ENERGY ZONES STUDY

A Comprehensive Web-Based Mapping Tool to Identify and Analyze Clean Energy Zones in the Eastern Interconnection

Argonne
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OAK RIDGE
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U.S. DEPARTMENT OF ENERGY

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A Comprehensive Web-Based Mapping Tool to Identify and Analyze Clean Energy Zones in the Eastern Interconnection

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Contents

Contents (Cont.)

Contents (Cont.)

Contents (Cont.)

Figures

Figures (Cont.)

Figures (Cont.)

Figures (Cont.)

Figures (Cont.)

Tables

Tables (Cont.)

Preface

This report describes the work conducted in support of the Eastern Interconnection States' Planning Council (EISPC) Energy Zones Study and the development of the Energy Zones Mapping Tool performed by a team of experts from three National Laboratories. The multi-laboratory effort was led by Argonne National Laboratory (Argonne), in collaboration with the National Renewable Energy Laboratory (NREL) and Oak Ridge National Laboratory (ORNL).

In June 2009, the U.S. Department of Energy (DOE) and the National Energy Technology Laboratory published Funding Opportunity Announcement FOA-0000068, which invited applications for interconnection-level analysis and planning. In December 2009, the Eastern Interconnection Planning Collaborative (EIPC) and the EISPC were selected as two award recipients for the Eastern Interconnection. Subsequently, in 2010, DOE issued Research Call RC-BM-2010 to DOE's Federal Laboratories to provide research support and assistance to FOA-0000068 awardees on a variety of key subjects. Argonne was selected as the lead laboratory to provide support to EISPC in developing a methodology and a mapping tool for identifying potential clean energy zones in the Eastern Interconnection. In developing the EISPC Energy Zones Mapping Tool (EZ Mapping Tool), Argonne, NREL, and ORNL closely collaborated with the EISPC Energy Zones Work Group which coordinated the work on the Energy Zones Study.

The main product of the Energy Zones Study is the EZ Mapping Tool, which is a web-based decision support system that allows users to locate areas with high suitability for clean power generation in the U.S. portion of the Eastern Interconnection. The mapping tool includes 9 clean (low- or no-carbon) energy resource categories and 29 types of clean energy technologies. The EZ Mapping Tool contains an extensive geographic information system database and allows the user to apply a flexible modeling approach for the identification and analysis of potential energy zones and is publicly available at http://eispctools.anl.gov. In addition to enabling EISPC members and other stakeholders to identify areas with a high concentration of clean energy resources that could provide significant power generation in the future, another objective of the study was to promote open and transparent collaboration among state-level energy planning and regulatory agencies and to foster consistent and coordinated direction for regional and interconnection-level electricity analyses and planning.

Acknowledgments

The three national laboratories—Argonne National Laboratory (Argonne), the National Renewable Energy Laboratory (NREL), and Oak Ridge National Laboratory (ORNL)—would like to acknowledge the excellent collaboration with the Eastern Interconnection States' Planning Council (EISPC) and its Energy Zones Work Group. The Work Group members, led by Commissioner David Littell (Maine Public Utilities Commission), collaborated very closely with the three-laboratory project team and provided outstanding guidance and coordination for the Energy Zones Study. Special thanks are due to all EISPC staff, and, in particular, to former and current EISPC directors, Marya White and Valerie Lemmie, for the extraordinary support and direction they provided to the Energy Zones Study, as well as Bob Pauley, the EISPC Studies and White Papers Work Group lead. The laboratories would also like to acknowledge the following Energy Zones Work Group members, past and present: Hans Mertens (Vermont Department of Public Service), Jerry Lein (North Dakota Public Service Commission), Brian Rybarik (Wisconsin Public Service Commission), Michael Ryan (New Jersey Board of Public Utilities), Chairman Betty Ann Kane (District of Columbia Public Service Commission), C. Dukes Scott (South Carolina Office of Regulatory Staff), Allyn Powell (South Carolina Office of Regulatory Staff), Bob Leker (North Carolina Department of Commerce, State Energy Office), Michael Wegner (Kansas Corporation Commission), Brian Davison (Texas Public Utilities Commission), Delanie Breuer (Wisconsin Public Service Commission), Ed McNamara (Vermont Department of Public Service), and Ginny Kreitler (National Audubon Society).

The authors would also like to acknowledge the beneficial collaboration with the National Association of Regulatory Utility Commissioners (NARUC), National Energy Technology Laboratory (NETL), Eastern Interconnection Planning Collaborative (EIPC), and numerous other organizations with whom the three-laboratory team has interacted during this project. The project team would also like to acknowledge the Clean Energy States Alliance (CESA) for very close collaboration in implementing its energy policy and regulations database into the Energy Zones Mapping Tool, as well as Navigant Consulting for its contributions related to demand–side resources.

In addition, the project team is very grateful to numerous environmental and non-governmental organizations, including The Conservation Fund, NatureServe, National Audubon Society, The Wilderness Society, and many others, for their collaboration and active role in the Energy Zones Study. Many of these organizations provided valuable environmental information for the Study. In addition, many environmental experts volunteered their time and effort to serve on the Environmental Focus Group and provided valuable input and guidance to the project team regarding the use of environmental information and criteria in assessing the suitability of different geographical areas for clean energy resource development.

Finally, the project team would like to thank the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability (DOE/OE) for supporting this work. Special thanks are due to David Meyer for outstanding management and coordination of the entire project and to Lawrence Mansueti for providing valuable input and direction to the project team.

Notation

Acronyms

AC	alternating current
AMI	Automated Metering Infrastructure
ANS	American Nuclear Society
Argonne	Argonne National Laboratory
AWST	AWS Truepower, LLC
BAU	business as usual
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement (formerly Minerals Management Service)
BWR	boiling-water reactor
C&I	commercial and industrial
CAES	compressed-air energy storage
CBECS	Commercial Building Energy Consumption Survey
CCGT	combined-cycle gas turbine
CCS	carbon capture and sequestration
CESA	Clean Energy States Alliance
CFB	coal fluidized bed
CO	carbon monoxide
COL	combined operating license
CO_2	carbon dioxide
CSC	Costal Services Center
CSP	concentrating solar power
CVR	Conservation Voltage Reduction
DC	direct current
DLC	direct load control
DNI	direct normal irradiance
DOC	Department of Commerce
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DR	demand response
DSIRE	Database of State Incentives for Renewable Energy
EFG	Environmental Focus Group
EGS	enhanced geothermal system
EIA	Energy Information Administration
EIPC	Eastern Interconnection Planning Collaborative
EISPC	Eastern Interconnection States' Planning Council
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 2005
EPRI	Electric Power Research Institute

EZ	Energy Zone
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FRA	Federal Railroad Administration
GHI	global horizontal irradiance
GIS	geographical information system
HAP	Hydropower Advancement Program
HRSG	heat recovery steam generator
HTGR	high-temperature gas-cooled reactor
HVAC	heating, ventilation, and air-conditioning
IGCC	integrated gasification combined cycle
iPWR	integrated pressurized-water reactor
IRP	Integrated Resource Plan
LIPA	Long Island Power Authority
LNG	liquefied natural gas
LWR	light-water reactor
MCDSS	Multi-Criteria Decision Support System
MIT	Massachusetts Institute of Technology
MMS	Minerals Management Service
MSW	municipal solid waste
NADR	National Assessment of Demand Response
NARUC	National Association of Regulatory Utility Commissioners
NCSU	North Caroline State University
NEI	Nuclear Energy Institute
NETL	National Energy Technology Laboratory
NGA	National Geospatial-Intelligence Agency
NGNP	Next Generation Nuclear Plant
NGO	non-governmental organization
NHD	National Hydrography Dataset
NHDPlus	National Hydrography Dataset Plus
NOAA	National Ocean and Atmospheric Administration
NOS	National Ocean Service
NO_x	nitric oxides
NPD	non-powered dam
NRC	U.S. Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory

OpenEI	Open Energy Information
ORNL	Oak Ridge National Laboratory
OR-SAGE	Oak Ridge Siting Analysis for Power Generation Expansion
PC	pulverized coal
PHMSA	Pipeline and Hazardous Materials Safety Administration
PLMA	Peak Load Management Alliance
PM	particulate matter
$PM_{2.5}$	particulate matter with an aerodynamic diameter of 2.5 µm or less
PM_{10}	particulate matter with an aerodynamic diameter of 10 µm or less
PSH	pumped storage hydroelectric
PV	photovoltaic
PWR	pressurized-water reactor
Reclamation	U.S. Bureau of Reclamation
RECS	Residential Energy Consumption Survey
RPS	Renewable Portfolio Standard
SMESE	superconductive magnetic energy storage
SMR	small modular reactor
SO_2	sulfur dioxide
SO_x	sulfur oxides
SUNY	State University of New York
TBR	Time-Based Rate
TVA	Tennessee Valley Authority
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WSU	Washington State University

Units of Measure

bbl	barrel(s)
Bcf	billion cubic feet
Btu	British thermal unit(s)
°C	degree(s) Celsius
cfs	cubic feet per second
cm	centimeter(s)
°F	degree(s) Fahrenheit
ft	foot (feet)
ft^2	square foot (feet)

GJ	gigajoule(s)
gpm	gallons per minute
GW	gigawatt(s)
J	joule(s)
kg	kilogram(s)
km	kilometer(s)
kV	kilovolt(s)
kWh	kilowatt hour(s)
m	meter(s)
m^2	square meter(s)
MMBtu	1 million British thermal units
MW	megawatt(s)
MW(e)	megawatt(s) electric
MWh	megawatt hour(s)
ppm	part(s) per million
Qcf	quadrillion cubic feet
s	second(s)
Tcf	trillion cubic feet
TWh	terawatt hour(s) (10^{12} watt hour[s])
Wh	watt-hour(s)
yr	year(s)

Executive Summary

Background and Objectives

The Energy Zones Study was carried out by the Eastern Interconnection States' Planning Council (EISPC) in collaboration with three U.S. Department of Energy (DOE) National Laboratories. The multi-laboratory effort was led by Argonne National Laboratory (Argonne) in collaboration with the National Renewable Energy Laboratory (NREL) and Oak Ridge National Laboratory (ORNL).

The main purpose of the EISPC Energy Zones (EZ) Study was to develop a comprehensive mapping tool that would enable EISPC members and other stakeholders to identify areas within the U.S. portion of the Eastern Interconnection that are suitable for the development of clean (low- or no-carbon) electricity generation. This report details the methodologies used in developing the tool's many features and databases.

The EZ Study itself does not identify specific energy zones. Rather, its objective was to provide EISPC members and stakeholders with an interactive, web-based decision support system to assist them in identifying areas with a high density of clean energy resources that may potentially be designated as Clean Energy Zones. Defining and designating Clean Energy Zones is left to jurisdictional authorities in each state. In addition to enabling states and regions to identify areas with a high concentration of energy resources conducive to developing clean power generation, the second objective was to promote collaboration among state-level energy planning and regulatory agencies for regional and interconnection-level electricity analyses and planning.

The main tasks of the EISPC EZ Study can be summarized as follows:

- Compile clean energy resource data for nine clean energy resource categories;

- Develop a web-based geographical information system (GIS) mapping tool that utilizes clean energy resource availability information and flexible screening factors for identifying areas suitable for clean power generation;

- Provide policy and law information that encourages or inhibits potential clean energy resource development; and

- Conduct outreach and training so that states (and stakeholders) can use the tool to collaborate effectively on long-term regional transmission planning.

The work on the study was coordinated by the EISPC's Energy Zones Work Group. Funding for the EZ Study was provided by DOE's Office of Electricity Delivery and Energy Reliability (DOE/OE) under the American Recovery and Reinvestment Act.

Clean Energy Resources and Technologies

The EZ Study included an investigation of nine types of clean energy resources that could be considered for the development of clean (low- or no-carbon) electricity generation facilities in the U.S. portion of the Eastern Interconnection (Figure ES-1). These energy resources are:

1. Biomass,
2. Clean coal technologies with carbon capture and sequestration (CCS),
3. Geothermal,
4. Natural gas,
5. Nuclear,
6. Solar photovoltaic (PV) and concentrated solar thermal, as well as rooftop PV,
7. Storage (pumped storage hydroelectric and compressed-air energy storage),
8. Water (hydrokinetic and tidal power), and
9. Wind (land-based and offshore).

For each of these major categories, the resource data and information have been compiled, reviewed, and assembled into a web-based GIS database. Because an energy resource category may comprise multiple technologies for electricity generation that utilize different types of energy inputs, the database also includes a total of 29 clean energy technologies (Table ES -1).

