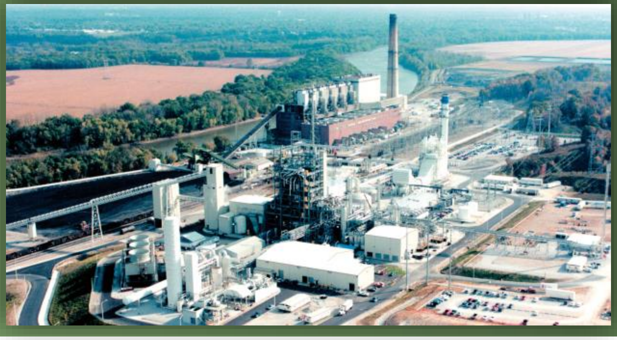
2018 WATER BRIEF

For Fossil Energy Applications of the Contiguous 48 United States

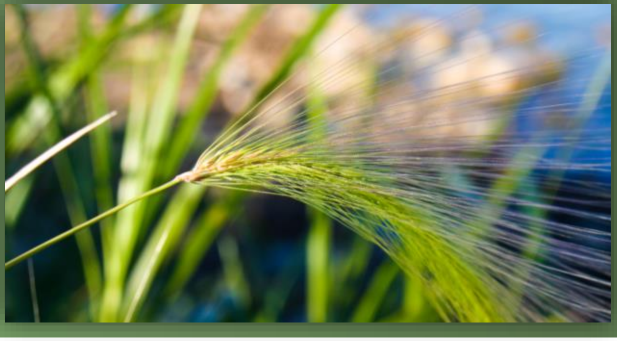
U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

ELECTRICITY

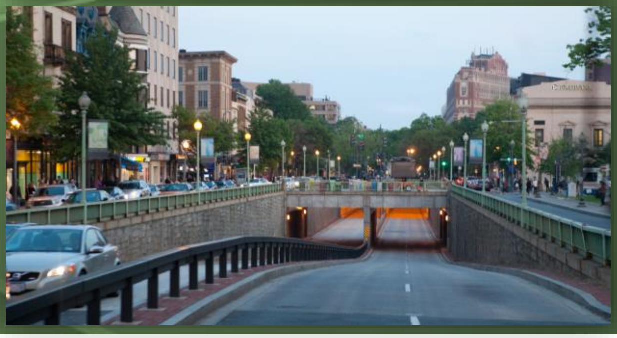


AGRICULTURE



INDUSTRY

MUNICIPAL



Foreword

The U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) is proud to present the *2018 Water Brief for Fossil Energy Applications*. This brief was produced with watershed data from Sandia National Laboratory (Sandia), Environmental Protection Agency (EPA) and the United States Geological Survey (USGS). Data was collected from various state, federal, academic, and industry institutions.

The primary purpose of this brief is to examine the interaction of water and energy production. Further, this brief presents information about the role of various sources of water, growth in population, agriculture water use, city size, and various sources of power production. It serves as a mechanism to provide information about water availability for energy generation. Moving toward the future, understanding how water scarcity impacts power generation may help the U.S. secure a reliable energy future.

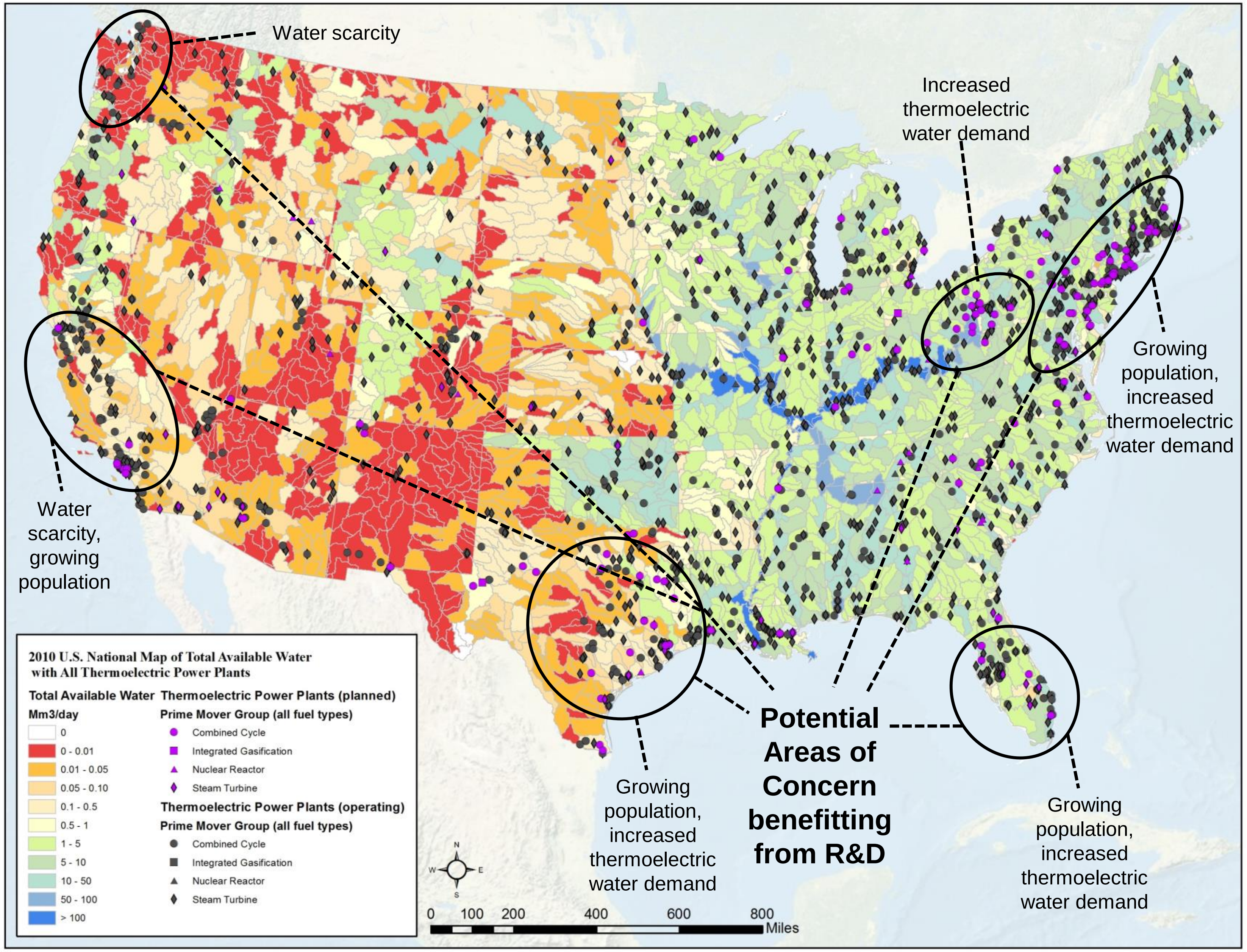
The data in this brief are current as of 2010 for water sources, 2018 for power plants, and 2000 for city populations.

Maps

National Perspectives

Regional Perspectives

Available Water and Thermoelectric Power Plants



Watershed data are current as of 2010 and thermoelectric powerplant data are current as of February 2018.

Water and Power Plants

Thermoelectric power refers to power generation using water as an integral ingredient to the process. For this Brief's purposes, thermoelectric power consists of combined cycle, integrated gasification, and other steam turbine applications used in: nuclear reactors, coal power plants, and natural gas power plants. Power generation sources stem from coal, natural gas, and uranium.

The east has the privilege of spreading thermoelectric power across multiple watersheds due to availability; the west does not have this luxury. The west concentrates thermoelectric power in watersheds with the highest availability relative to populations. Thermoelectric power plants are centralized where water is available, and this may put additional strain on these water rich areas. Direct competition with agriculture, municipalities, and industry across the U.S. suggests R&D in water management is vital.

R&D OPPORTUNITIES

- As thermoelectric power grows to keep up with demand in the east, more effective water management may help maintain low operating costs.
- In the water constrained west, thermoelectric power is looking to utilize technologies such as waterless plants employing dry cooling technologies to help alleviate current water stress.

