	1	-2-5	4	-3-15
Seattle - Puget Sound	WA	4	1-9	11	4-21

Table 2. Increase in flood odds driven by sea level rise from global warming.[18]

NOAA water level station	State	Historic "century" floods: Height (feet)	Historic "century" floods: Projected Odds by 2030	Historic "century" floods: Global Warming Multiplier	Floods to 4 feet: Projected Odds by 2030	Floods to 4 feet: Global Warming Multiplier	Floods to 5 feet: Projected Odds by 2050	Floods to 5 feet: Global Warming Multiplier
Median, all listed stations		4.7	25%	>3	55%	1.9	41%	2.8
Median, listed Atlantic stations		4.7	27%	>3	43%	2.1	39%	2.9
Median, listed Gulf stations		6.6	20%	1.4	68%	1.4	71%	1.4
Median, listed Pacific stations		4.1	39%	>3	66%	>3	11%	>3
Eastport - Passamaquoddy Bay	ME	5.4	28%	>3	100%	1.2	98%	>3
Portland - Casco Bay	ME	4.0	36%	>3	24%	>3	2%	>3
Boston - Boston Harbor	MA	5.6	23%	2.5	90%	1.7	76%	2.5
Woods Hole - Buzzards Bay	MA	4.8	25%	>3	55%	2.4	41%	>3
Nantucket Island, Nantucket Sound	MA	4.4	28%	>3	37%	2.9	24%	>3
Newport - Narragansett Bay	RI	4.7	24%	2.7	47%	2.3	37%	2.9
Providence - Providence River	RI	8.5	20%	1.3	93%	1.2	94%	1.2
New London - Thames River	CT	4.1	37%	>3	35%	>3	10%	>3
Bridgeport - Bridgeport Harbor	CT	5.6	23%	2.6	86%	1.7	75%	2.4
Montauk - Fort Pond Bay	NY	4.2	36%	>3	39%	>3	16%	>3
The Battery - New York Harbor	NY	5.2	26%	>3	81%	2	65%	>3
Atlantic City - Atlantic Ocean	NJ	5.2	30%	>3	87%	1.8	74%	>3
Cape May - Cape May Canal	NJ	4.7	32%	>3	65%	2.7	45%	>3
Reedy Point - C&D Canal	DE	3.9	33%	>3	18%	>3	11%	>3
Lewes - Ft. Miles	DE	5.4	28%	>3	92%	1.7	78%	>3
Cambridge, Choptank River	MD	4.1	27%	>3	23%	2.4	19%	2.9
Baltimore - Fort McHenry	MD	5.7	22%	1.8	66%	1.7	63%	1.8
U.S. Naval Academy - Severn R.	MD	5.3	22%	1.9	53%	1.7	51%	1.9
Solomons Island - Patuxent River	MD	4.4	24%	2.1	28%	1.8	28%	2
Washington - Potomac River	DC	10.1	19%	1.2	95%	1.2	97%	1.1
Kiptopeke - Chesapeake Bay	VA	3.9	42%	>3	19%	>3	6%	>3
Lewisetta - Potomac River	VA	4.2	29%	2.9	25%	2.1	23%	2.7
Sewells Point - Hampton Roads	VA	5.4	29%	>3	89%	1.6	81%	2.6
Chesapeake Bay Bridge Tunnel	VA	4.8	45%	>3	79%	2.4	61%	>3
Beaufort, Duke Marine Lab	NC	4.9	22%	1.8	39%	1.7	40%	1.8
Wilmington - Cape Fear River	NC	4.0	24%	2.6	19%	2.2	17%	2.5
Springmaid Pier - Atlantic Ocean	SC	4.1	36%	>3	25%	>3	14%	>3
Charleston - Cooper River Entrance	SC	5.1	22%	1.9	50%	1.8	46%	2
Fort Pulaski - Savannah River	GA	3.3	83%	>3	0%	>3	0%	n/a
Fernandina Beach - Amelia River	FL	3.3	55%	>3	1%	>3	0%	>3
Vaca Key - Florida Bay	FL	3.0	25%	2.6	7%	1.7	8%	1.9
Key West	FL	3.1	24%	2.4	8%	1.7	9%	1.7
Naples - Gulf Of Mexico	FL	3.9	25%	>3	19%	2.9	12%	>3
St. Petersburg, Tampa Bay	FL	6.5	20%	1.5	69%	1.5	71%	1.5
Clearwater Beach - Gulf Of Mexico	FL	6.6	20%	1.4	67%	1.4	71%	1.5
Apalachicola - Apalachicola River	FL	15.0	19%	1.1	95%	1.1	98%	1.1
Pensacola - Pensacola Bay	FL	14.0	19%	1.1	85%	1.1	93%	1.1
Grand Isle, East Point	LA	9.2	20%	1.2	78%	1.3	89%	1.2
Sabine Pass North	TX	6.3	20%	1.4	61%	1.5	65%	1.5
Galveston Pier 21 - Galveston Channel	TX	7.0	21%	1.5	81%	1.3	86%	1.4
Galveston Pleasure Pier - Gulf Of Mexico	TX	11.3	20%	1.2	96%	1.1	99%	1.1
Freeport, Dow Barge Canal	TX	5.2	23%	2.1	62%	1.9	59%	2.3
Rockport - Aransas Bay	TX	6.1	20%	1.3	47%	1.5	56%	1.4
Port Isabel - Laguna Madre	TX	5.9	20%	1.4	45%	1.4	53%	1.5
La Jolla - Pacific Ocean	CA	3.2	89%	>3	0%	n/a	0%	n/a
Los Angeles - Outer Harbor	CA	3.2	83%	>3	0%	n/a	0%	n/a
Port San Luis - Pacific Ocean	CA	3.5	32%	>3	4%	>3	0%	>3
Monterey - Monterey Harbor	CA	3.4	39%	>3	2%	>3	0%	>3
San Francisco - San Francisco Bay	CA	4.1	27%	>3	28%	>3	14%	>3
Charleston - Coos Bay	OR	4.4	38%	>3	85%	>3	16%	>3
South Beach - Yaquina River	OR	4.6	42%	>3	94%	>3	42%	>3
Astoria - Tongue Point	OR	4.5	43%	>3	99%	>3	11%	>3
Toke Point - Willapa Bay	WA	6.5	24%	>3	100%	1	100%	1.2
Neah Bay - Strait of Juan De Fuca	WA	4.7	21%	>3	100%	>3	28%	>3
Seattle - Puget Sound	WA	4.1	65%	>3	66%	>3	2%	>3