Figure ES-1 U.S. Portion of the Eastern Interconnection (Source: Argonne National Laboratory)

The information in the database is accessible in the web-based EISPC Energy Zones Mapping Tool (EZ Mapping Tool) that allows stakeholders to identify potentially suitable areas for developing clean energy resources or to analyze and determine potential clean energy zones. This tool contains an extensive library of GIS data layers, including energy resources, electrical transmission, oil and gas pipelines, protected lands, habitat, and other related information. It also includes interactive suitability models, a variety of reports that can be run and customized for user-specified regions, and a searchable energy policy and regulations database. The EZ Mapping Tool is publicly available on the web at http://eispctools.anl.gov (Figure ES-2).

Table ES-1 Clean Energy Resources and Technologies

Resource	Technology
Biomass	New biomass-fired plant with traditional combustion Biomass co-fired with existing coal plant Landfill gas extraction and plant inventory Methane extraction from wastewater treatment Methane extraction from animal manure processing
Clean Coal (with CCS)	New clean pulverized coal (PC) technology (subcritical and supercritical technologies) New integrated gasification combined cycle (IGCC) New coal fluidized bed (CFB) Retrofitting of existing pulverized coal (PC) with clean coal technology
Geothermal	Enhanced geothermal systems (EGS) Geopressured geothermal
Natural Gas	Combined cycle Underground natural gas storage Aboveground natural gas storage
Nuclear	Large light-water reactor Small modular reactor, integral pressurized-water reactor High-temperature gas-cooled reactor (HTGR)/very high temperature gas-cooled reactor (VHTR)
Solar	Concentrating solar power (CSP) Utility-scale photovoltaic (PV) Rooftop PV
Storage	Pumped storage hydroelectric (PSH) Compressed-air energy storage (CAES)
Water	Added output from existing hydropower dams New output from existing non-powered dams River and tidal hydrokinetic energy Marine tidal hydrokinetic energy Wave energy
Wind	Land-based wind turbines Offshore wind turbines

As one of the objectives of the study is to assist with the long-term regional and interconnection-level transmission planning process, the scope of the EZ Study includes the analysis of generation and storage technologies identified by the EISPC that are capable of providing grid-scale power generation. The EZ Mapping Tool may assist transmission planners by providing information on the areas within the Eastern Interconnection where a significant potential for new power generation exists, thus potentially requiring new transmission lines (or upgrades of existing ones) for transferring that power to electricity demand centers. For this purpose, the EZ Mapping Tool also includes a screening capability of potential future energy corridors. Just as the EZ Mapping Tool is designed for identifying potential geographical areas suitable for clean energy resource development and power generation and not for the siting of individual power plants, the corridor screening capability is designed for analyzing potential energy corridors and not for the siting of specific transmission lines or gas and oil pipelines. The corridor screening tool provides the capability to generate custom reports for potential energy corridors defined by the user. The report provides mileposted information along the corridor, including the states, counties, populated places it overlaps; major road, railroad, transmission line, pipeline, stream, and water body crossings; and other factors meaningful for corridor analysis. Reports can also be

Figure ES-2 Home Page for the EISPC EZ Mapping Tool

generated to examine environmental information for corridors, such as protected lands, sensitive habitats, and imperiled species.

With the exception of the rooftop PV solar resource, which is included because of its potential impact on the reduction of peak electricity demand and reduced need for new transmission lines, the EZ Study does not include analysis of distributed generation resources. Distributed energy resources and non-zonal technologies, such as demand response, energy efficiency, and smart grid, have been covered by separate studies and white papers commissioned by the EISPC. The main results and findings of these separate studies are included in the EZ Study and are available within the EZ Mapping Tool through the Rooftop PV and Demand Side Resources reports.

The geographical scope of the EZ Study for which the mapping of energy resources is provided includes the U.S. portion of the Eastern Interconnection. However, the policy and regulations database that is provided within the EZ Mapping Tool also covers the Canadian provinces that are part of the Eastern Interconnection.

Methodological Approach

Figure ES-3 illustrates the general modeling approach for identifying clean energy resource areas. The analysis can be performed either for a single clean energy resource or for a combination of resources or technologies (synergy analysis). The EZ Mapping Tool has more than 250 GIS data layers to which users can apply customized screening factors and other criteria. Users can analyze energy resource availability data under various scenarios, and the tool will provide customized maps depicting the suitability of different areas within the Eastern Interconnection for clean power generation based on criteria selected by the user. The EZ Mapping Tool database contains more than 100 environmental data layers to help ensure that protected lands, imperiled species, and other environmental factors are taken into account when determining the suitability of certain areas for clean energy resource development.

Suitability Models

Suitability models built into the tool allow users to identify areas suitable for the development of a specific clean energy technology. Starting with the energy resource information, the user can define which thresholds of the resource are suitable for the technology of interest. Other screening criteria are then applied to filter out areas unsuitable for resource development because of land use, ecological, and other constraints. For example, these types of criteria might exclude areas with high topographic slope, high population density, protected lands such as national and state parks, and sensitive habitat areas.
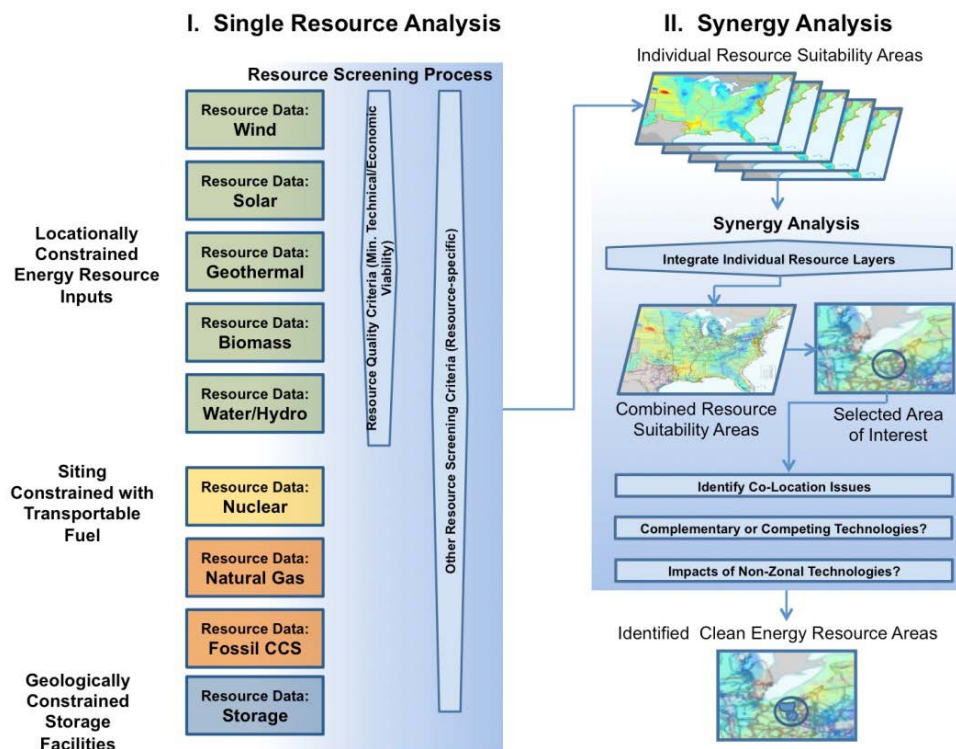
Figure ES-3 Methodology and Process for Identifying Clean Energy Resource Areas Using Single-Resource Analysis (I) and a Synergy Analysis (II)

Many of the screening factors represent terrain, land use, or other location-based characteristics that could affect whether areas can be developed, regardless of whether the energy resource itself is productive enough to be economical. For each location in the U.S. portion of the Eastern Interconnection, the "suitability" metric from these models combines the quality of the energy resource itself with factors that could limit development. Having selected an area based on its overall suitability, the user may then look more closely at the separate factors that affect whether development would be economical. Suitability scores generated by the models in the EZ Mapping Tool range from 0 (unsuitable) to 100 (best suitability). Results are dependent on the quality and accuracy of the input data, the user's choices about how to weight the importance of different parameters, and input suitability scores within each layer. They are intended to provide a regional screening-level analysis to compare locations with respect to the same technology. The models have not been calibrated to the level that suitability scores can be quantitatively compared across different technologies.

Figure ES-4 shows sample input mapping layers and criteria for the utility-scale PV model. Suitability model results include customized maps that show areas that fit user-specified screening factors and criteria with different suitability levels (Figure ES-5). These suitability levels for clean energy resource development are illustrated in the maps using a gradation of colors. For example, the areas with highest suitability for solar PV development are shown in red, while those with the lowest suitability are shown in black.
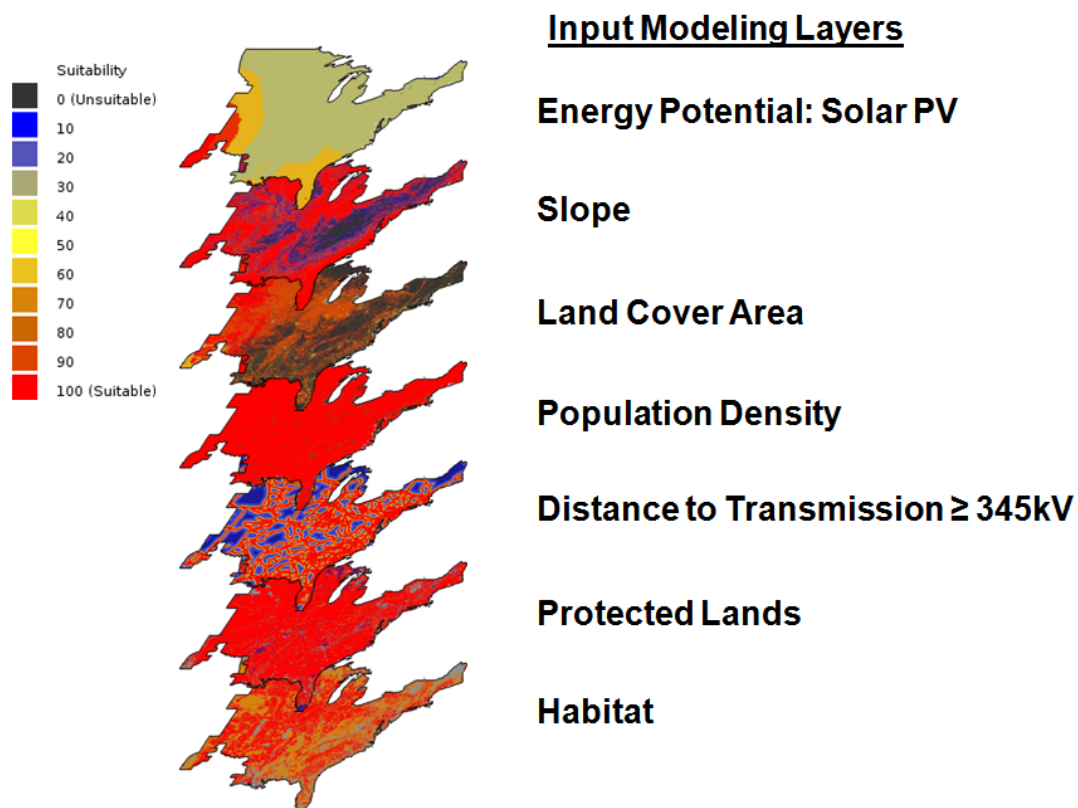
Figure ES-4   Sample Input Layers and Screening Criteria for Utility-Scale Solar PV Modeling
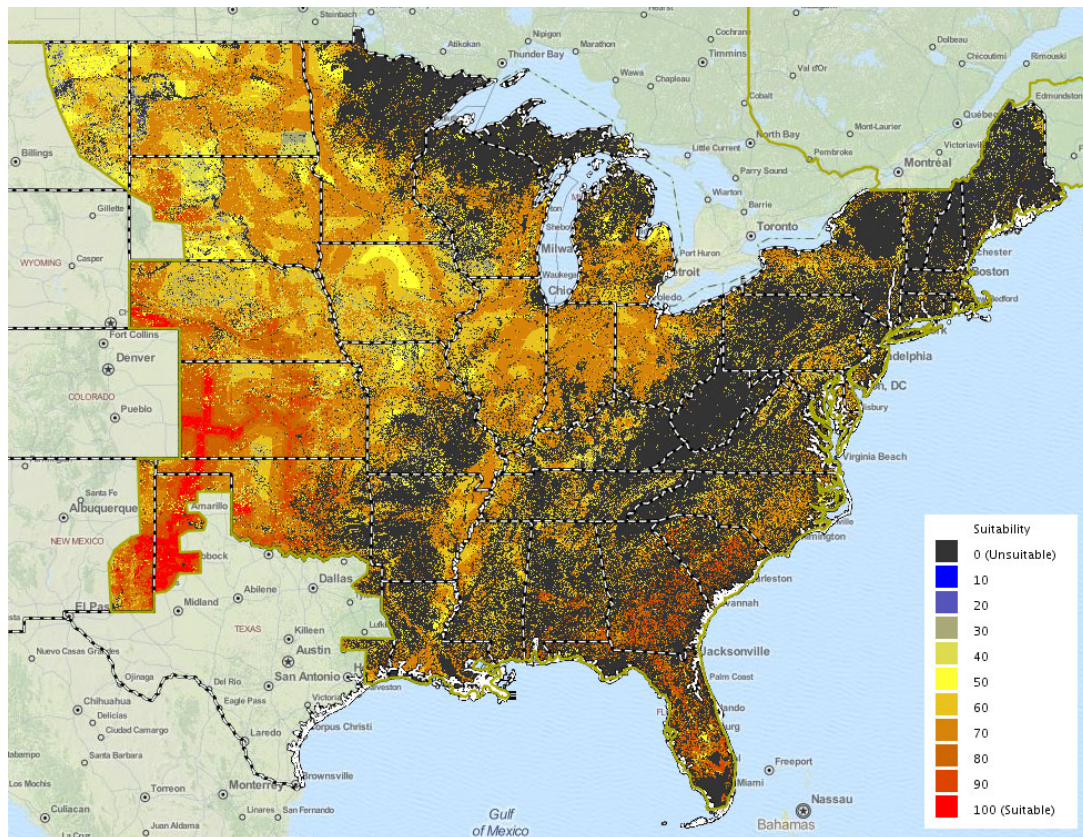
Figure ES-5 Draft Suitability Map for Solar PV Technology