Projected 2030 Available Water and Urban Expansion

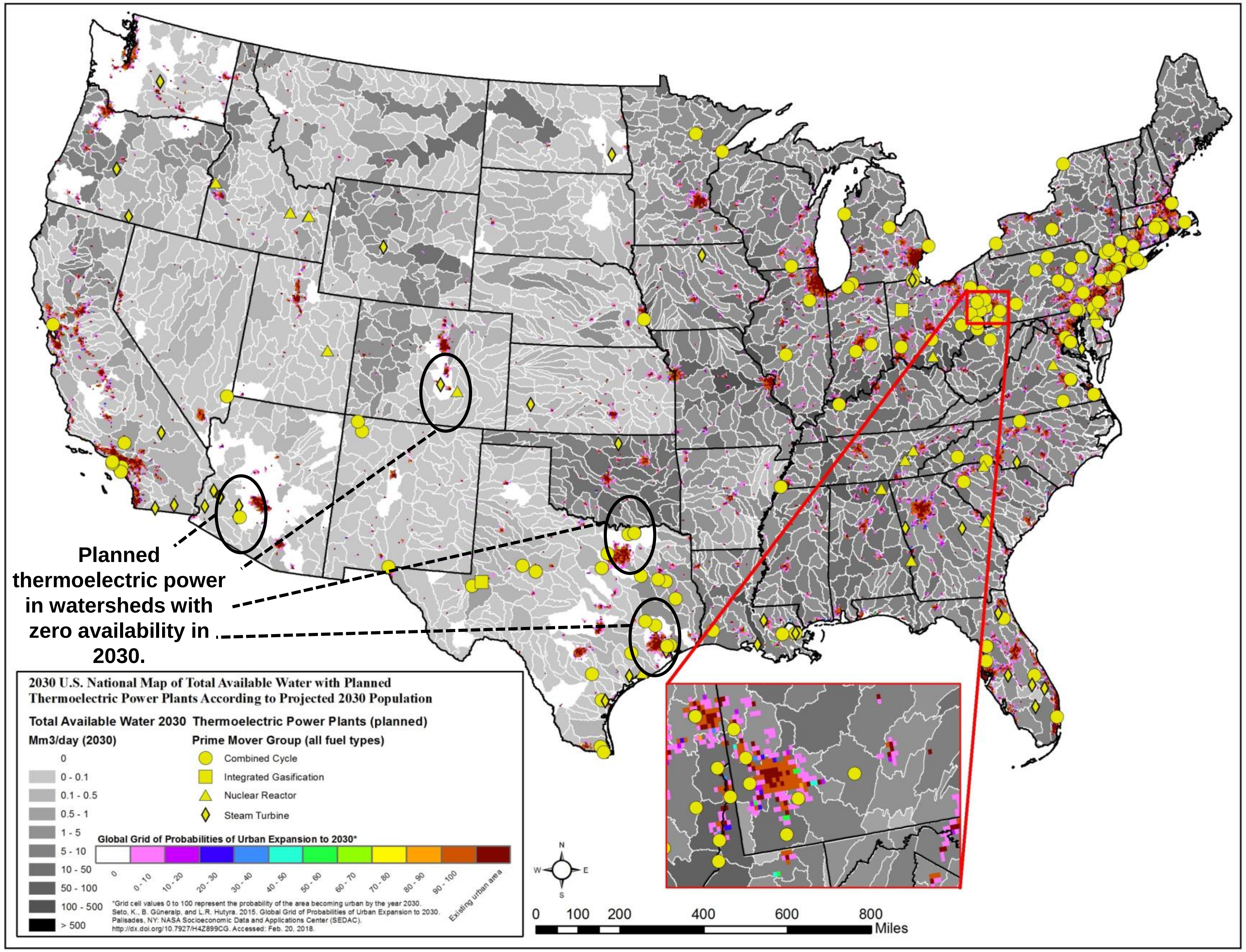
Water and Urban Growth

Projected 2030 water availability data are Sandia National Laboratory best-case-scenario estimates. Sandia estimates Projected 2030 available water by subtracting projected increases in consumptive use from the 2010 available water data. Projected increases in consumptive use include industry, municipal, and agriculture water expected growth. Weather patterns are not considered.

In the east, planned thermoelectric power plants circle urban growth. In the western U.S., this is not the case. Based on projected water availability, several planned thermoelectric power plants in Arizona, Colorado, Texas, Nevada, and North Dakota are in arid locations with zero projected water availability in 2030, but whose watersheds had mild availability in 2010. These planned plants are relatively far from urban centers.

R&D OPPORTUNITIES

- In western locations of Arizona, Colorado, and Texas, planned thermoelectric power plants may want to consider effluent reuse technologies because several watersheds are expected to have limited availability by 2030.
- Advances in treating alternative sources of water, such as municipal gray water, will offset thermoelectric power plant's consumption of available freshwater in the western states.

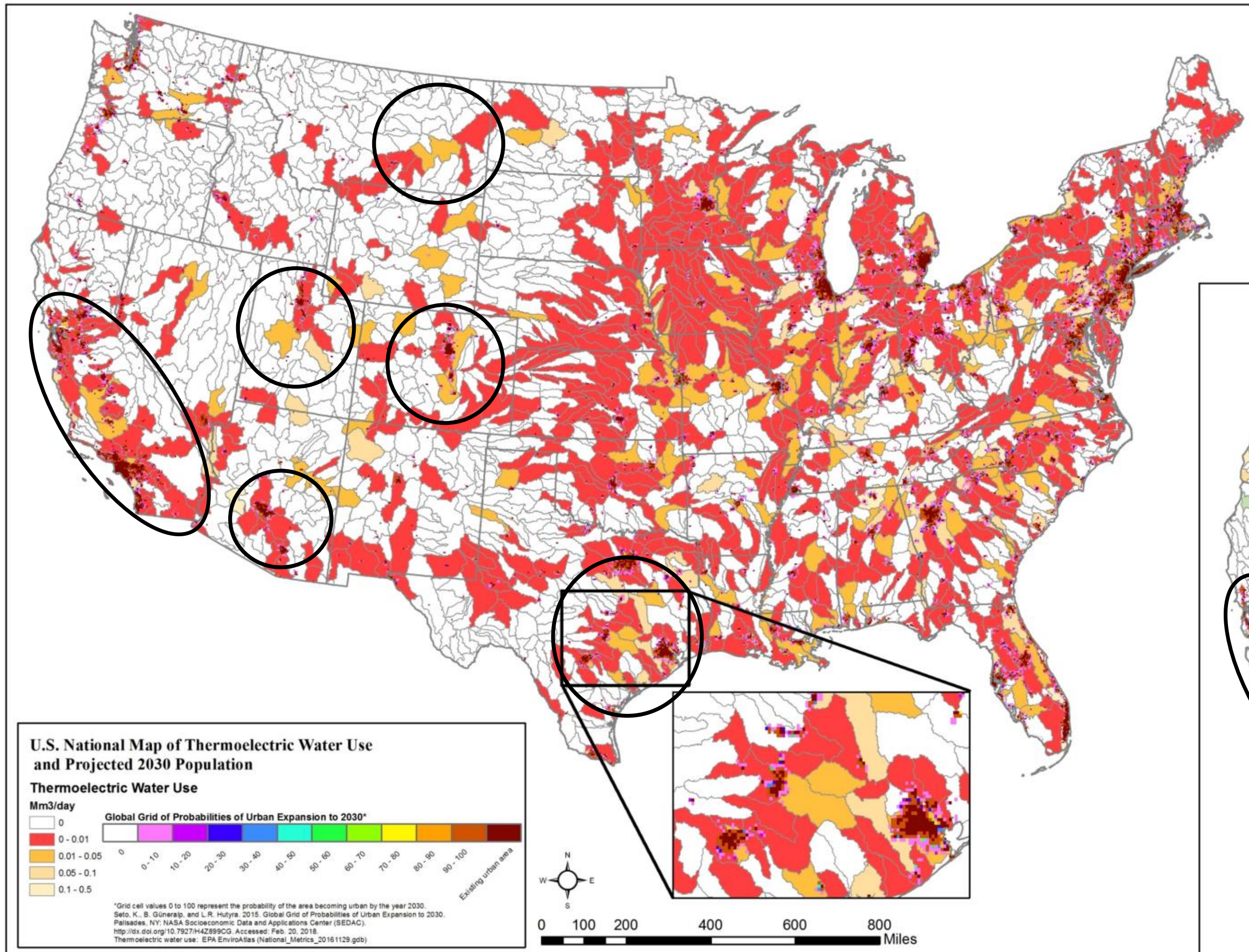


Watershed data are current as of 2010, thermoelectric powerplant data are current as of February 2018, and population data are current as of 2000.

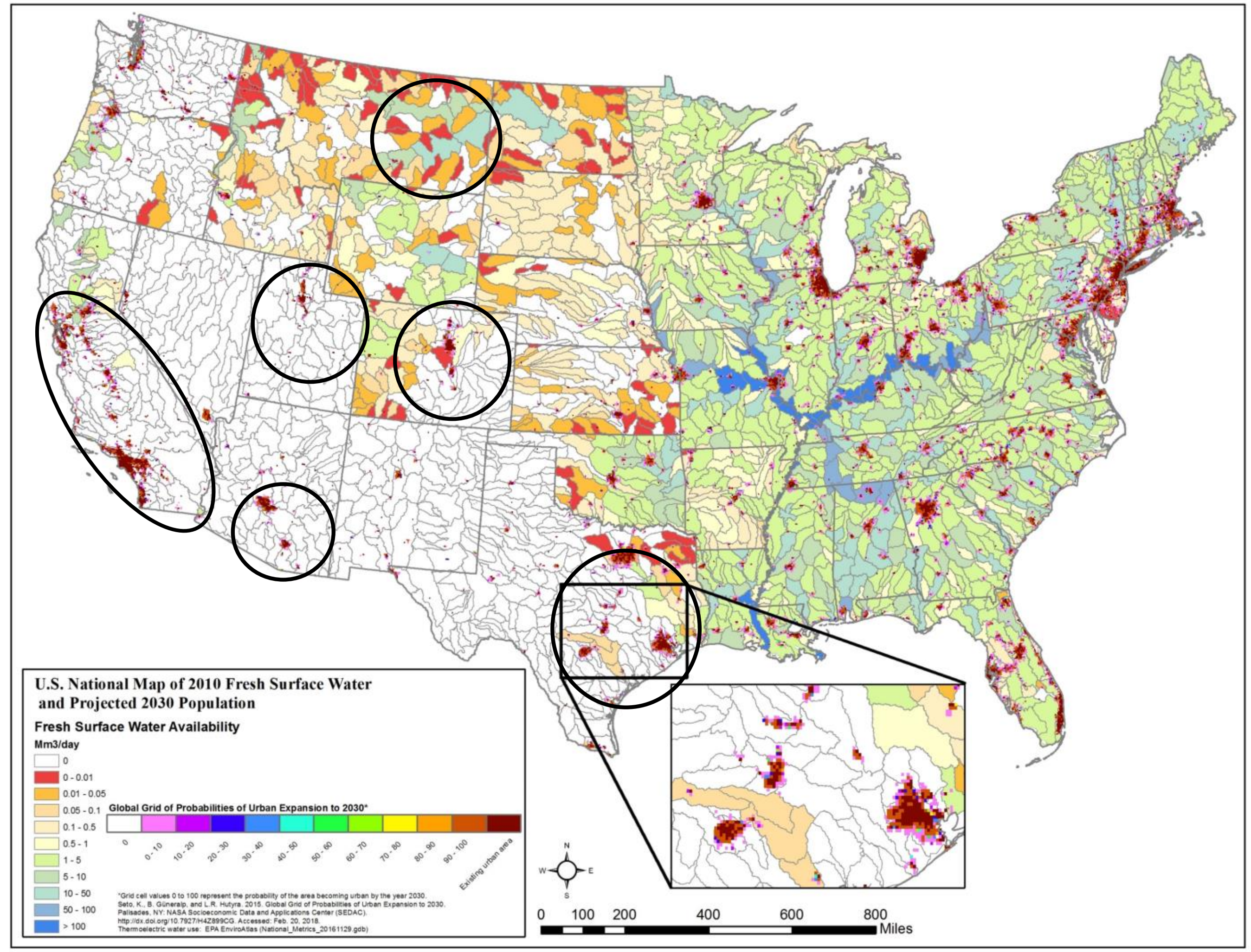
Fresh Surface Water and Thermoelectric Water Withdrawal

R&D OPPORTUNITIES

- Six circled areas represent locations where thermoelectric water withdrawals (left map) nearly equal or exceed available fresh surface water (right map). These locations stress the need for advances in dry cooling and water management technologies to minimize water use throughout thermoelectric power generation.