Table 3. Top ten nationally-ranked states, counties and cities for largest total populations living on land less than four feet above local high tide.

Rank		Top 10 States		Top 10 Counties		Top 10 Cities
1		Florida		Miami-Dade, FL		New Orleans, LA*
2		Louisiana*		Broward, FL		New York, NY
3		California		Jefferson, LA*		Hialeah, FL
4		New York		Orleans, LA*		Metairie, LA*
5		New Jersey		Lee, FL		Pembroke Pines, FL
6		Virginia		Pinellas, FL		Cape Coral, FL
7		Texas		Nassau, NY		Miami Beach, FL
8		North Carolina		San Mateo, CA		Plantation, FL
9		South Carolina		Collier, FL		Miramar, FL
10		Massachusetts		Hillsborough, FL		Fort Lauderdale, FL

* includes significant populations on land already under the local high tide line, and protected by levees

Figure 1. Odds of century or worse floods by 2030, with and without sea level rise from global warming, at select sites. Table 2 provides detail for all sites studied.

Figure 2. City populations on land less than four feet above local high tide for 2,206 American cities. Nonlinear scale used.

Notes

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[18] Odds are for floods *by* given years, not within given years. Flood heights measured relative to local high tide. Century flood levels estimated using historic flooding patterns and assuming 2009 sea level as a baseline. Global warming multipliers indicate how much sea level rise from global warming has multiplied flood odds, compared to a world without warming, to reach the projected odds shown. 90% of historic global average sea level rise since 1880 is assumed to come from warming. Historic century flood odds have *already* doubled at all sites with multipliers >2 by 2030, except for at Solomons Island, MD and Freeport, TX, where odds have increased by 90% or more.

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Sea Level Rise Threats to Energy Infrastructure

A Surging Seas Brief Report by Climate Central • April 19, 2012

Ben Strauss
Remik Ziemlinski

Summary

Sea level rise from global warming is well on the way to doubling the risk of coastal floods 4 feet or more over high tide by 2030 at locations nationwide. In the lower 48 states, nearly 300 energy facilities stand on land below that level, including natural gas infrastructure, electric power plants, and oil and gas refineries. Many more facilities are at risk at higher levels, where flooding will become progressively more likely with time as the sea continues to rise. These results come from a Climate Central combined analysis of datasets from NOAA, USGS and FEMA.