Reports

In addition to customized suitability maps, the EZ Mapping Tool includes custom reporting capabilities for technologies that do not have suitability models. Several of the technologies included in the EZ Study are associated with either specific existing facilities, or are new technologies in early stages of development and/or deployment and lacked sufficient data for meaningful suitability models to be developed. The analysis approach for these technologies was therefore based on existing studies and plant or resource inventories rather than suitability modeling.

Reports can be run for an analysis area drawn on the map by the user or for a state or county of interest. The reports provide useful information pertaining to the technology that can help guide EZ planning. Figure ES-6 provides an example report for wave energy potential in the state of Maine.

Reports can also be run to obtain other information of interest in the process of identifying potential clean energy zones. Figure ES-7 provides an example of a report on protected lands for Livingston County in Illinois and surrounding areas.

Wave Energy Report

Location Analyzed: Maine

The area of interest is located at **45° 23' 21.874, 69° 14' 3.409.**
It covers some or all of **Androscoggin, Aroostook, Cumberland, Franklin, Hancock, Kennebec, Knox, Lincoln, Oxford, Penobscot, Piscataquis, Sagadahoc, Somerset, Waldo, Washington,** and **York** in Maine and **Carroll, Coos,** and **Strafford** in **New Hampshire.**
It has an area of **32161.176 square miles** with surrounding buffers of areas **55954.438** and **82077.749 square miles.**

Water Depth (m)

Minimum	Maximum	Mean
1.0	60.8	11.2

Source: National Renewable Energy Laboratory; et al (Wave Energy - Power Density).

Wave Energy
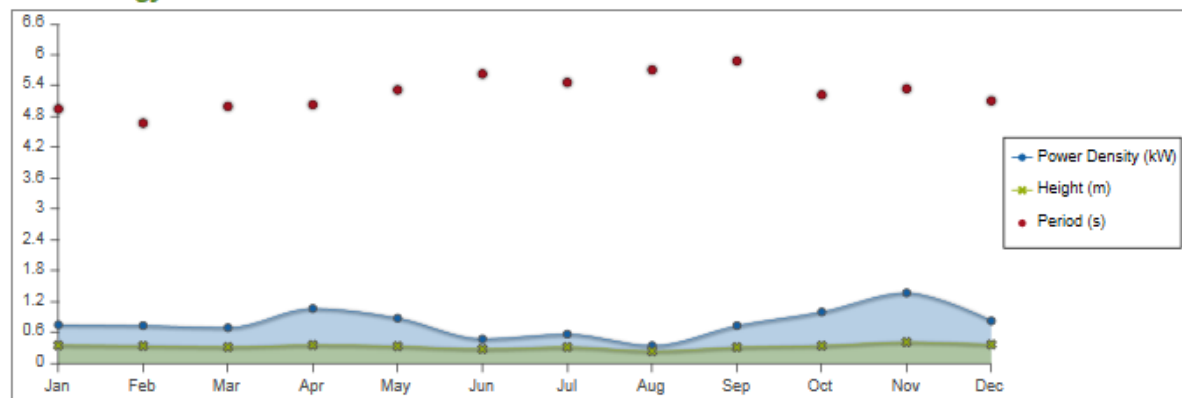
	Period[1] (sec)	Power Density[2] (kW)	Height[3] (m)	Hindcast Direction[4] (deg)
Annual	5.193	0.781	0.326	175.00
January	4.950	0.748	0.351	206.80
February	4.673	0.733	0.340	223.40
March	4.997	0.693	0.317	206.40
April	5.031	1.067	0.357	165.20
May	5.320	0.879	0.333	155.80
June	5.630	0.474	0.279	143.80
July	5.464	0.567	0.318	142.60
August	5.710	0.343	0.236	131.40
September	5.882	0.733	0.314	150.60
October	5.223	1.000	0.343	177.40
November	5.340	1.371	0.414	182.00
December	5.107	0.826	0.366	212.40

Figure ES-6 Sample Wave Energy Report

EISPC EZ Mapping Tool

Protected Lands Report

Location Analyzed: Livingston, Illinois

The area of interest is located at **40° 53' 44.101, 88° 33' 48.543**.
It covers some or all of **Ford, Grundy, Kankakee, La Salle, Livingston, McLean,** and **Woodford** in **Illinois**.
It has an area of **1055.694 square miles** with surrounding buffers of areas **6390.799** and **15567.503 square miles**.

Mapping Color*	Recommendation
Red	Exclude from development
Orange	Develop with extreme caution
Yellow	Develop with caution

*Locations having three or more data sources with yellow classifications are reclassified as orange for modeling, but are listed individually as yellow in this report.

Protected Areas Database

Primary Designation Name	Owner Name	IUCN Category	GAP Status	Exists inside Analysis Area	Exists within 25 Miles of Analysis Area	Exists within 50 Miles of Analysis Area
Kankakee River	Other State	V - Protected landscape/seascape	3 - Permanent Protection: Subject to extractive (e.g. mining or logging) or OHV use		✔	✔
Barnhart Prairie Restoration	Private Conservation	IV - Habitat or species management area	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Monticello's Sangamon River Land And Water Reserve	Private Conservation	V - Protected landscape/seascape	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Robert Allerton Park	Private Conservation	V - Protected landscape/seascape	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Robert Allerton Park	Private Conservation	V - Protected landscape/seascape	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Robert Allerton Park	Private Conservation	V - Protected landscape/seascape	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Weldon Springs	Other State	Unassigned	3 - Permanent Protection: Subject to extractive (e.g. mining or logging) or OHV use			✔
Lodge Park	Private Conservation	V - Protected landscape/seascape	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Lodge Park	Private Conservation	V - Protected landscape/seascape	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Robert Allerton Park	Private Conservation	V - Protected landscape/seascape	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Robert Allerton Park	Private Conservation	V - Protected landscape/seascape	1 - Permanent Protection: Ecological disturbance events allowed to proceed			✔
Monticello's Sangamon	Private	V - Protected	1 - Permanent Protection:			✔

Figure ES-7 Sample Protected Lands Report

Synergy Analysis

The main objective of synergy analysis is to integrate the results of multiple "single-resource" analyses and to produce a map showing the resulting concentrations, or clustering, of selected clean energy resources. In this process, the suitability maps developed during the single-resource analysis are used to develop a composite image showing the resulting areas suitable for the joint development of multiple energy technologies. The resulting map provides visual information of highly suitable areas which could be considered for further analysis. Figure ES-8 illustrates a composite map for land-based wind and solar PV resources.

On the basis of model results, data visualization, and the user's own knowledge of energy planning, the user may examine an area of specific interest for possible development of a clean energy zone. First, the analysis will include examining potential co-location compatibility of different energy technologies within the selected area, mainly with regard to the land use (e.g., wind and biomass could be co-located using the same land area). Next, other potential compatibility or competing issues need to be identified, especially if two or more technologies are competing for the same resource (e.g., cooling water needs). Lastly, the potential impacts of non-zonal technologies should be considered, such as the smart grid, energy efficiency, and
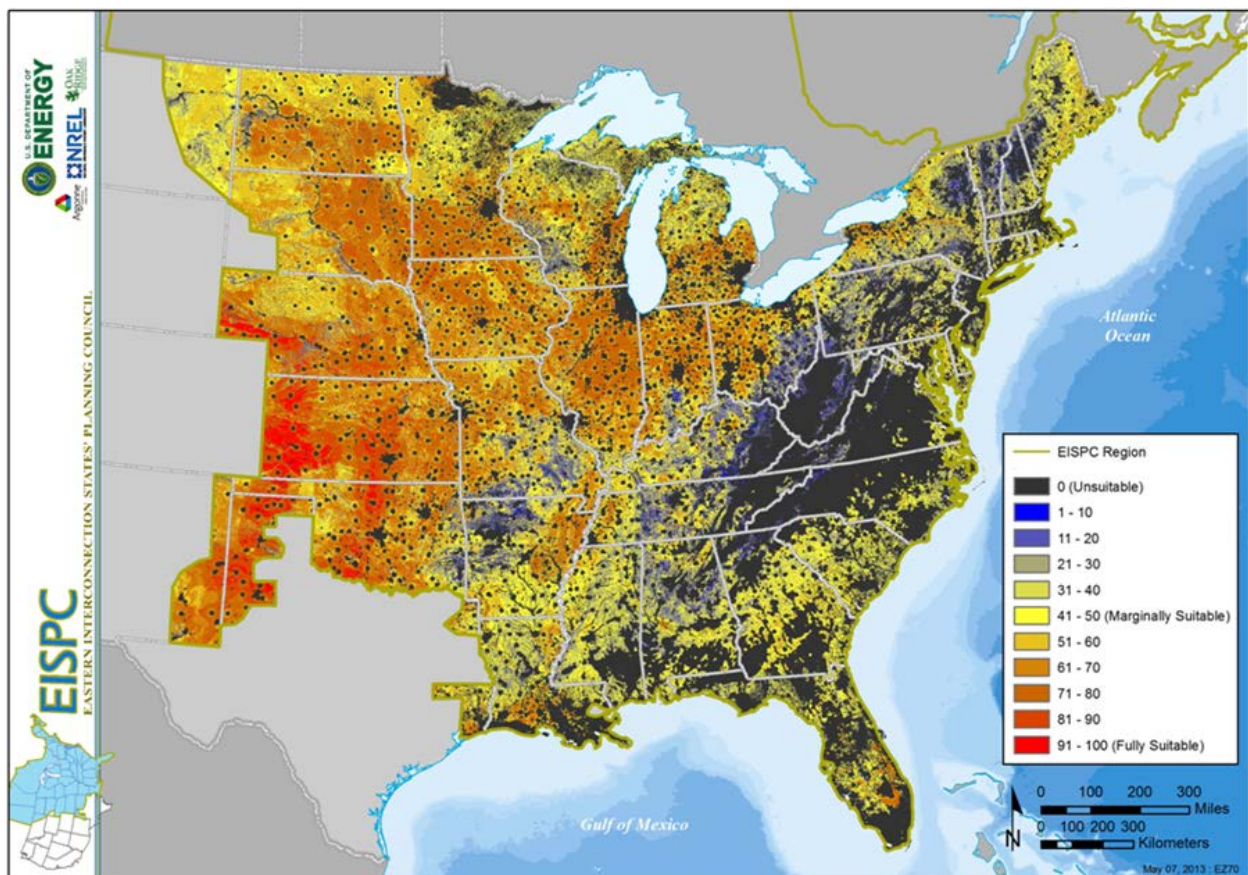
Figure ES-8 Synergy Results of Equally Weighted Solar PV and 80-m Land-Based Wind Models

demand response. In some cases, these non-zonal technologies may provide some positive synergies and enable wider penetration of certain clean energy resources (e.g., smart grid technology may support and accelerate the growth of rooftop solar generation).

Reviewing model results and analytical reports for the analysis area will provide information for which parts of the selected area of interest are most favorable for the development of multiple clean energy resources. This information may serve to identify potential clean energy zones that can support multiple co-existing technologies.