Watershed data are current as of 2016 and 2010, respectively, and provided by the EPA (above) and Sandia (right), thermoelectric withdrawal data are current as of 2010, and population data are current as of 2000.



Fresh Surface Water and Thermoelectric Water Withdrawal

In the United States, 99% of thermoelectric power plants use fresh surface water to cool their systems. The remainder utilize groundwater or municipal wastewater. Per EPA thermoelectric withdrawal estimates, the six outlined locations withdrew nearly equal to or more than the available fresh surface water. Thermoelectric plants in these outlined locations may be utilizing unconventional sources of water.

"Withdrawal" designates any water diverted from a surface or groundwater source. "Consumed water" designates withdrawn water that is not returned to its source (e.g., because it has evaporated, been transpired by plants, or incorporated into products).

Fresh Groundwater, Mining, and Active Coal Power

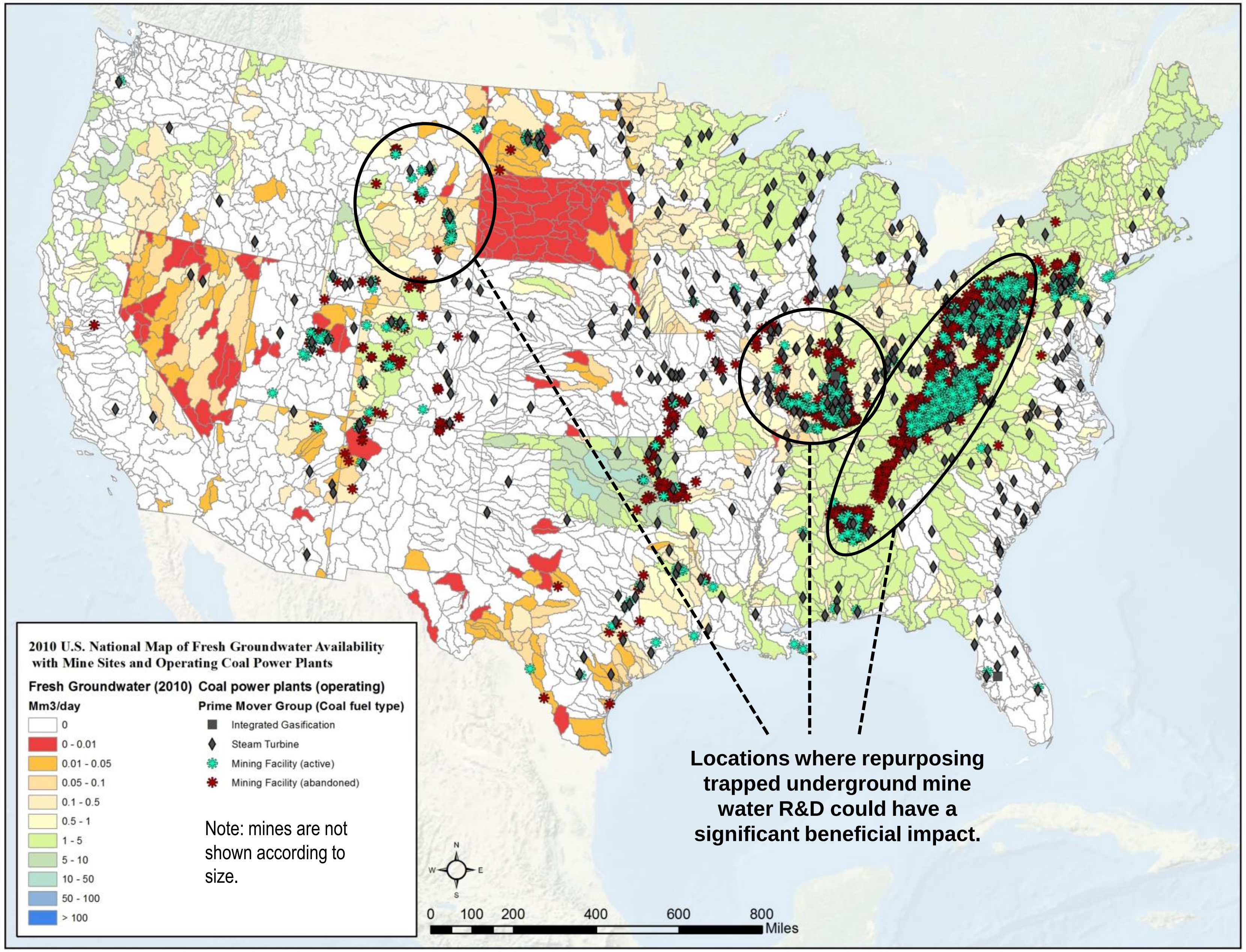
Groundwater and Mining

Groundwater availability is key in geographic locations where there is a lack of fresh surface water or where fresh surface water is primarily used for agriculture or residential purposes. While this examination does not look into which coal power plants directly use groundwater, some areas of concern (AOCs) can be identified in Wyoming, Colorado, Kentucky/Indiana, and Pennsylvania/West Virginia.

Historically, mining was primarily underground and as technology improved, mining shifted to surface methods. The U.S. had 710 active mines in 2016, with 36% underground and 63% surface. Each of the AOCs have several mining sites and coal plants. In Wyoming/Colorado, fresh groundwater is a source of freshwater for thermoelectric power and mining uses. Moreover, an opportunity is also presented at these sites; if research and development focuses on how power plants can use water found in mining sites, thermoelectric power may have a new water source and can move away from utilizing fresh groundwater as a cooling source.

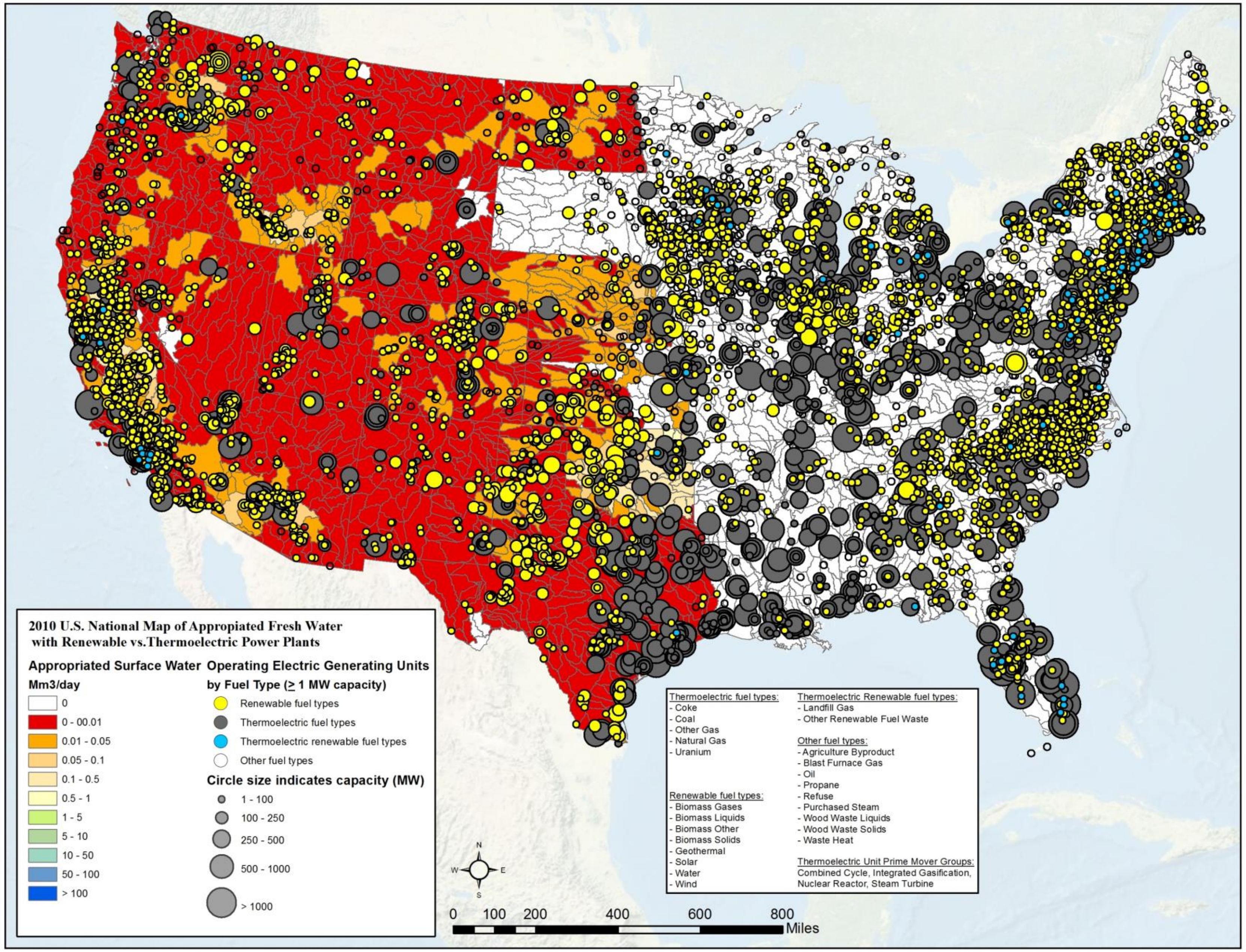
R&D OPPORTUNITIES

- Water trapped in abandoned underground mines could become a source of freshwater for local thermoelectric power plants.
- Repurposing trapped mine water could remove the need for some thermoelectric power to utilize groundwater which is difficult to source and expensive to treat.