Rising seas

Global warming has raised sea level about 8 inches since 1880, and the rate of rise is accelerating. Scientists expect 20 to 80 more inches this century, a lot depending upon how much more heat-trapping pollution humanity puts into the atmosphere. In the near term, rising seas will translate into more and more coastal floods reaching higher and higher, as sea level rise aggravates storm surges. These increases threaten widespread damage to the nation's energy infrastructure. This brief analyzes the potential risk.

Multiplying risk

Based on peer-reviewed research, Climate Central's March 2012 report, *Surging Seas* (surgingseas.org/NationalReport), made local sea level rise and coastal flood risk projections at 55 water-level stations distributed around the lower 48 states. At the majority of these sites and across the U.S., according to the projections, climate change more than doubles the odds of near-term extreme flooding, compared to a hypothetical world without warming. Across sites, median odds for floods reaching at least 4 feet above local high-tide lines are 55 percent by 2030. Median odds for floods exceeding 5 feet are 41 percent by 2050. Odds vary regionally, but generally rank highest along the Gulf of Mexico. However, warming *multiplies* odds the most along the Pacific and then Atlantic coasts. Numbers are detailed in Table 2 of *Surging Seas*.

Energy infrastructure exposed

A great number of coastal energy facilities lay below these elevations, exposed to increasing risk of floods. This analysis identifies 287 facilities less than 4 feet above the high-tide line, spread throughout the 22 coastal states of the lower 48. More than half of these are in Louisiana, mainly natural gas facilities. Florida, California, New York, Texas, and New Jersey each have 10-to-30 exposed sites, mainly for electricity in the first three states, and for oil and gas in the last two. All told, this brief catalogs 130 natural gas, 96 electric, and 56 oil and gas facilities built on land below the 4-foot line. Below the 5-foot line, the total jumps to 328 facilities with similar geographic and type distribution.

Figure 1 shows a map of coastal facility locations below 4 feet. Table 1 presents total energy facilities below 1-to-10 feet, state by state. Tables 2-4 break out natural gas, electric, and oil and gas facilities.

Analysis methods

To arrive at the values presented here, we overlay point coordinate data for energy facilities from the Federal Emergency Management Agency HAZUS Database / MH (version 1.1), against previously developed flood-risk zones. *Surging Seas* documents the methodology for developing these zones, which are based on the elevation of land relative to local high-tide lines (as opposed to standard elevation). The Surging Seas analysis employed national datasets from NOAA and USGS.

The HAZUS database breaks down energy facilities into several classes. We lump “Oil / Gas Refinery” and “Oil / Gas Storage Facility / Tank Farm” together with “Oil / Gas Facility”; the database includes only two sites in the first two categories less than 10 feet, vs. 118 for the last category. Similarly, we lump “Substation” (1 below 10 feet) together with “Electric Facility” (201).

Limitations

The results presented here should be presented with certain limits in mind. For example, the FEMA source data used includes only point coordinate values for each energy facility. Actual facilities cover larger areas that may include higher or lower elevations. This analysis uses the best publicly available elevation data covering the entire coast of the lower 48 states. However, like most datasets, the elevation dataset includes errors, so any point may be higher or lower than the value provided. These factors mean that results for any individual facility should be viewed cautiously. We therefore do not present results at the individual level. However, averaged over many facilities, potential errors should cancel out, making the aggregate findings presented more reliable.

This analysis simply tallies facilities under different elevations. It does not account for levees, seawalls, or other features that may offer protection. However, areas depressed below a sea-flood level, even if isolated from the ocean, may be more subject to flooding from rainwater during storms, as drainage would be impeded.

The *Surging Seas* report presents more thorough and detailed limits that all apply for this brief as well.

Figure 1. Low-lying coastal energy facilities map.