Energy Policy and Regulations Database

Finally, the user can check relevant energy policies and regulations pertaining to the area of interest for clean energy resource development. These energy policies may either promote or inhibit the development of certain energy technologies and resources.

The EZ Mapping Tool contains a database with a large inventory of laws, regulations, incentives, and other policies in the EISPC states related to clean energy electricity generation (Figure ES-9). The policies and regulations database was developed by the Clean Energy States Alliance (CESA). It connects to and incorporates other online databases through NREL's Open Energy Information (Open EI). The EZ Mapping Tool incorporates the database with a tab in the main navigation bar that allows the user to search for the policies and regulations by any combination of four main query boxes: political entity, policy type, implementation sector, and affected technologies. The search results are provided and include state-level summaries of the applicable policies.

Figure ES-9 Policy and Regulations Database

Environmental Considerations

Environmental data layers and information have been fully incorporated into the EZ Mapping Tool's methodology and process for identifying potential clean energy zones, and environmental screening factors are included in each suitability model.

Environmental screening factors were grouped into three model input layers: Protected Lands, Habitat, and Imperiled Species, and categorized with sensitivity levels related to energy development. The protected lands and habitat environmental screening layers are composites made from many individual datasets. Selection of the included layers and determination of sensitivity levels were guided by an Environmental Focus Group (EFG). The EFG included subject matter experts from federal and state agencies, environmental non-governmental organizations (NGOs), and industry stakeholders.

Conclusions

The EZ Mapping Tool provides an extensive library of energy resource data and other relevant information useful for identifying potential areas suitable for clean energy resource development. It also includes interactive suitability models, a variety of reports that can be run and customized for user-specified regions, and a searchable energy policy and regulations database. The EZ Mapping Tool provides the user with a very flexible and well-documented web-based decision support system developed with open-source programming libraries, highly scalable cloud architecture for the server, a form-based administrative interface for maintaining the content, and flexible user interfaces for the GIS map layer library, models, and reports. The EZ Mapping Tool was publicly launched at the end of March 2013 and is already being accessed by a large number (more than 600 as of August 2013) of federal and state energy planners, NGOs, grid operators, energy industry professionals, and researchers.

1 Introduction

This section provides the background, goals and objectives, scope, and approach of the Energy Zones (EZ) Study and describes the organization of the report.

1.1 Background

The Eastern Interconnection States' Planning Council (EISPC) EZ Study included an investigation of nine types of energy resources to be considered for development of clean energy generation facilities in the U.S. portion of the Eastern Interconnection (Figure 1-1). These energy resource types are (1) biomass, (2) clean coal technologies with carbon capture and sequestration (CCS), (3) geothermal, (4) natural gas, (5) nuclear, (6) solar (photovoltaic [PV] and concentrated solar thermal, as well as rooftop PV), (7) storage (pumped storage hydro and compressed-air energy storage [CAES]), (8) water (hydrokinetic and tidal power), and (9) wind (both land-based and offshore). For each of these major categories, the resource data and information have been compiled, reviewed, and assembled into a geographic information system (GIS) database. The information in the database is accessible in a web-based EISPC Energy Zones Mapping Tool (EZ Mapping Tool) that is available at http://eispctools.anl.gov. The EISPC EZ Mapping Tool will allow stakeholders to identify potentially suitable areas for developing clean energy resources or to determine potential clean energy zones. Because an energy resource category may comprise multiple technologies for electricity generation that utilize different types of energy inputs, the database also includes a total of 29 clean energy technologies (Table 1-1).

The EZ Mapping Tool incorporates numerous models for which the user can specify custom screening factors. Many of these screening factors represent terrain, land use, or other location-based characteristics that could affect whether areas can be developed, regardless of whether the energy resource itself is productive enough to be economical. When the screening factors are combined with energy resource data (map layers showing the locational productivity of wind, solar energy, or other resources) in the models, maps of suitable areas are provided.

The "suitability" metric from these models combines the locational quality of the energy resource itself with locational factors that could limit development. Having selected an area based on its overall suitability, the user may then look more closely at the separate factors that affect whether development would be economical. Suitability scores generated by the models in the EZ Mapping Tool range from 0 (unsuitable) to 100 (best suitability) and are dependent on the quality and accuracy of the input data, the user's choices about how to weight the importance of different parameters, and input suitability scores within each layer. They are intended to provide a regional screening-level analysis to compare locations with respect to the same technology. The models have not been calibrated to the level that suitability scores can be quantitatively compared across different technologies.

This EISPC EZ Study was a collaboration of three National Laboratories. Study team members from Argonne National Laboratory (Argonne), the National Renewable Energy Laboratory (NREL), and Oak Ridge National Laboratory (ORNL) provided analytical and model development support to the EISPC.
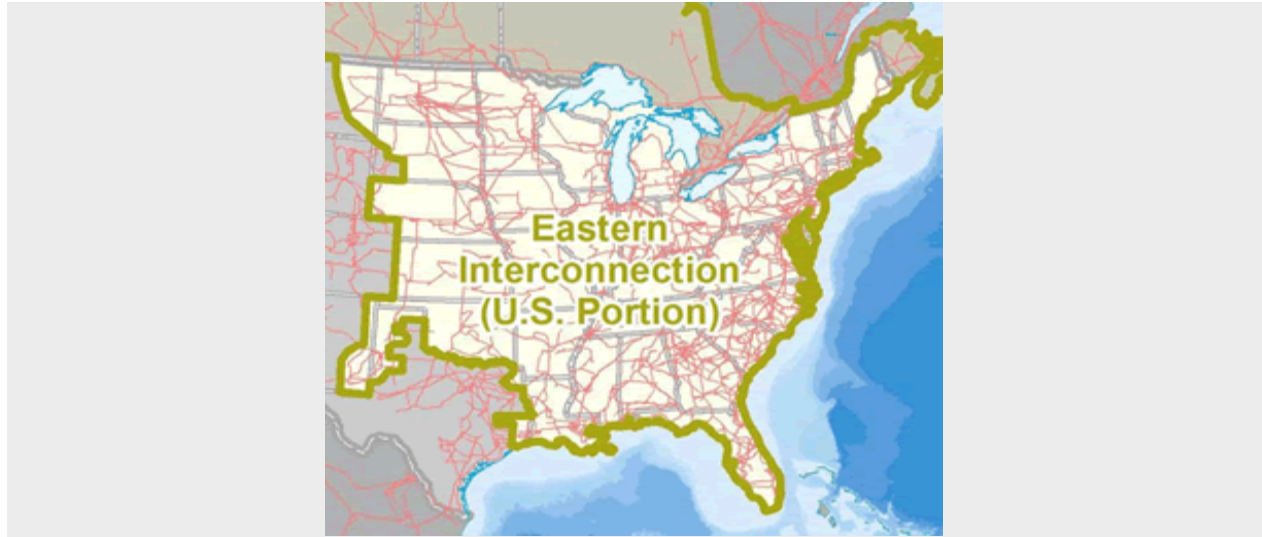
Figure 1-1 U.S. Portion of the Eastern Interconnection (Source: Argonne National Laboratory)

Table 1-1 Clean Energy Resources and Technologies

Resource	Technology
Biomass	New biomass-fired plant with traditional combustion Biomass co-fired with existing coal plant Landfill gas extraction and plant inventory Methane extraction from wastewater treatment Methane extraction from animal manure processing
Clean Coal (with CCS)	New clean pulverized coal (PC) technology (subcritical and supercritical technologies) New integrated gasification combined cycle (IGCC) New coal fluidized bed (CFB) Retrofitting of existing pulverized coal (PC) with clean coal technology
Geothermal	Enhanced geothermal systems (EGS) Geopressured geothermal
Natural Gas	Combined cycle Underground natural gas storage Aboveground natural gas storage
Nuclear	Large light-water reactor Small modular reactor, integral pressurized-water reactor High-temperature gas-cooled reactor (HTGR)/very high temperature gas-cooled reactor (VHTR)
Solar	Concentrating solar power (CSP) Utility-scale photovoltaic (PV) Rooftop PV
Storage	Pumped storage hydroelectric (PSH) Compressed-air energy storage (CAES)
Water	Added output from existing hydropower dams New output from existing non-powered dams River and tidal hydrokinetic energy Marine tidal hydrokinetic energy Wave energy
Wind	Land-based wind turbines Offshore wind turbines

1.2 Goals and Objectives

The Laboratories supported EISPC in addressing the following EZ Study goals and objectives:

- To provide information to identify (in map form) and to inventory opportunities for developing resources in all states and regions in the Eastern Interconnection that could potentially be used to support the development of energy facilities defined by the EISPC Energy Zones Work Group. Also, to develop a suite of methodologies that lays out the process for identifying EZs that support public policy objectives;

- To provide information to regions and states regarding circumstances (e.g., environmental factors, population densities) that could inhibit or prevent the potential development of energy infrastructure within areas containing identified energy resources and offer potential solutions;

- To enable the states to inform and collaborate in stakeholder generation and transmission planning within the time frames of the other EISPC modeling efforts, which is generally to 2030. Also, to include technologies and resources developed on both a long- and short-term basis; and

- To focus analysis on identifying resource areas in the Eastern Interconnection that have sufficient energy resources in concentrated areas. Depending on their locations in relation to load centers, such concentrated energy resource areas could potentially be developed to either avoid the need for transmission construction or to optimize transmission planning.

The Laboratories provided EISPC with a decision support tool that facilitates regional collaboration among states for planning future generation and transmission expansion, so that these states can achieve their energy policy objectives in the most efficient manner.

1.3 Scope

The scope of this study includes the U.S. portion of the Eastern Interconnection as described in Section 1.1. It also includes analysis of generation and storage technologies identified by EISPC and capable of grid-level power production. The study does not include analysis of distributed resources that generate electricity from many small energy sources, with the exception of rooftop photovoltaic.

1.4 Approach

The analysis approach and the EISPC EZ Mapping Tool enable stakeholders to identify, on a map, clean energy resource areas in the U.S. portion of the Eastern Interconnection that could potentially be developed as EZs. The EZs are not predefined in the study or the EZ Mapping Tool.

The EZ Mapping Tool will enable EISPC stakeholders to perform analyses and identify clean energy resource areas for potential generation development within the entire Eastern Interconnection or their state or region of interest. To perform this analysis, the web-based tool will allow EISPC stakeholders to use energy resource availability, flexible screening parameters, and other user-defined criteria to develop customized maps depicting the suitability of different areas within the Eastern Interconnection for clean energy resource development. The stakeholders will be able to perform custom-analysis for a single clean energy resource or for two or more energy resources by taking possible synergies among the resources into account. The synergy analysis will highlight areas suitable for more than one technology of interest and consider both positive synergies, where energy projects would complement each other, and negative synergies, where energy projects would compete with each other.

The EZ Mapping Tool may assist transmission planners by providing information on the areas within the Eastern Interconnection where a significant potential for new power generation exists, thus potentially requiring new transmission lines (or upgrades of existing ones) for transferring that power to electricity demand centers. For this purpose, the EZ Mapping Tool also includes a screening capability of potential future energy corridors. Just as the EZ Mapping Tool is designed for identifying potential geographical areas suitable for clean energy resource development and power generation and not for the siting of individual power plants, the corridor screening capability is designed for analyzing potential energy corridors and not for the siting of specific transmission lines or gas and oil pipelines. The corridor screening tool provides the capability to generate custom reports for potential energy corridors defined by the user. The report provides mileposted information along the corridor, including the states, counties, populated places it overlaps; major road, railroad, transmission line, pipeline, stream, and water body crossings; and other factors meaningful for corridor analysis. Reports can also be generated to examine environmental information for corridors, such as protected lands, sensitive habitats, and imperiled species.

1.5 Report Organization

The remainder of the report includes the following sections: Section 2, Methodology and Process for Identifying Clean Energy Resource Areas, which describes the general suitability modeling approach for identifying clean energy resource areas; Section 3, Clean Resource/Technology Options, which discusses the resources and technologies included in the study and possible synergistic effects of the technologies; Section 4, Environmental Considerations, which discusses the environmental screening layers included in the study; Section 5, Policy, Demand Response, and Smart Grid Considerations, which discusses their role in determining areas for potential EZs; Section 6, EISPC EZ Mapping Tool Overview and Tutorial, which describes the EZ Mapping Tool functions; Section 7, Case Studies and Interpreting Results, which describes the EZ Mapping Tool capabilities and how the tool can be utilized; Section 8, Recommendations for Future Work, which describes possible follow-up activities to this project; and Section 9, Bibliography. Appendices A, B, C, D, and E follow Section 9.