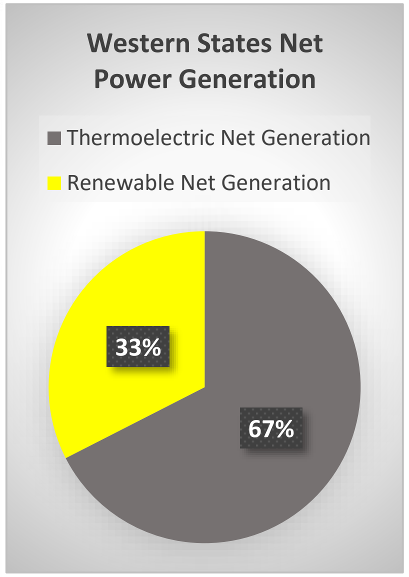
Watershed data are current as of 2010 and thermoelectric powerplant and mining data are current as of February 2018.

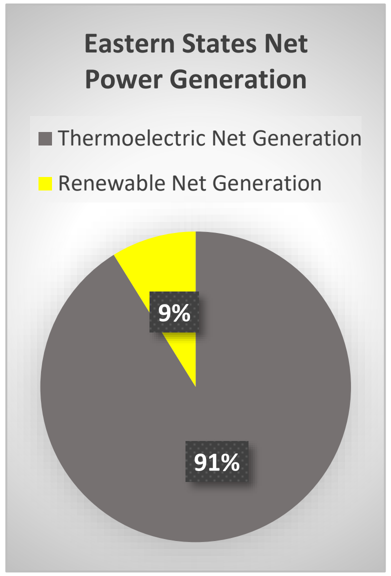
Appropriated Water and Power Sources



Watershed data are current as of 2010 and power plant data are current as of February 2018. Western and Eastern state designation is located on the last page.

Note: Thermoelectric renewable fuel types are not included in the graphical analysis because they are small subset of renewable generation located in both the east and west.





What is Appropriated Water?

Appropriated water refers to the legal doctrine which states that the first person to take a quantity of water from a source for beneficial use—be it agricultural, industrial, or residential—has the right to continue to use that quantity of water for said purpose.

R&D OPPORTUNITIES

- In the west, renewable sources of power utilizing little to no water are more common (33% to 9% net generation), which may be partly due to water appropriation; flexible effluent and cooling technologies may help thermoelectric power plants when cycling due to renewable integration.
- Advanced water management techniques in the eastern states may help thermoelectric power remain cost-competitive.

Change in Consumptive Use and Growth in Population

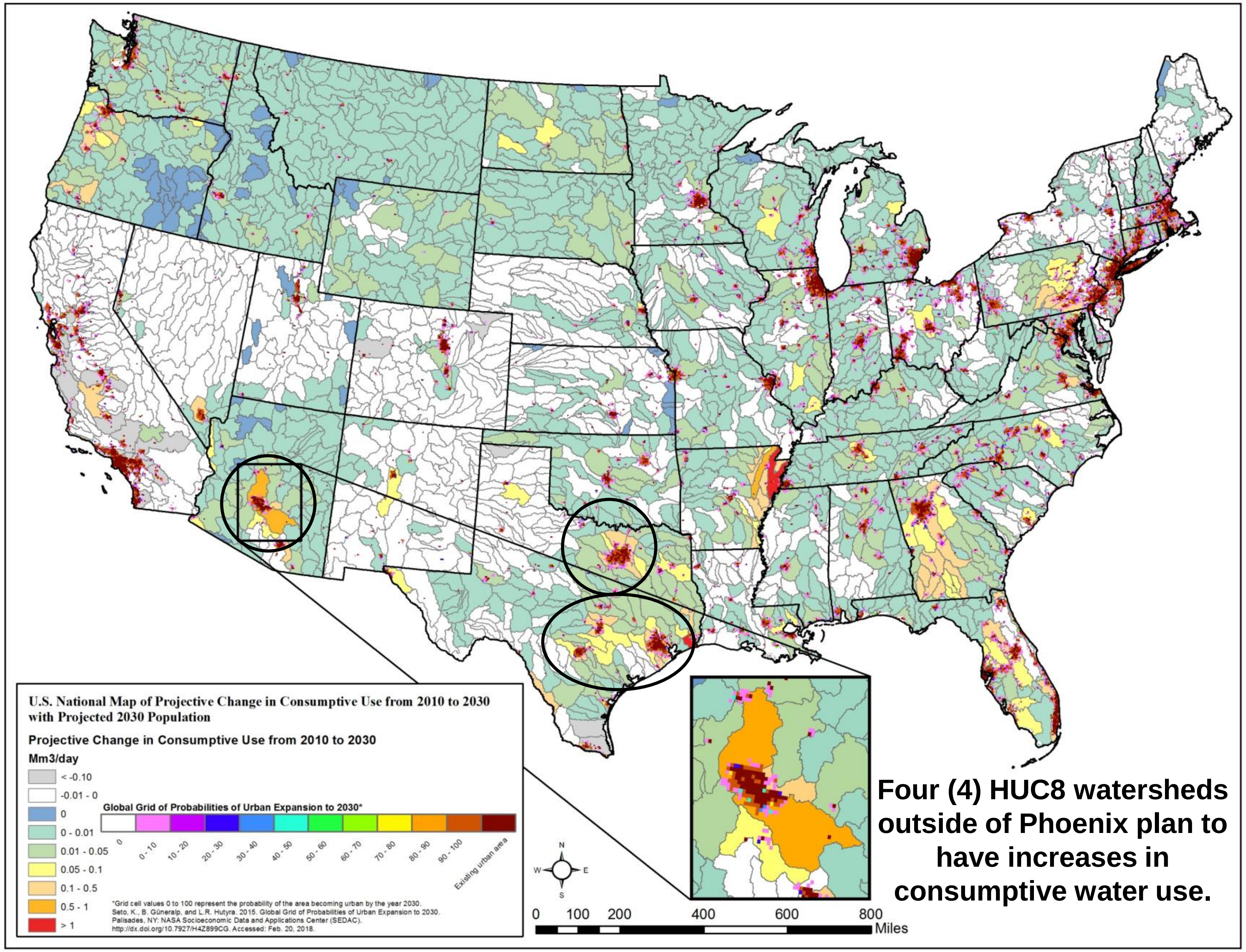
Consumptive Use and Population

Historically, change in consumptive water use and growth in population are intrinsically linked; as the population increases, the consumptive use of water also increases. In an exception to this rule, California has growing populations in Los Angeles and San Francisco, but the change in consumptive use is projected to be negative from 2010 to 2030. This is due to strict water regulation measures and public awareness.

Outside of California, the growth in urban population corresponds positively with the change in consumptive use. In major arid cities of Arizona and Texas, water conservation methods may need to be deployed. As consumptive use increases and urban growth continues, watersheds will become additionally stressed. Further, these data are from 2010 and do not reflect oil and gas hydraulic fracturing taking place in the Permian Basin in southwestern Texas in recent years.