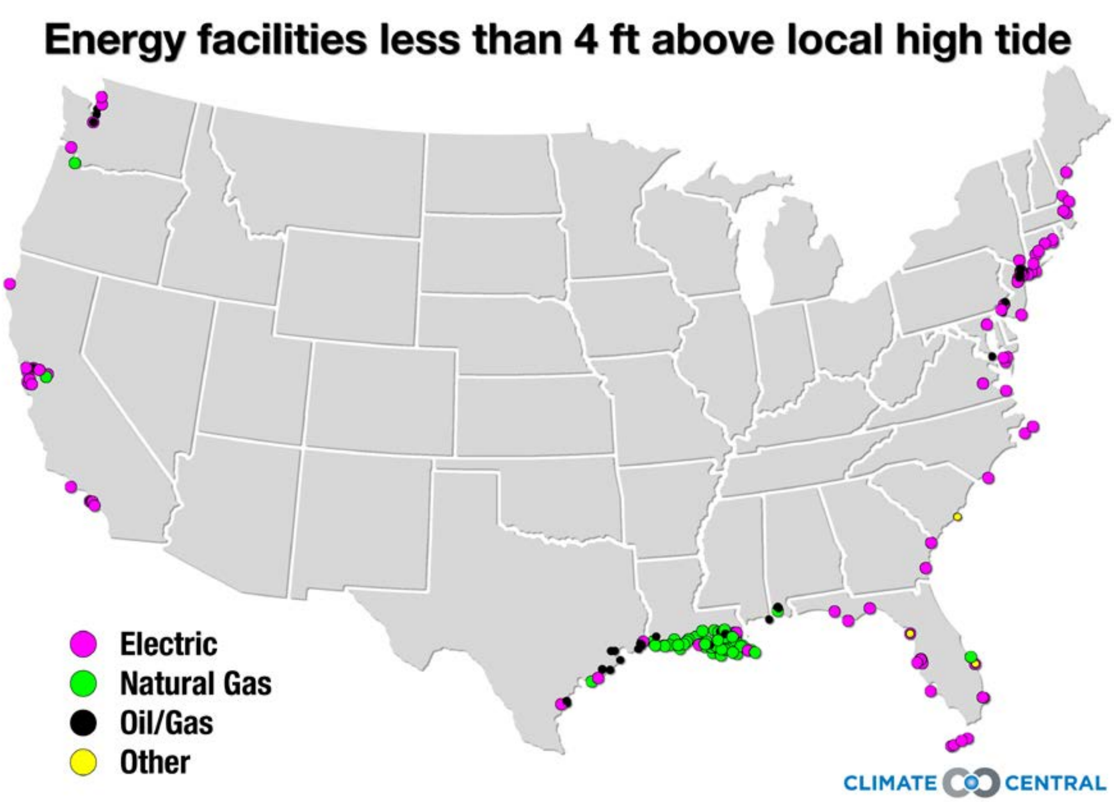

Table 1. Total energy facilities on land less than 1-to-10 feet below local high tide. Includes oil and gas, natural gas, and electric facilities, as well as other facilities.

State	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
Alabama	0	0	1	3	3	3	5	6	8	8
California	8	12	19	22	24	27	29	34	40	42
Connecticut	5	5	5	5	5	5	6	7	7	7
Delaware	0	0	0	0	0	3	4	4	4	5
Florida	6	12	19	26	30	33	34	44	47	49
Georgia	2	2	5	5	5	7	8	9	10	10
Louisiana	101	114	131	148	163	170	182	184	203	206
Maine	1	1	1	1	1	1	1	1	1	1
Maryland	1	2	3	4	5	5	6	7	10	11
Massachusetts	2	2	2	3	6	9	11	11	12	12
Mississippi	0	0	0	1	1	2	2	2	2	2
New Hampshire	2	2	2	2	2	2	2	2	3	3
New Jersey	10	12	15	17	21	22	34	40	46	50
New York	7	8	11	13	14	15	16	20	23	27
North Carolina	3	3	5	5	5	5	5	5	5	5
Oregon	1	1	1	1	2	2	2	2	2	2
Pennsylvania	1	1	1	1	1	2	4	6	7	7
Rhode Island	0	0	0	0	0	1	2	2	2	2
South Carolina	1	1	1	1	2	2	3	3	3	3
Texas	4	5	5	17	23	25	27	29	33	35
Virginia	1	1	2	3	5	5	6	8	13	14
Washington	6	6	6	9	10	12	14	14	14	18
Total	162	190	235	287	328	358	403	440	495	519

Table 2. Natural gas facilities on land less than 1-to-10 feet below local high tide.