2 Methodology and Process for Identifying Clean Energy Resource Areas

2.1 Modeling Approach

Figure 2-1 illustrates the general modeling approach for identifying clean energy resource areas. The energy resources are grouped into several categories related to the main type of their constraints. The first group includes resources with energy potential primarily dependent on geographical location. These resource types include wind, solar, geothermal, biomass, and water (hydroelectric potential). The second group represents resources with energy potential primarily dependent on siting-related constraints—an example being nuclear technologies which have transportable fuel but are heavily dominated by other siting constraints, and natural gas technologies which are dominated by the proximity of existing large-diameter natural gas lines. The siting of energy storage facilities, such as CAES, is dominated by siting factors which require the existence of favorable geological formations for the economical construction of these facilities. Specifically, CAES plants typically need large air-tight underground caverns to store air under high pressure. Finally, clean coal technologies are positioned between nuclear and storage technologies because, similar to the nuclear technologies, they have transportable fuel, but are geologically constrained like CAES energy storage because they require underground caverns to store the carbon dioxide (CO_2) captured during plant operation. Suitability maps for individual energy resources can then be combined to identify locations suitable for multiple resources, and then analyzed in terms of the ways technologies exploiting the resources might compete with or complement each other.
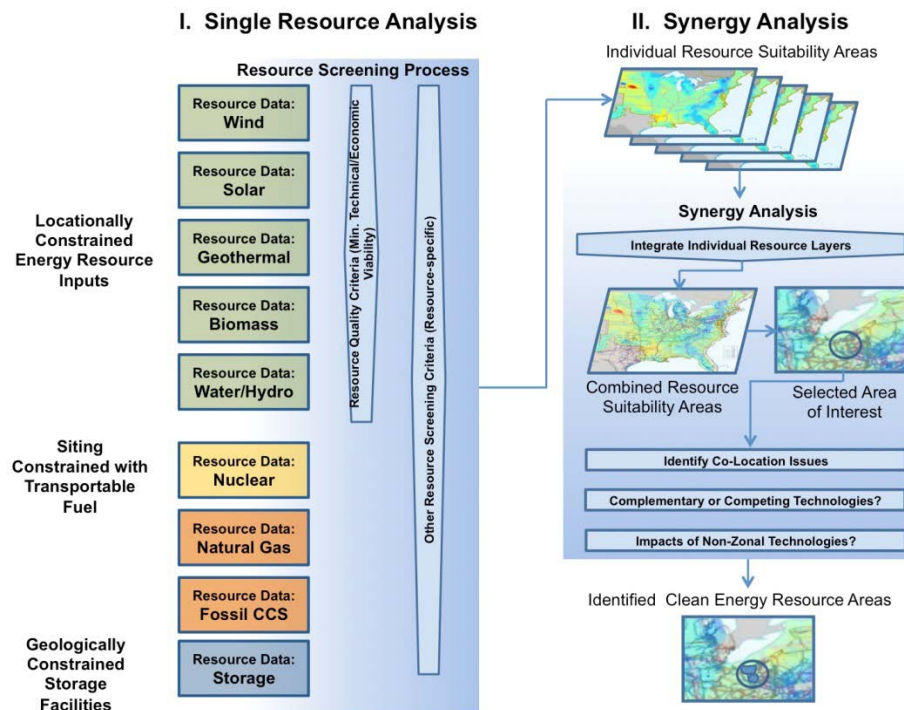
Figure 2-1 Methodology and Process for Identifying Clean Energy Resource Areas Using Single-Resource Analysis (I) and a Synergy Analysis (II)

For each major technology category shown in Figure 2-1, the resource data and information were compiled, reviewed, and assembled into a GIS database. The information in the database is accessed by a web-based tool that allows the stakeholders to identify areas suitable for developing clean energy resources. The analysis can be performed either for a specific clean energy resource (single-resource analysis) or for a combination of two or more energy resources or technologies (synergy analysis). The methodology for identifying single-resource areas involves the following major steps:

I. **Single-Resource Analysis**
    a. Select a clean energy resource of interest by choosing a model from the model catalog.
    b. Review the default layers in the model and add additional layers from the modeling layers catalog if required. Layers may also be removed if desired.
    c. Modify the importance of each layer present in the model by adjusting its weight.
    d. Modify the individual suitability of each feature within a layer.
    e. Run model and add model results to the map.
    f. If desired, add additional overlay layers such as energy infrastructure layers to provide visual information on how well the resulting energy resource areas are supported by the existing (and projected future) energy infrastructure facilities (e.g., transmission system, railroad network).
    g. Input area(s) of interest for a potential clean EZ development and further analysis. The area considered is expected to be a smaller geographical area, typically a state or part of a state. In addition, a geographical area with sufficient energy generation potential to justify a new transmission line could be of interest as an analysis area.
    h. Choose reporting options to run on the analysis area.
    i. Check relevant energy policies and laws for statutory and regulatory issues (e.g., land use exclusions or other policies and laws providing incentives or disincentives for the development of certain clean energy resources).
    j. Print or save the results of the analysis.

II. **Synergy Analysis**
    a. Perform single-resource analyses for selected clean energy resources.
    b. Develop a customized map by combining the suitability area maps for selected clean energy resources. This user-developed customized map will provide visual information regarding the concentration (or clustering) of different clean energy resources and indicate potential high-energy density areas which could be developed into clean EZs.
    c. Input area(s) of interest for a potential clean EZ development and further analysis. The area considered is expected to be a smaller geographical area, typically a state or part of a state.
    d. Identify potential co-location compatibility of different technologies within the selected area.
    e. Identify possible impacts of complementary or competing technologies.
    f. Identify potential impacts of non-zonal resources and technologies (e.g., demand response, energy efficiency, and smart grid).

g. Print or save the results of the analysis.

More details on each of the process steps are provided in Sections 2.3 and 2.4.

2.1.1 Methodology for Analysis of Rooftop PV

The methodology for mapping the resource potential of rooftop PV is different from that for the other resources included in this analysis. First, the location of rooftop solar resource areas is not the main concern because location is primarily a function of known factors such as urban space and building density. Second, the ability of rooftop solar to offset demand within a high-load area is unique among the resources analyzed. Transmission is unnecessary to deliver the rooftop PV generated electricity to a load center, but more significantly, a high penetration of rooftop solar can change the peak load within a control area (or within a transmission-congested part of the control area). This in turn could affect planning for transmission to deliver power to the area. The questions most pertinent to this project, therefore, have to do with the characteristics of rooftop PV at known population centers. Figure 2-2 illustrates the approach for the analysis of rooftop solar PV and its load offset potential.

Mapping rooftop PV potential combines two analytical threads: population and buildings stock (residential, commercial, and industrial), and the amount of sunshine the area has during a typical year. This analysis relies on recent estimates of the building stock rooftop area that is potentially available for solar PV, aggregated by county. The data used for this are from NREL.

Not all of the rooftop surface can be utilized for solar PV, however. Out of what can be used, owners often choose to install less PV than the roof can actually accommodate. Most rooftop PV is sized commensurate with the amount of electricity consumed within the building where it is installed. Surplus power may flow to the grid during clear midday hours, but over a typical day or year, the net surplus fed back into the electric system is usually small. In addition, the level of rooftop solar market penetration may be affected by policies such as the availability of net metering, rebates, feed-in tariffs, and potential smart grid technologies in the future.

The results generated by the rooftop PV model are presented in report format. The user determines the geographic extent for the results by using an analysis area drawn on the map or
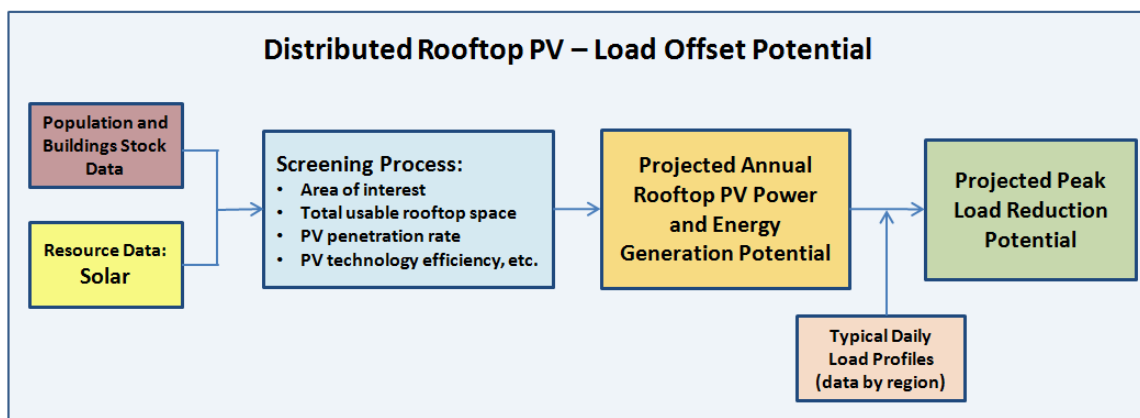
Figure 2-2 Methodology for Identifying Rooftop Solar PV Resource Potential

by choosing a pre-existing boundary such as a county or state. Pre-computed results of the model are then summarized in the report, by county, including different efficiency levels based on current and future panel efficiency and on the inverter efficiency to transform direct current (DC) power to alternating current (AC).

Annual insolation during a typical year in the area selected for analysis is also used for the calculations. The annual energy estimates draw on NREL's data for solar resource potential. This particular dataset assumes that PV panels are installed facing south and tilted at an angle equal to the latitude of the site. Rooftop availability data are from work conducted at ORNL.
The report includes:

- Rooftop PV power potential (megawatt [MW] capacity),

- Peak load reduction potential (MW contribution to peak), and

- Annual energy generation (megawatt hours per year [MWh/yr]).

The methodology for this task is not intended to evaluate the solar capabilities of a specific site. Rather, its purpose is to estimate load reduction from rooftop PV generation across a larger jurisdiction, aggregated on a per-county level.

2.2 GIS-Based Multi-Criteria Decision Support System (EZ Mapping Tool)

A web-based mapping tool (EZ Mapping Tool) was developed during the project as part of this EZ Study. This web-based tool is a GIS-based, Multi-Criteria Decision Support System (MCDSS), with a set of operation options to guide the analysis. The analytical process involves a number of steps which may also be customized by the user depending on the type of clean energy resource being analyzed, the area of interest, and other user-specified parameters. This will allow for an analysis that can be tailored to the specific needs of each user and will result in customized maps of areas suitable for clean energy resource development. The MCDSS methodology and the EISPC EZ Mapping Tool are not intended to provide the means for a detailed siting analysis of any specific clean energy project. Rather, the intention is to enable stakeholders to identify clean energy resource areas that could have the potential to be developed as EZs in a map form.

2.3 Single-Resource Analysis

To identify areas suitable for the development of a specific clean energy technology, the user can perform a screening process using the web-based EISPC EZ Mapping Tool (Figure 2-3). Starting with the energy resource a user can, in order to focus only on areas which satisfy certain economic or technical criteria, define which thresholds of the resource are suitable for the technology of interest. Other screening criteria are then applied to filter out areas unsuitable for resource development because of land use, ecological, and other constraints. For example, these types of criteria might exclude areas with high topographic slope, high population density, protected lands such as national and state parks, and sensitive habitat areas. Then, a customized map is computed using a geometric mean calculation based on the layers selected and layer
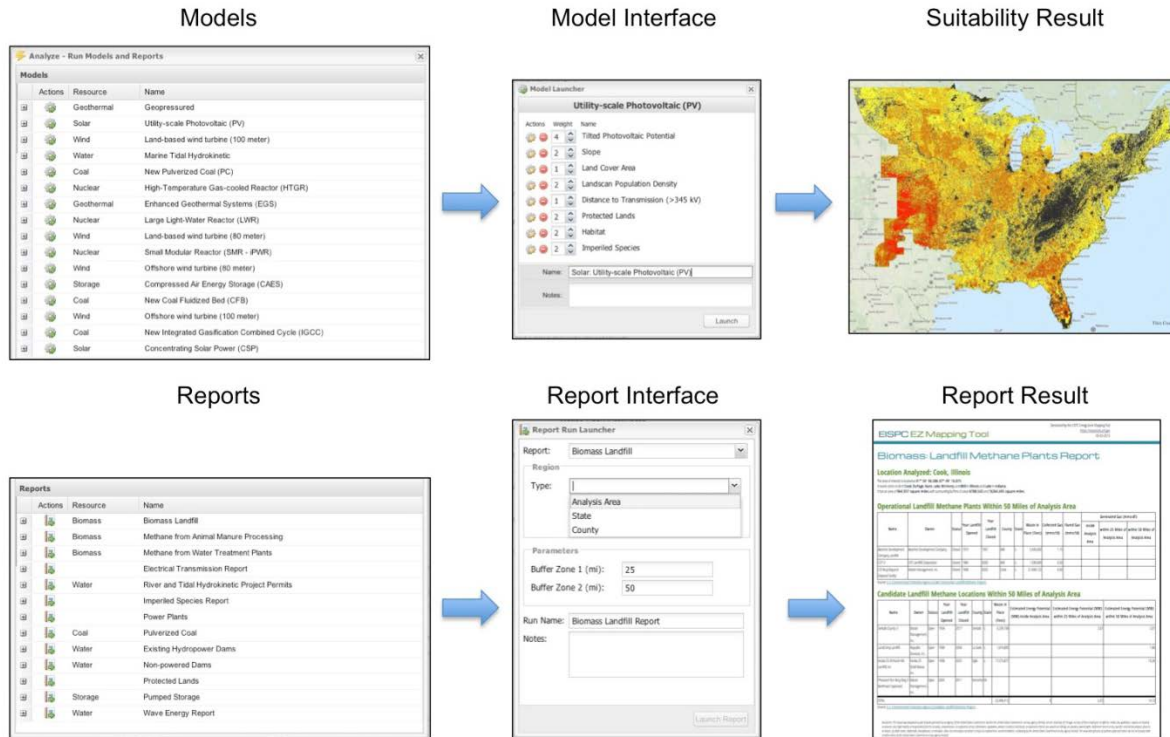
Figure 2-3 General Methodology for a Single-Resource Analysis Model (top) and Report (bottom)