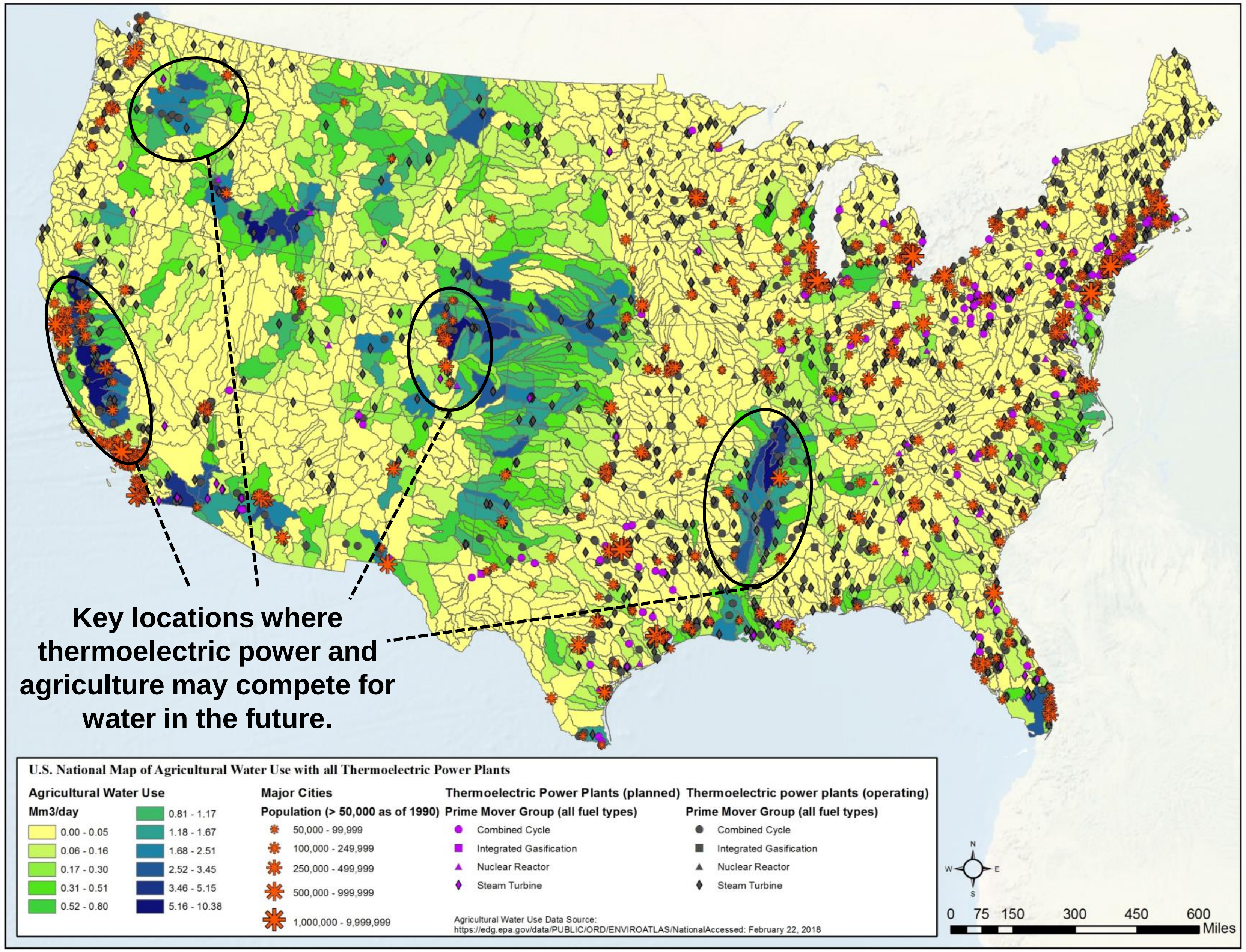
R&D OPPORTUNITIES

- As populations grow in the west, consumptive water use is projected to grow; to avoid water availability issues, thermoelectric power in these locations may look towards advances in dry cooling and hybrid technologies.
- In locations such as Phoenix, where consumptive use is projected to grow across all surrounding watersheds, thermoelectric power may actively consider effective automation technologies to use as little water as possible.



Watershed data are current as of 2010 and population growth data are current as of 2000.

East vs. West: Agriculture and Thermoelectric Power



EPA watershed data are current as of 2010, power plant data are current as of February 2018, and agriculture water data are current as of 2016.

Agriculture and Power

The agriculture belt runs throughout the Midwest and extends into California. Generally speaking, areas of high agriculture water use are not competing directly with thermoelectric power plants under normal weather conditions. It is important to note that it does not include water use from rainfall and other naturally occurring sources of precipitation.

However, expanding urban areas in California, Colorado, Oregon, and Washington could lead to competition for water use for agriculture, residential, industrial, and electricity uses. Agriculture is also a major American export. In 2015, agricultural exports accounted for $133 billion of the U.S. economy. Competition amongst resources in the agriculture and thermoelectric power sources may lead to economic challenges.

R&D OPPORTUNITIES

- Agriculture and thermoelectric water competition is a local issue that is difficult to decipher at the national scale; pinpointed advancements in water management and hybrid technologies may alleviate individual watershed stresses in Arkansas, Colorado, California, and Washington.
- Local thermoelectric power plant automation using sensors and controls may also limit the amount of water needed for electricity production.

Northern Appalachia: Available Water and Thermoelectric Power

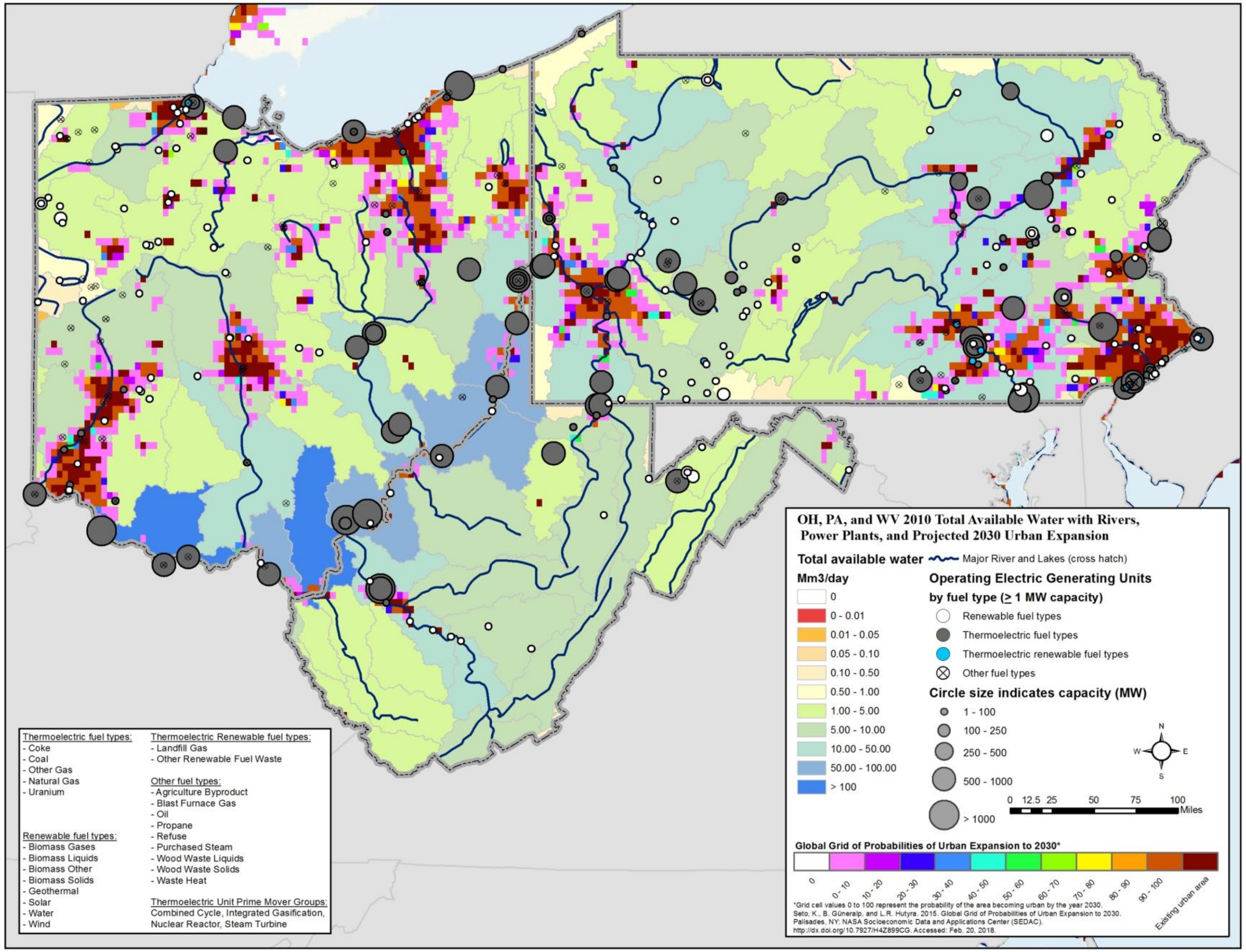
Regional Thermoelectric Power

Pennsylvania, Ohio, and West Virginia are rich in natural gas and coal reserves making thermoelectric power a natural choice. Examining power sources by region provides a better understanding of how to diversify the energy portfolio in the future. By spatially examining how many coal power plants are located closely together versus the locations of natural gas and nuclear power, watersheds can be diversified in the case of a drought or other major weather event. Water quality also needs to be considered when thermoelectric power plants are in close proximity to one another.

In terms of planning, one watershed may be growing exponentially in terms of population, but it would not be wise to overload the watershed with additional thermoelectric power. Instead, specific watersheds could rely on other forms of power to provide citizens with the energy they require. Regionally, renewables are concentrated in areas of low water availability.

R&D OPPORTUNITIES

- When multiple thermoelectric power plants are placed upstream of one another, two issues impacting the ecosystem arise: increasing effluent water temperature and water quality.
- To ensure thermoelectric power remains environmentally friendly, efficient cooling and water treatment detection technologies may benefit the Northern Appalachia region.