State	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
Alabama	0	0	1	1	1	1	1	2	2	2
California	0	0	1	1	1	1	1	1	1	1
Connecticut	0	0	0	0	0	0	0	0	0	0
Delaware	0	0	0	0	0	0	0	0	0	0
Florida	1	1	1	1	2	2	3	3	3	3
Georgia	0	0	1	1	1	1	1	1	1	1
Louisiana	84	96	110	123	135	140	150	151	165	166
Maine	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	0	0	0	0	0	0	0	0
Massachusetts	0	0	0	0	0	1	1	1	1	1
Mississippi	1	1	1	1	1	1	1	1	1	1
New Hampshire	0	0	0	0	0	0	0	0	1	2
New Jersey	0	0	0	0	0	0	0	0	0	0
New York	0	0	0	0	0	0	0	0	0	0
North Carolina	0	0	0	0	0	0	0	0	0	0
Oregon	0	0	0	0	0	0	0	0	0	0
Pennsylvania	0	0	0	0	0	0	0	0	0	0
Rhode Island	1	1	1	1	2	2	2	2	3	3
South Carolina	0	0	0	0	1	1	1	2	2	2
Texas	1	1	1	1	1	2	2	2	2	3
Virginia	1	1	2	3	5	5	6	8	13	14
Washington	6	6	6	9	10	12	14	14	14	18
Total	88	100	117	130	145	152	163	166	182	185

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Table 3. Electric facilities on land less than 1-to-10 feet below local high tide.

State	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
Alabama	0	0	0	0	0	0	2	2	3	3
California	5	9	12	15	17	19	20	23	27	28
Connecticut	5	5	5	5	5	5	5	6	6	6
Delaware	0	0	0	0	0	3	4	4	4	5
Florida	3	8	15	22	25	27	27	34	36	38
Georgia	1	1	3	3	3	4	5	5	6	6
Louisiana	6	6	8	8	9	10	10	10	14	14
Maine	1	1	1	1	1	1	1	1	1	1
Maryland	1	2	2	3	4	4	4	5	8	9
Massachusetts	2	2	2	3	6	9	10	10	11	11
Mississippi	0	0	0	0	0	0	0	0	0	0
New Hampshire	1	1	1	1	1	1	1	1	1	1
New Jersey	3	4	6	7	10	10	17	19	23	24
New York	6	7	10	12	13	14	15	17	18	21
North Carolina	3	3	5	5	5	5	5	5	5	5
Oregon	1	1	1	1	2	2	2	2	2	2
Pennsylvania	0	0	0	0	0	1	2	4	5	5
Rhode Island	0	0	0	0	0	1	2	2	2	2
South Carolina	0	0	1	1	1	1	2	2	2	2
Texas	0	0	0	3	3	3	3	3	3	4
Virginia	1	1	2	3	4	4	4	4	8	8
Washington	2	2	2	3	4	5	6	6	6	7
Total	42	54	76	96	113	129	147	165	191	202

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Table 4. Oil and gas facilities on land less than 1-to-10 feet below local high tide.

State	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
Alabama	0	0	0	2	2	2	2	2	3	3
California	2	2	5	5	5	6	7	9	11	12
Connecticut	0	0	0	0	0	0	1	1	1	1
Delaware	0	0	0	0	0	0	0	0	0	0
Florida	0	0	0	0	0	0	0	3	4	4
Georgia	1	1	1	1	1	2	2	3	3	3
Louisiana	11	12	13	17	19	20	22	23	23	25
Maine	0	0	0	0	0	0	0	0	0	0
Maryland	0	0	1	1	1	1	2	2	2	2
Massachusetts	0	0	0	0	0	0	1	1	1	1
Mississippi	0	0	0	1	1	1	1	1	1	1
New Hampshire	0	0	0	0	0	0	0	0	1	1
New Jersey	6	7	8	9	10	11	15	18	20	23
New York	1	1	1	1	1	1	1	2	3	3
North Carolina	0	0	0	0	0	0	0	0	0	0
Oregon	0	0	0	0	0	0	0	0	0	0
Pennsylvania	1	1	1	1	1	1	2	2	2	2
Rhode Island	0	0	0	0	0	0	0	0	0	0
South Carolina	0	0	0	0	1	1	1	1	1	1
Texas	3	4	4	13	18	20	22	24	27	28
Virginia	0	0	0	0	0	0	1	2	3	3
Washington	3	3	3	5	5	5	6	6	6	7
Total	28	31	37	56	65	71	86	100	112	120

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