parameters. Figure 2-4 provides an example of sample input mapping layers for the utility-scale PV model. The resulting suitability map is depicted as a range of high to low suitability levels to highlight the areas most suitable for developing the selected clean energy resource. These suitability levels for clean energy resource development are illustrated in the maps using a gradation of colors. For example, the areas with highest suitability for solar PV development are shown in red, while those with the lowest suitability are shown in black.

Maps of energy infrastructure facilities (e.g., transmission grid, pipeline network) can be superimposed on the model results to show the proximity of the energy infrastructure to high-suitability areas.

2.3.1 Single-Resource Suitability Modeling

Single-resource analysis begins with the selection of one of the technologies listed in Figure 2-5. For most of these technologies, the system will then display a dialog similar to the one in Figure 2-6, which shows an example of a land-based wind turbine (100–meter [m]) model. The dialog will default to predetermined energy resource and screening layers, with predetermined suitability levels; however, users have the ability to add or remove screening layers, adjust the weights for the layers, and edit the suitability values within particular layers. For the energy resource, a minimum threshold level can be specified, such as the following examples:
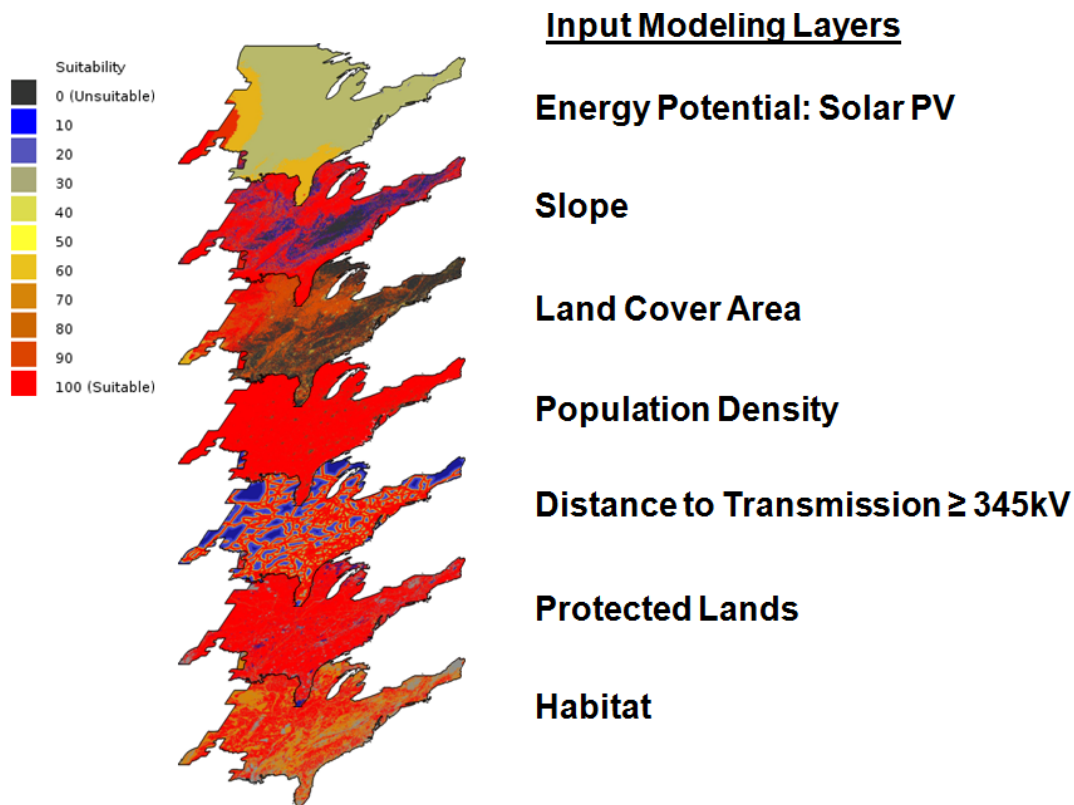
Figure 2-4 Sample Input Layers for Utility-Scale Solar PV Modeling

- Land-based wind turbine: wind gross capacity factor ≥ 30% at turbine height of 80 or 100 m,

- Concentrating solar: > 5.0 kilowatt hours per square meter per day ($kWh/m^2/day$) annual average direct normal solar resource, or

- Enhanced geothermal: Favorability class ≥ Medium (on a scale with 5 levels).

See Appendix A for additional details about screening factors.

For biomass technologies, there are many potential fuel sources, and the U.S. Department of Energy (DOE) Billion-Ton Study database used in the project includes annual estimates from the present to 2030, which allows the user to choose the fuel sources and year of interest.

The interface allows the exclusion criteria for each screening layer to be adjusted. Figure 2-7 shows an example window for adjusting the suitability of each resource interval (left) and a non-resource layer (right), which uses categorical intervals. For some layers, the user may specify a specific threshold value that will delineate clearly suitable and non-suitable areas, while other layers may have gradations of suitability. Screening layers can be removed from the model by clicking an icon next to the layer, and layers may also be added from the modeling layer catalog if desired.

	Actions	Resource ▲	Name
⊞	⚙	Biomass	New Biomass-fired Plant with Traditional Combustion
⊞	⚙	Biomass	Biomass Co-Fire With Existing Coal Plant
⊞	⚙	Coal	New Pulverized Coal (PC)
⊞	⚙	Coal	New Coal Fluidized Bed (CFB)
⊞	⚙	Coal	New Integrated Gasification Combined Cycle (IGCC)
⊞	⚙	Geothermal	Geopressured
⊞	⚙	Geothermal	Enhanced Geothermal Systems (EGS)
⊞	⚙	Natural Gas	New Combined-Cycle Gas Turbine (CCGT)
⊞	⚙	Nuclear	High-Temperature Gas-cooled Reactor (HTGR)
⊞	⚙	Nuclear	Large Light-Water Reactor (LWR)
⊞	⚙	Nuclear	Small Modular Reactor (SMR - iPWR)
⊞	⚙	Solar	Utility-scale Photovoltaic (PV)
⊞	⚙	Solar	Concentrating Solar Power (CSP)
⊞	⚙	Storage	Compressed Air Energy Storage (CAES)
⊞	⚙	Water	Marine Tidal Hydrokinetic
⊞	⚙	Wind	Land-based wind turbine (100 meter)
⊞	⚙	Wind	Land-based wind turbine (80 meter)
⊞	⚙	Wind	Offshore wind turbine (80 meter)
⊞	⚙	Wind	Offshore wind turbine (100 meter)

Figure 2-5 Resource Technology Model Options

Model Launcher

Land-based wind turbine (100 meter)

Actions	Weight	Name
⚙ ⊖	5	Wind Turbine Gross Capacity Factor (100m)
⚙ ⊖	2	Slope
⚙ ⊖	2	Land Cover Area
⚙ ⊖	1	Population Density (with 2 mile buffer)
⚙ ⊖	1	Distance to Major Road
⚙ ⊖	2	Distance to Airport Runway
⚙ ⊖	3	Distance to Transmission (>345 kV)
⚙ ⊖	3	Protected Lands
⚙ ⊖	2	Habitat
⚙ ⊖	3	Imperiled Species

Name: Wind: Land-based wind turbine (100 meter)

Notes:

Launch

Figure 2-6 User Interface for Land-Based Wind Turbine (100 m) Model

Figure 2-7 Suitability Adjustment Window for an Interval-Based Resource Layer (left) and Categorical Screening Layer (right)

When the screening layers, weights, and parameters have been set, the user can run the model. All settings and customizations are saved for retrieval and possible modification later. The model computes a composite suitability value for each of the 250-m × 250-m cells in the EISPC region using a geometric mean operation and the user-specified settings. The result is a suitability map with values ranging from 0 to 100. Values of no suitability will occur when one or more input layers have a suitability value of 0 defined. Values of 100 represent the highest suitability. Suitability values under 50 are considered to be below the minimum level necessary for an EZ to be viable. The model results are displayed on the map with a gradational color scheme. Model output maps function as any other layer in the mapping tool, including zooming in and out, adjusting transparency, and retrieving a cell's value with the information tool. The screening layers and any other layer in the EISPC catalog can be superimposed over the model results to examine the contributing factors for high- or low-suitability areas, or to look up other contextual information on the feature. Two methods exist for this; adding the actual modeling layer that the model uses from the "model layer catalog," or adding the raw data from the "map layer catalog."

2.3.2 Modeling Resources with Specific Existing Facilities

Several of the technologies included in the project are associated with specific existing facilities, or are new technologies in early stages of development and lacked sufficient available data for meaningful suitability models to be developed. The analysis approach for these technologies was therefore based on existing studies and inventories rather than suitability modeling. These technologies include:

- Methane extraction from
  - Landfills,
  - Wastewater treatment, and
  - Animal manure processing;

- Retrofitted pulverized coal (PC) with clean coal technology;

- Pumped storage hydroelectric (PSH);

- Additional power output from existing hydropower dams (NPDs);

- New output from existing non-powered dams;

- River and tidal hydrokinetic project permits; and

- Wave energy.

For these technologies, the locations of existing facilities or sites are available in the GIS database, or basic data are available about the energy resource. Reports can be run for analysis areas input on the map (Section 2.3.3) or a state or county of interest (Figure 2-8). The reports provide useful information pertaining to the technology that can help guide EZ planning.

2.3.3 Creating Analysis Areas

The Analysis Areas tool allows areas of interest to be drawn on the map for further analysis. The suggested approach is to use models to identify regions with high suitability for specific technologies and then to sketch areas on the map for further analysis. The EZ Mapping Tool

Figure 2-8 Interface for Running a Pumped Storage Hydroelectric Report

interface is shown in Figure 2-9 with a hypothetical clean energy analysis area. Clicking "New Analysis Area" will allow a new area to be sketched on the map, given a name, and added to the list. Clicking the Actions icon to "Run a Report on this Area" for an analysis area opens the Report Run Launcher shown in Figure 2-8. Additional actions include hiding the area on the map; zooming the map to the full extent of the analysis area; or renaming, editing, or deleting the analysis area. Analysis capabilities are further described in Section 2.3.5.

2.3.4 Checking Relevant Energy Policies and Laws

The EZ Mapping Tool contains an inventory database of laws, regulations, incentives, and other policies in the EISPC states related to clean energy electricity generation. The database connects to and incorporates other online databases through NREL's Open Energy Information (Open EI). The tool incorporates the database with a tab in the main navigation bar that allows the user to search for the policies and regulations by any combination of four main query boxes: political entity, policy type, implementation sector, and affected technologies. The search results are provided and include state-level summaries of the applicable policies.