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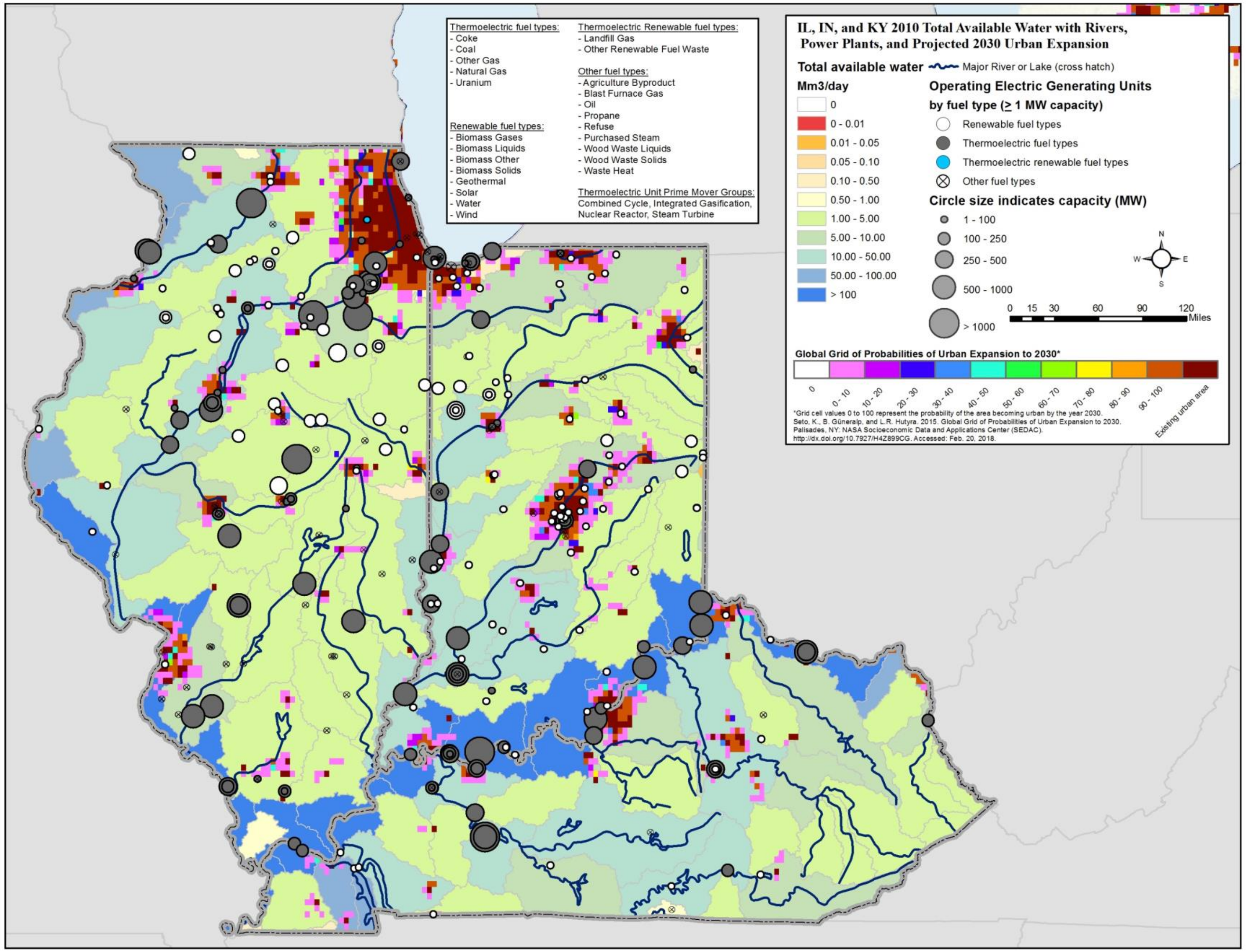
Midwest: Available Water and Thermoelectric Power



Watershed data are current as of 2010, power plant data are current as of February 2018, and agriculture water data are current as of 2016.

Regional Thermoelectric Power

A snapshot of the Midwest includes the high-coal producing states of Illinois, Indiana, and Kentucky. The Midwest is known globally for its superior topsoil and water availability, and should also be known for its unique energy profile. Chicago, Illinois, is famously nicknamed the Windy City, but thermoelectric power is the prime supplier of electricity. Chicago is situated on Lake Michigan and the Illinois and Fox rivers, providing ample water for thermoelectric power to deliver a steady base of electricity to the city. Central Illinois utilizes a mix of renewables and thermoelectric power for electricity needs.

Chicago's neighboring city, Indianapolis, Indiana, derives approximately half of its power from thermoelectric energy and the remainder from renewable energy. Due to water-rich watersheds in northern Kentucky, thermoelectric power is heavily utilized to meet electricity demands in the northern, heavily populated part and throughout the rest of the state.

R&D OPPORTUNITIES

- Even though the Midwest region is water-rich and has a diversified energy portfolio, advancements in water quality detection may benefit the major cities in the region.
- Agriculture accounts for a significant portion of the Midwest's economy; designing effluent reuse techniques deployable in a drought may benefit both thermoelectric power and agriculture.

Southern Atlantic Coast: Available Water and Thermoelectric Power

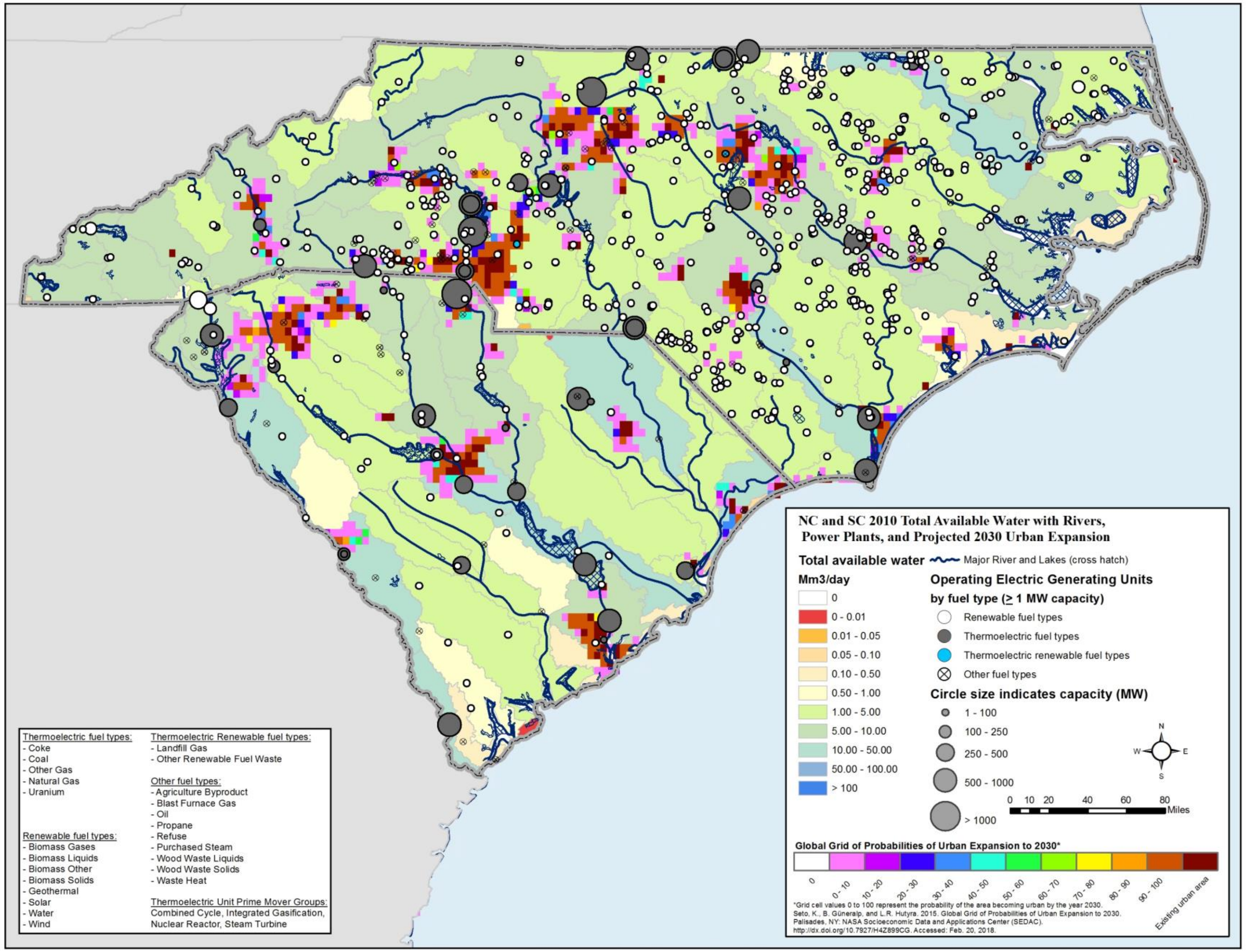
Regional Thermoelectric Power

North Carolina and South Carolina comprise the Southern Atlantic Coast region. The entire region is rather freshwater-rich with the exception of a few coastal regions. North Carolina's population is approximately twice as large as South Carolina's, roughly 10 million and 5 million people, respectively. Both Carolinas utilize a mix of thermoelectric power and renewables. While the area is water-rich, the plains and coasts of the states are prone to both flooding and droughts. Flooding and droughts may impact thermoelectric power plant's ability to produce electricity.

South Carolina's largest renewable plant, located in the state's northwest quadrant, is larger than any of North Carolina's individual renewable power plants. However, North Carolina utilizes more renewables to power the eastern portion of the state. South Carolina relies on thermoelectric power to provide electricity for its residents; North Carolina relies on thermoelectric power to supply baseloads for its largest cities of Charlotte, Greensboro, and Durham.

R&D OPPORTUNITIES

- Due to potential cycling from distributed generation in this region, advancements in anti-corrosion materials, boilers, and load following may increase thermoelectric power efficiencies.
- The Carolinas are known for their unique estuaries; advancements reducing thermoelectric power effluent temperatures will help preserve these ecosystems.