Before developing the policy database, the Clean Energy States Alliance (CESA) requested input from a representative sample of more than 30 state policymakers, industry representatives, and non-governmental organization (NGO) stakeholders on what information to include in the inventory and EZ Mapping Tool and how to present it. CESA's work to populate the inventory for all of the selected technologies and the full EISPC region included compiling export market information about all of the state Renewable Portfolio Standards (RPSs) for which generation in a specific location can qualify; information that significantly impacts a project's potential revenue stream but is not published elsewhere. The inventory work included reviewing websites of individual states and provinces and compiling information on economic development policies, environmental regulations, forestry policies, and climate plans. To ensure the accuracy and
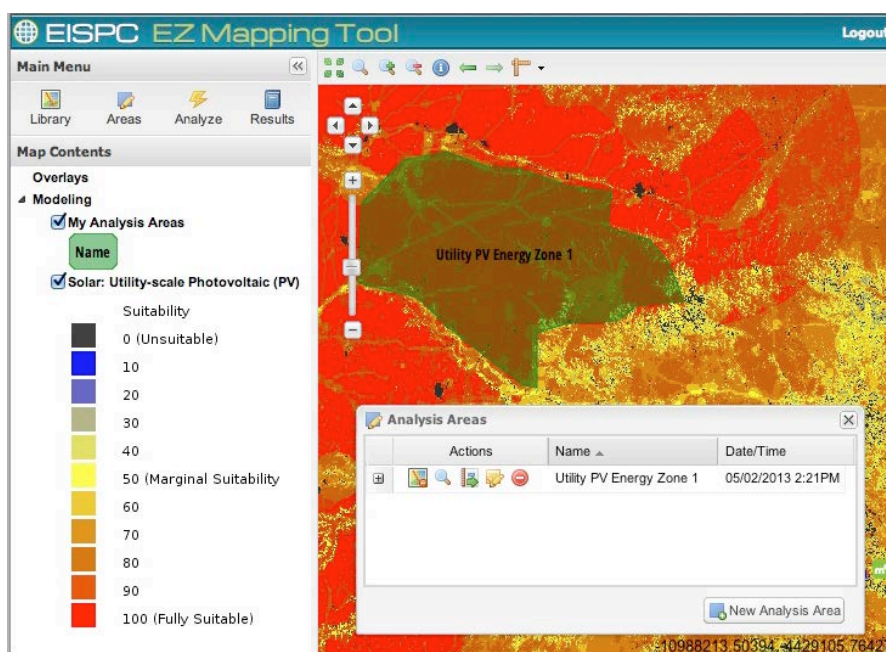
Figure 2-9 Main Dialog for Creating an Energy Zone or Analysis Area

appropriateness of the information contained in the policy inventory, CESA asked representatives of state and provincial governments to review the entries in the inventory and provide edits as necessary. Representatives of public utility commissions, renewable energy programs, and economic development agencies provided valuable information for the database. A detailed discussion of policy considerations is provided in Section 5.1.

2.3.5 Energy Infrastructure Map Overlays

The tool includes energy infrastructure layers from Platts/Bentek Energy shown in Figure 2-10. They are accessible as part of the same EZ Mapping Tool catalog as the rest of the GIS layers and are useful for evaluating the proximity of high suitability areas to existing energy infrastructure. The layers contain detailed information about the features such as transmission line voltage and pipeline diameter. This information can be accessed with the Identify tool.

A user may superimpose energy infrastructure layers over a model's suitability results by using the map layer catalog to show the available layers and clicking the Actions icon "Add this layer to the map." Metadata for each of the layers, which include detailed descriptions of attributes, can be accessed by clicking the Actions icon "View the metadata for this layer."

2.3.6 Model Results Report

The Model Results Report is very useful for understanding the results of any suitability model for an analysis area and documenting the specific layers and settings that were used in the model. It displays results for the composite model output and each model input layer. The first graph shows the mean and total range of suitability values in the model output and each input layer for the analysis extent for which it was run (Figure 2-11). In this example, the overall output in the analysis area was marginally suitable (mean of approximately 60) and ranged from unsuitable (0) to about 80. Contributions to the score of each input can be rapidly assessed. Those with higher means were generally more favorable (such as population density), and those with lower means
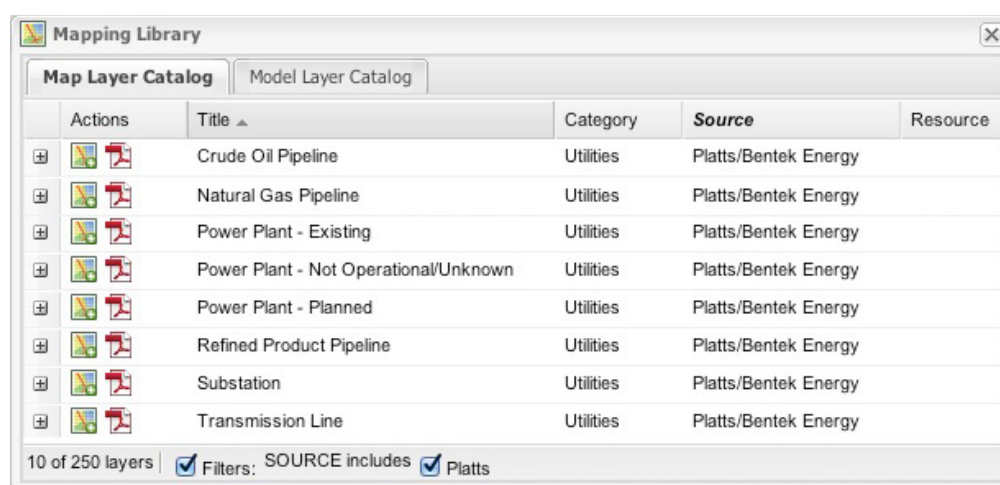
Figure 2-10 Energy Infrastructure Layers from Platts/Bentek Energy within the Map Layer Catalog
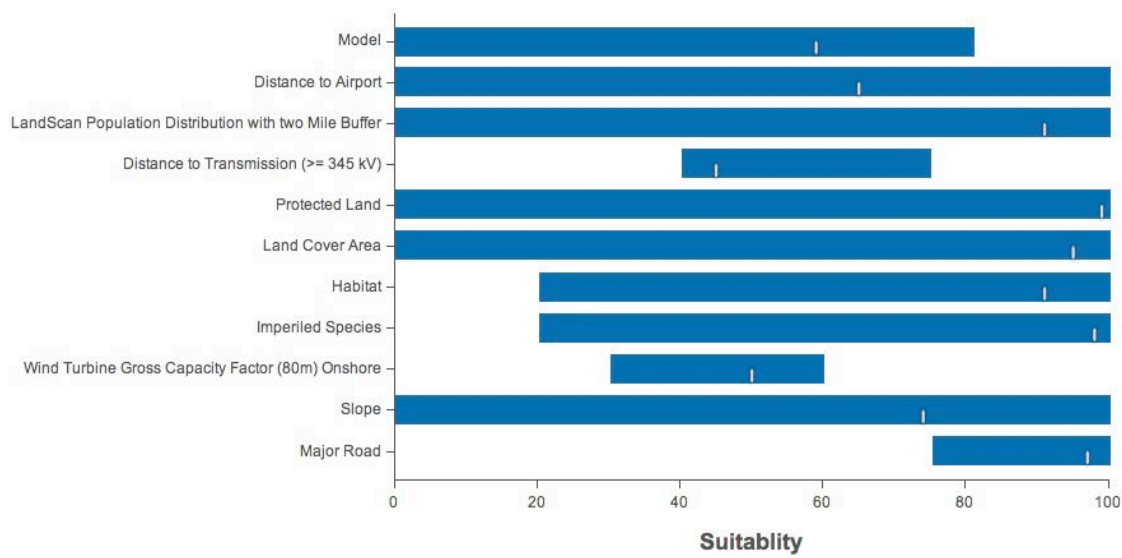
Figure 2-11 Chart Displaying the Range of Suitability Values That Are Found in the Model Result Report

(such as transmission proximity and wind turbine gross capacity factor) were generally less favorable. With one of the most important factors of wind turbine gross capacity factor being low to marginally suitable for this location, it is doubtful that this region would be advantageous for siting wind turbines.

To provide more detail for the model output and each input layer, the report provides a histogram showing the data distribution across the range of suitability (Figure 2-12). In this example, the majority of the analysis area is suitable (100) in terms of proximity to airports, but portions of it are marginally suitable (50) or lower (5 and lower). For further analysis, this and other layers can be viewed on the map to see how they contribute to the suitability of the area.

The final section of the report lists each input layer, its overall weight in the model, and the suitability values settings within the layer—all the settings entered into the model when it was originally run.
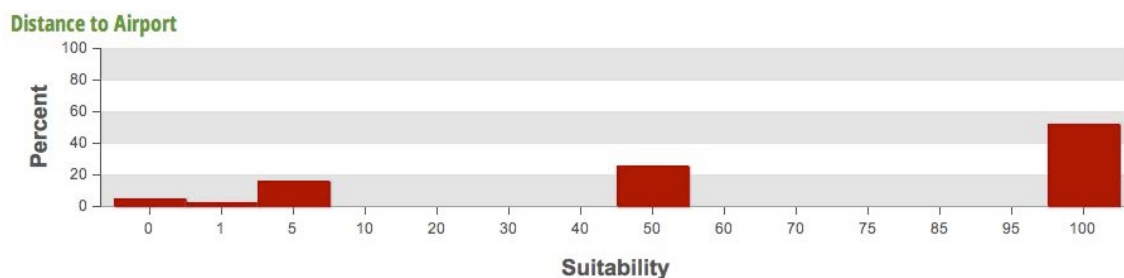
Figure 2-12 Chart Displaying a Histogram of Suitability Values within One Model Input Layer for a Specific Analysis Area of Interest

Running model result reports to compare different analysis areas is useful in understanding the complex mix of siting factors contributing to the model results, contrasting pros and cons among the analysis areas, and considering the broad implications of developing energy zones in each location.

2.4 Synergy Analysis

Figure 2-13 illustrates the methodology and process for synergy analysis. The main objective of the synergy analysis is to integrate the results of "single-resource" analyses for two or more resource technologies and to produce a map showing the resulting concentrations, or clustering, of selected clean energy resources. In this process, the suitability maps developed during the single-resource analysis are used to develop a composite image showing the resulting areas suitable for the development of multiple energy technologies (Figure 2-14). Methods for weighting the layers and computing the results are the same as single-resource models, and the output is a composite map with the same 0 to 100 scale of suitability levels. Results are based on the energy technologies selected by the user and the weight assigned to each technology. This approach also allows for favoring one or more technologies if desired. The resulting map provides visual information of highly suitable areas which could be considered for further analysis.

In the next step, the user may input an area of interest for possible development of a clean EZ. First, the analysis will include examining potential co-location compatibility of different energy technologies within the selected area, mainly with regard to the land use (e.g., wind and biomass could be co-located using the same land area, as described in

Figure 2-13 Methodology and Process for Synergy Analysis

Section 3.10). Next, other potential compatibility or competing issues need to be identified, especially if two or more technologies are competing for the same resource (e.g., cooling water). Lastly, it should be checked if there are potential impacts of non-zonal technologies, such as the smart grid, energy efficiency, and demand response. In some cases, these non-zonal technologies may provide some positive synergies and enable wider penetration of certain clean energy resources (e.g., smart grid technology may support and accelerate the growth of rooftop solar generation).

The review of the results will provide information for which parts of the selected area of interest are most favorable for the development of multiple clean energy resources. This information may serve for the identification of potential clean EZs with multiple technologies co-existing.

Figure 2-14 Synergy Results of Equally Weighted Solar PV and 80-m Land-Based Wind Models

2.5 Corridor Analysis

Corridor reports offer a screening-level assessment of key factors for planning an electrical transmission or pipeline corridor. Similar to defining an analysis area, corridors are sketched on the map; in this case, by clicking along the corridor centerline, then entering a total width in feet and name when prompted. Figure 2-15 shows a hypothetical corridor and its corresponding entry in the Analysis Areas and Corridors dialog.