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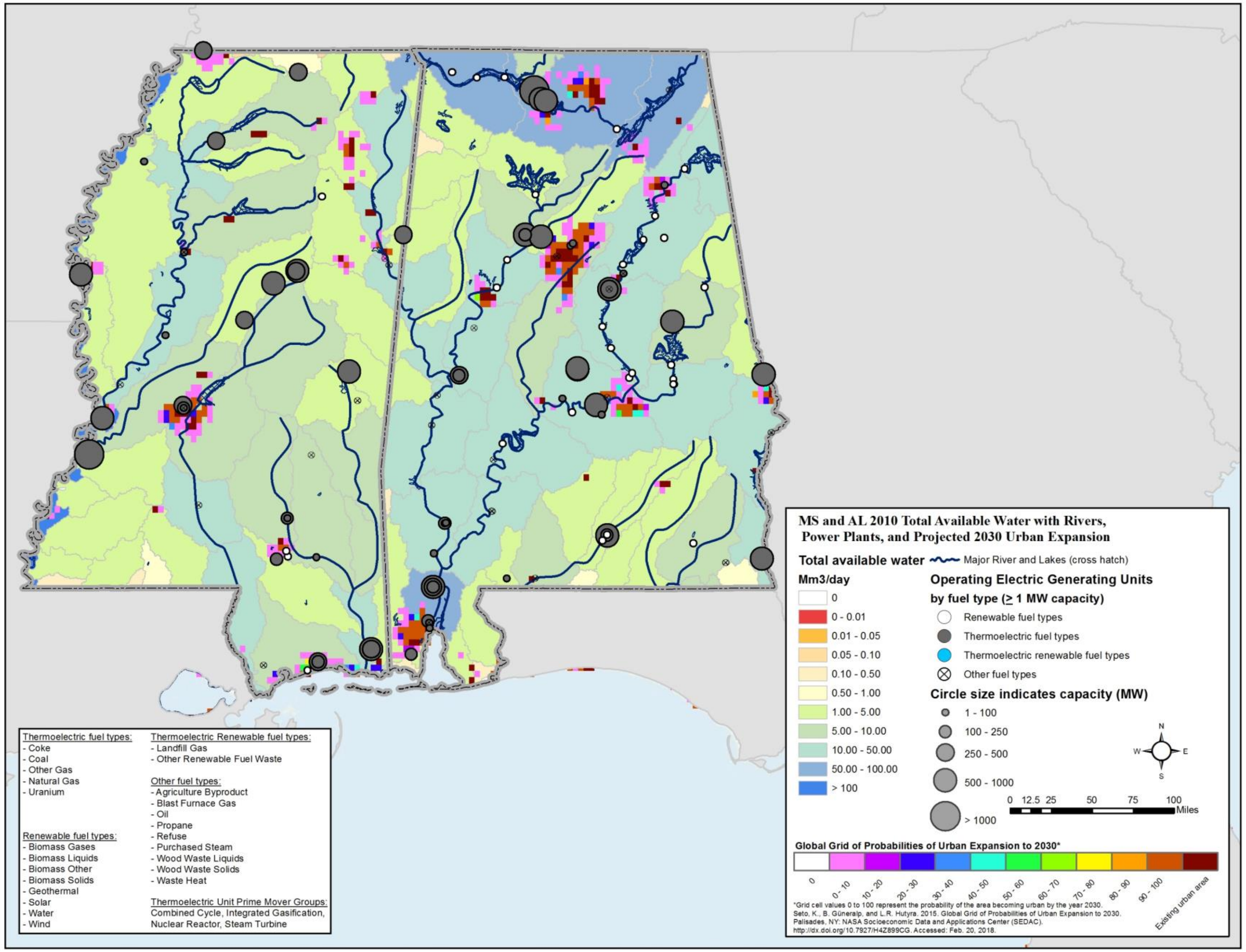
Eastern Gulf Coast: Available Water and Thermoelectric Power



Watershed data are current as of 2010, power plant data are current as of February 2018, and agriculture water data are current as of 2016.

Regional Thermoelectric Power

The Eastern Gulf Coast region includes Alabama and Mississippi, and is known for its oil exploration in the gulf. The region is also incredibly water-rich as is most of the east coast. Both Mississippi and Alabama have moderate populations, 2.9 million and 4.9 million, respectively. To supply the populations with electricity, both states predominately utilize thermoelectric power plants centralized on major rivers. However, because the entire region is water-rich, several thermoelectric power plants utilize local water sources and are not located on major rivers.

Renewable sources of power are more common in Alabama in comparison to Mississippi, but both are scarce throughout the region. Moreover, the region's urban population is expected to grow considerably over the next 30 years and consumptive water use is projected to increase. This could cause significant competition between agriculture, municipal, and thermoelectric power water uses in times of drought.

R&D OPPORTUNITIES

- Estuaries are common in the Gulf; alike the Carolinas, advancements reducing effluent temperatures will help preserve these ecosystems.
- Agriculture plays a major role in the Eastern Gulf Coast's economy; improvements treating alternative sources of water, such as brackish water, may alleviate future stresses between thermoelectric power and agriculture.

Western Gulf Coast: Available Water and Thermoelectric Power

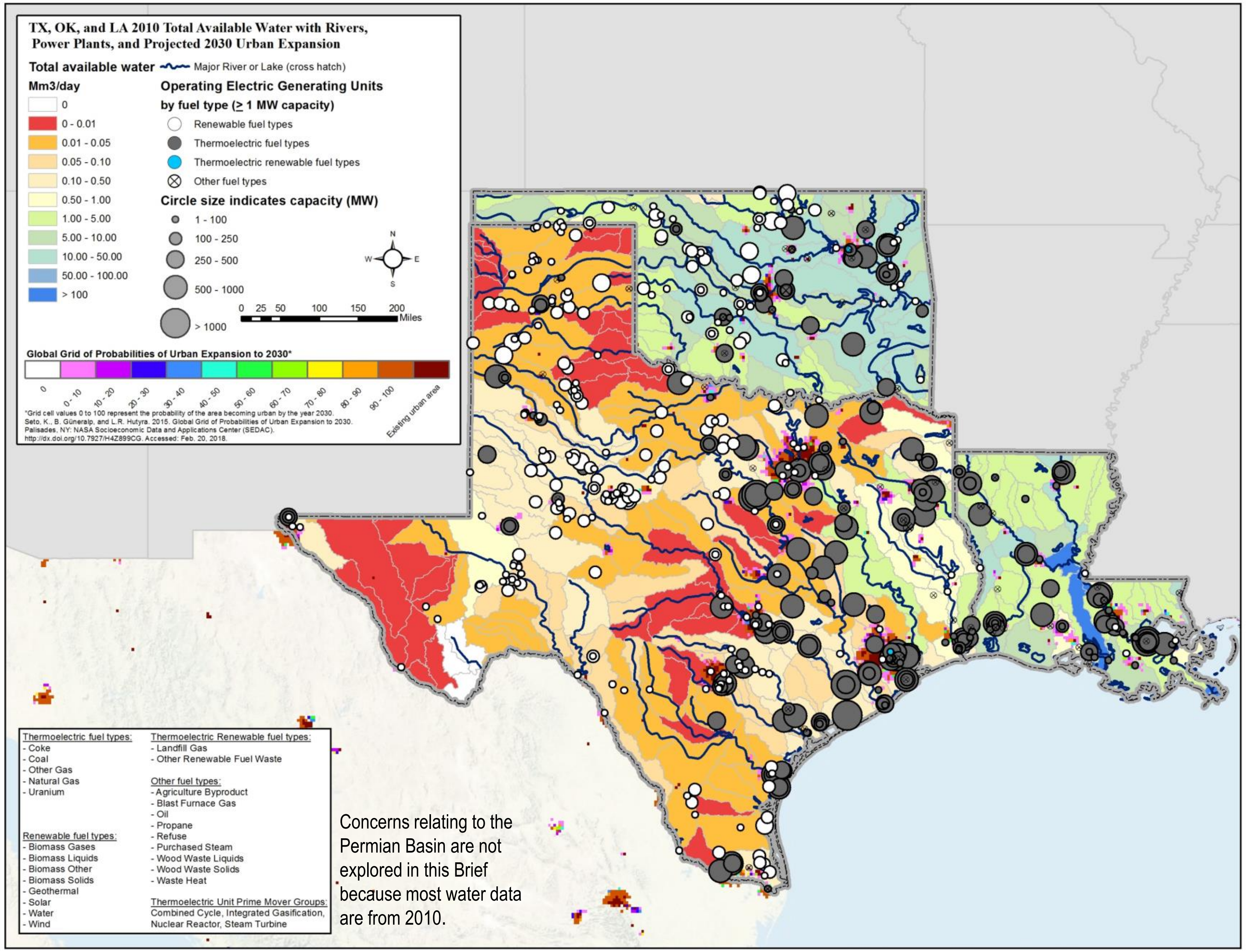
Regional Thermoelectric Power

The Western Gulf Coast, encompassing Texas, Oklahoma, and Louisiana, is booming—both in terms of population growth and energy production. Both Oklahoma and Louisiana have moderate water availability; additionally, outside of a few marshlands, Texas has scarce water availability. In terms of thermoelectric power production, most large-scale power plants are currently located on major rivers. Wind power plays a vital role in west Texas, specifically the Permian Basin. Texas generates the most electricity from wind in the United States. Moreover, the Permian Basin is currently facing water shortages to supply its oil and gas activity in the region.

Both Oklahoma and Texas appropriate water. In most cases, electricity production and agriculture fight for first water rights. This may present an issue: as the population grows, additional power sources are needed. The additional power requirement does not guarantee additional water rights.

R&D OPPORTUNITIES

- While Oklahoma and Louisiana in the Western Gulf Coast have moderate water availability, Texas is arid, and the region may benefit from advancements in dry cooling and hybrid technologies.
- Due to the high population density, improvements in water quality detection may also benefit the region and thermoelectric plants downstream of one another.



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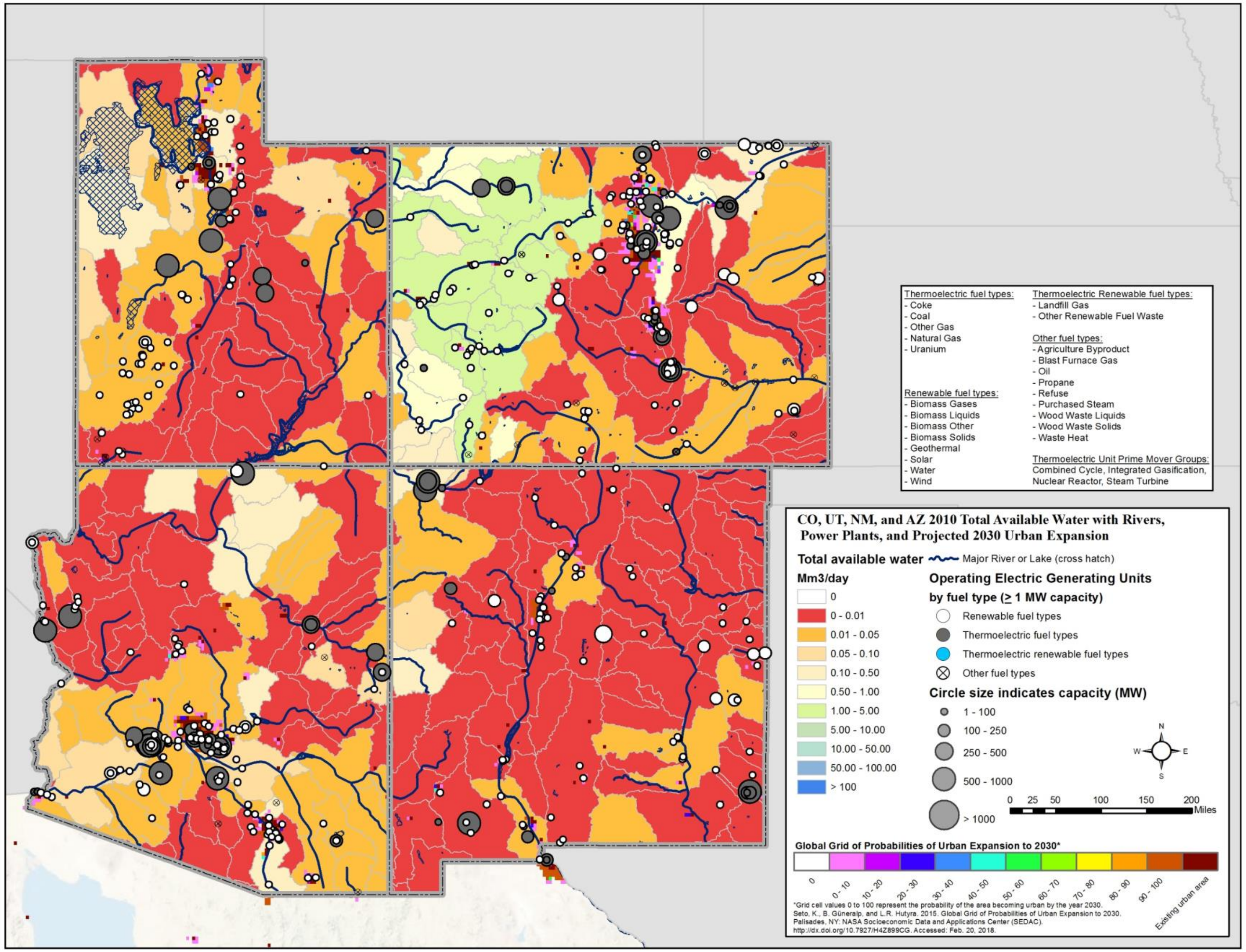
Mountain West: Available Water and Thermoelectric Power



Watershed data are current as of 2010, power plant data are current as of February 2018, and agriculture water data are current as of 2016.

Regional Thermoelectric Power

Colorado, Utah, New Mexico, and Arizona comprise the Mountain West region. This region, especially Colorado and Utah, are high coal producing states. Outside of the Rocky Mountains in Colorado, the entire region is incredibly arid. However, the population is exploding, especially in Phoenix, Arizona; Denver, Colorado; and Salt Lake City, Utah. The agriculture and ranching belt also runs through the Mountain West. This presents an inherent issue: water is very scarce for a growing population, power generation and agriculture.

Renewables are commonly found on the grid around city centers. Thermoelectric power is found almost exclusively on major rivers, such as the Colorado River, where water availability of specific watersheds is less of a concern. However in general, water availability is a major concern for the residents and local municipalities of the Mountain West.

R&D OPPORTUNITIES

- The Mountain West is an arid region and may benefit from an array of advancements in thermoelectric power production including: efficient water management practices, dry cooling, hybrid cooling, predictive maintenance, boilers, condensers, and anti-corrosion materials.
- The desert ecosystem is sensitive to environmental stimuli such as temperature fluxes, and reducing effluent temperatures will help preserve it.

Northern Mountain West: Available Water and Thermoelectric Power

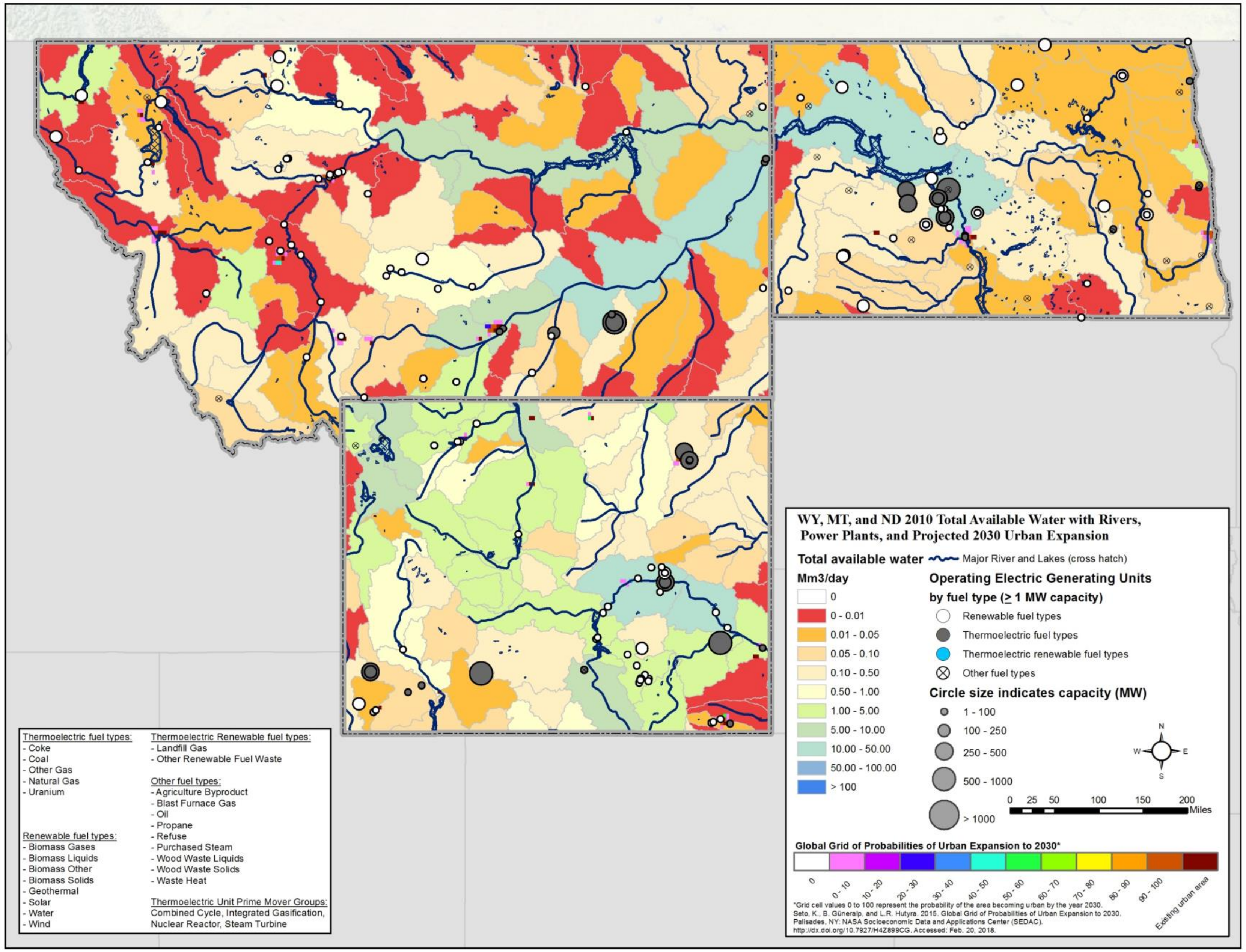
Regional Thermoelectric Power

The Northern Mountain West encompasses Montana, Wyoming, and North Dakota. The energy profile reflects the modest populations of the region. Thermoelectric power and renewables are both present throughout each state with thermoelectric power being more common in Wyoming and North Dakota. Even though the population of the region is dispersed, there are few pockets where significant energy production is required.

It is also important to note that the Northern Mountain West is rather arid. Further, the Bakken region of North Dakota requires significant water resources to support its oil and gas production activities, but it is located in a dry region of the state. Historically, thermoelectric power has been limited to a few watersheds with high water availability or major rivers. Moreover, population projections from 2000 to 2030 do not anticipate significant growth and consumptive water use does not project a rise in demand.

R&D OPPORTUNITIES

- The Northern Mountain West is arid and may benefit from a similar array of advancements as the Mountain West: efficient water management practices, dry cooling, hybrid cooling, predictive maintenance, boilers, condensers, and anti-corrosion materials.
- The mountainous region is prone to extreme weather events and may benefit from modular power systems to prevent local outages.



Watershed data are current as of 2010 and thermoelectric power plant data are current as of February 2018.

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Conversion factor: To convert from million meters cubed (Mm^3) to acre foot, multiply by 810.714.

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Eastern States include: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New Jersey, Delaware, Maryland, New York, Pennsylvania, West Virginia, Virginia, North Carolina, South Carolina, Georgia, Florida, Michigan, Ohio, Indiana, Kentucky, Tennessee, Alabama, Mississippi, Wisconsin, Illinois, Minnesota, Iowa, Missouri, Arkansas, and Louisiana.

Western States include: North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Texas, Montana, Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, Washington, Oregon, Nevada, and California.

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