By running the report on this corridor, the information below is generated, and listed by milepost along the corridor centerline:

- States and counties
- Populated places
- Elevated profile
- Topographic slope
- Major roads
- Railroads
- Rivers
- Water bodies

- Electrical substations
- Pipelines
- Military installations
- Airports
- Estimated peak horizontal ground acceleration
- Protected lands
- Habitat
- Imperiled species
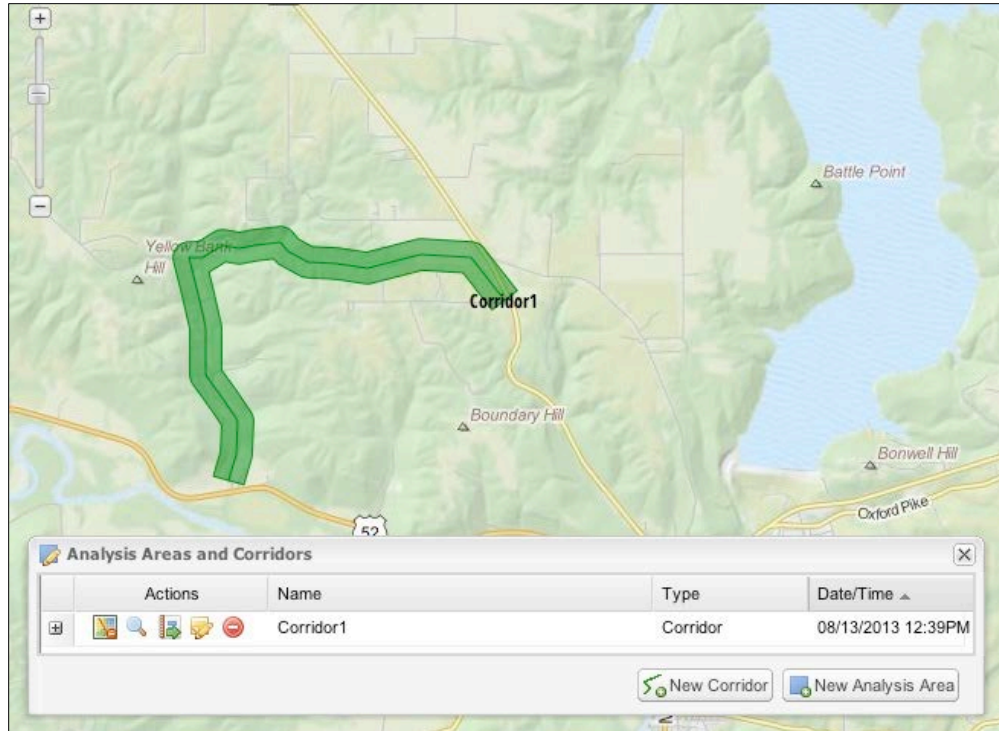
Figure 2-15 Map Showing a Hypothetical Corridor

Figure 2-16 shows typical content for a corridor report section listing crossings of areas (states and counties in this case) and part of the topographic profile section.

States and Counties Crossed, by Milepost

From Milepost (mi)	To Milepost (mi)	State Name	County Name	Area Within Corridor (sq mi)
0.00	10.21	Indiana	Rush	0.08
10.21	31.25	Indiana	Decatur	0.16
31.25	39.52	Indiana	Jennings	0.06
39.52	57.69	Indiana	Ripley	0.14
57.69	79.65	Indiana	Dearborn	0.17
79.65	93.82	Indiana	Franklin	0.11
93.82	94.29	Indiana	Union	0.00
TOTAL				0.74

Source: U.S. Census Bureau; et al (County Boundary (Generalized)) not available.

From Milepost 60.0 to Milepost 65.0

Elevation (ft): Min = 182.0, Max = 301.0 | Topographic Slope (percent): Min = 2.0 , Mean = 11.74, Max = 23.0
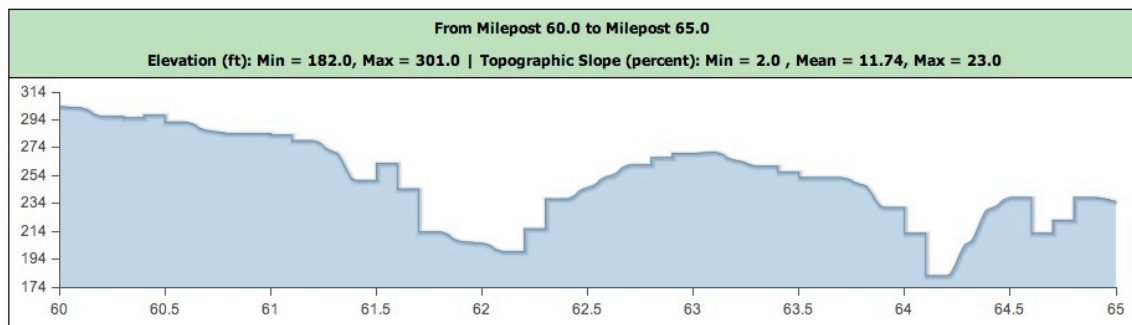
Figure 2-16 Corridor Report Example Content Showing States and Counties Crossed (top) and an Elevation Profile for the Corridor from Milepost 60 to 65

To investigate an alternate route for part of a corridor, a copy of the corridor can be created and revised to reroute around areas identified as having significant issues.

3 Clean Resource/Technology Options

The following sections describe the nine Clean Energy Resource categories that fall within the scope of the EZ Study, the resource characteristics and availability, the conversion technologies, the screening factors considered, and the data sources. The nine clean energy resource categories included in the EZ Study are (1) biomass, biopower, and biogenetic fuels; (2) clean coal with CCS; (3) geothermal; (4) natural gas; (5) nuclear; (6) solar; (7) storage; (8) water; and (9) wind.

3.1 Biomass, Biopower, and Biogenetic Fuels

3.1.1 Introduction

Conversion of light into plant materials through photosynthesis is a fundamentally important energy resource essential for life on earth. Since the 1970s, researchers have been investigating photosynthesis as an energy resource for the industrialized world and the potential of biomass to substitute for fossil fuels (Schneider 1973; Botlon and Hall 1979).

Biomass resources are plant-derived materials that store light energy that has been converted through photosynthesis. Depending on the type and composition of the plant matter, this energy may be stored as simple sugars, as starch, or as the more complex structural compounds cellulose,[1] hemicellulose,[2] and lignin (collectively known as lignocellulose).[3] Sugars and starches are primarily used for food, while lignocellulosic materials are used primarily as construction materials and for energy. Biomass is unique among renewable energy resources in that it consists of basic and complex hydrocarbons and can be converted to carbon-based fuels and chemicals as well as electric power. Biopower generally refers to the generation of electricity from biomass directly; biogenic fuels (biofuels) are generally refined fuels created from biomass. Methane from various wastes, biodiesel from oil seed plants, and ethanol converted from corn sugars and sugar cane are the most common biofuels.

Biomass resources are present in many areas of the Eastern Interconnection. Figure 3-1 illustrates biomass crop residue resources.

In 2012, 57.6 terawatt hours (TWh) of biopower generation came from about 11 gigawatts (GW) of capacity, making biopower the third-largest form of renewable electricity generation after hydropower and wind energy (Augustine et al. 2012).[4] Of this capacity, 7.0 GW was derived from the forest product industry and agricultural residues, 3 GW was derived from municipal solid waste (MSW), and about .5 GW from other sources such as landfill gas. The

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[1] Cellulose is a carbohydrate that is the principal constituent of wood and other biomass and forms the structural framework of the wood cells.

[2] Hemicellulose consists of short, highly branched chains of sugars. In contrast to cellulose, which is a polymer of only glucose, hemicellulose is a polymer of different sugars. Hemicellulose is more easily hydrolyzed than cellulose.

[3] Lignin is the major non-carbohydrate, polyphenolic structural constituent of wood and other native plant material that encrusts the cell walls and cements the cells together. Lignocellulose refers to plant materials made up primarily of lignin, cellulose, and hemicellulose.

[4] Data originate from the Energy Information Administration.
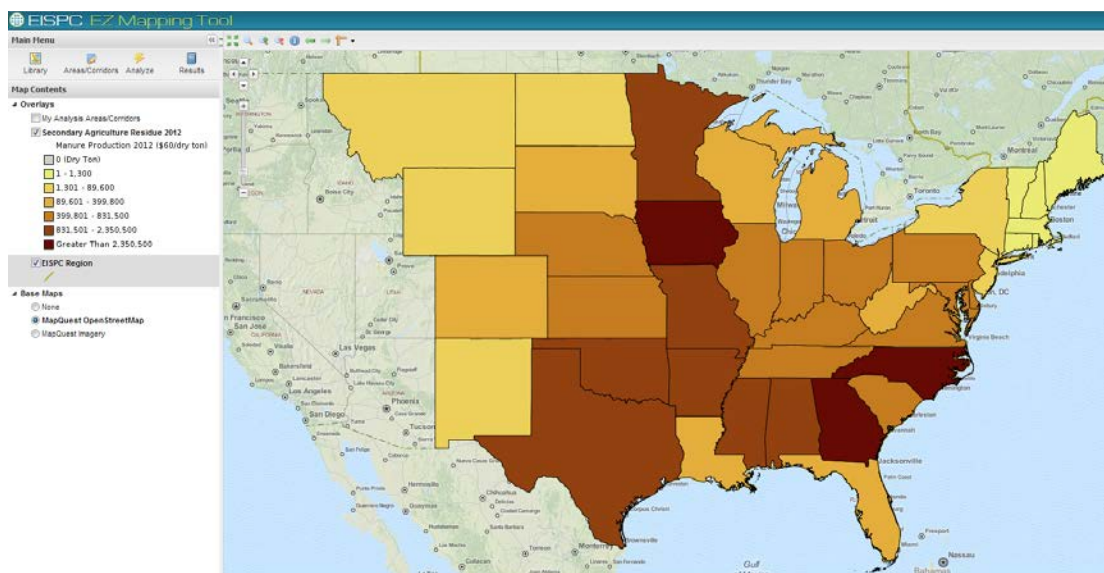
Figure 3-1 Secondary Agriculture Residue 2012 (Source: EISPC EZ Mapping Tool)

biopower generation in the electric sector in 2012 represents approximately 1.4% of the total electricity generated

Sections 3.1.2 through 3.1.7 discuss the scope of the biomass resources in the EZ Study, describe biomass technologies, describe conversion technologies, list screening factors considered, and provide data sources for the resources and screening factors.

3.1.2 Scope

Biomass resources are suitable for direct combustion through co-firing in coal plants or dedicated biomass-to-electricity-conversion facilities. While other biomass applications exist, they are out of scope for the purposes of this analysis. These out-of-scope applications include the conversion of the various biomass resources to biofuels (e.g., ethanol and biodiesel), any process involving algae, and charcoal production. Three sources of biomass-derived methane (landfill gas, wastewater treatment, and animal manure processing) are included as informational layers in the EISPC EZ Mapping Tool.

The following primary categories of biomass resources were examined for this study:

- Biomass
  - Forest biomass and wood waste,
  - Agricultural biomass and waste resources, and
  - Dedicated energy crops.

- Biofuels
  - Methane from landfills,
  - Methane from wastewater treatment, and
  - Methane from animal manure processing.

3.1.3 Resource Description

Biomass resources are very complex and diverse ranging from forest products to municipal or urban wastes. Several biomass resource assessments for the United States have been completed in recent years, as illustrated in Figure 3-2. While each study used different methodologies and assumptions, most of the results fall into a similar range: between 400 and 700 million tons per year. Data from the Billion-Ton Study (refer to DOE 2011 Base in Figure 3-2) were chosen for this project because it is the most recent analysis completed and also provides future projections. An excerpt from the Billion-Ton Study related to data uncertainty and model estimates states: "Although an attempt was made to use the best available data, there is still a great deal of uncertainty that cannot be overcome without a concerted effort to develop new data; for example…through the development of new data sources (e.g., use of remotely sensed data). Finally, the POLYSYS model[5] is deterministic and thus does not allow one to provide confidence intervals around model output. Results are thus presented as point estimates and should be interpreted with all the appropriate caveats related to data uncertainty."

3.1.4 Conversion Technologies

The two conversion technologies relevant to this study include dedicated biomass conversion via direct combustion and co-firing of the biomass materials in a coal plant. Within each biomass resource category there are many variations in the possible plant designs.[6]

For utility-scale power generation from biomass, direct combustion has long been the technology used in the United States. Almost all dedicated biomass power plants in the United States rely on direct combustion technology. Because biomass has lower sulfur content, coal-fired power plants that co-fire biomass can reduce sulfur dioxide (SO_2) emissions. Biomass gasification is an emerging technology that can be used in advanced power cycles such as integrated gasification combined cycle (IGCC) power plants.

In direct combustion, the biomass is fed into a boiler with excess air to generate hot flue gas, which then generates steam in the heat-exchange section of the boiler. The steam is used in a steam-Rankine cycle, with a resulting turning turbine shaft that is connected to a generator producing electricity. This process is illustrated in Figure 3-3.

The process shown represents a simplified generic direct combustion plant. This generic process diagram is similar to any steam cycle power plant, although the details of the plant design would have to accommodate the characteristics of the biomass feedstock. As the biomass materials have lower and more variable heating value than most coals and may have high moisture content, the plant design needs to accommodate these differences. The volumetric heat released by direct

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[5] The Policy Analysis System (POLYSYS) is a simulation model of the U.S. agriculture sector, which can incorporate agricultural supply and demand and related modules to estimate agricultural production response, resource use, price, income, and environmental impacts of projected changes from an agricultural baseline.

[6] Additional information about biopower technologies is available from the DOE Biomass Program at http://www1.eere.energy.gov/biomass/.
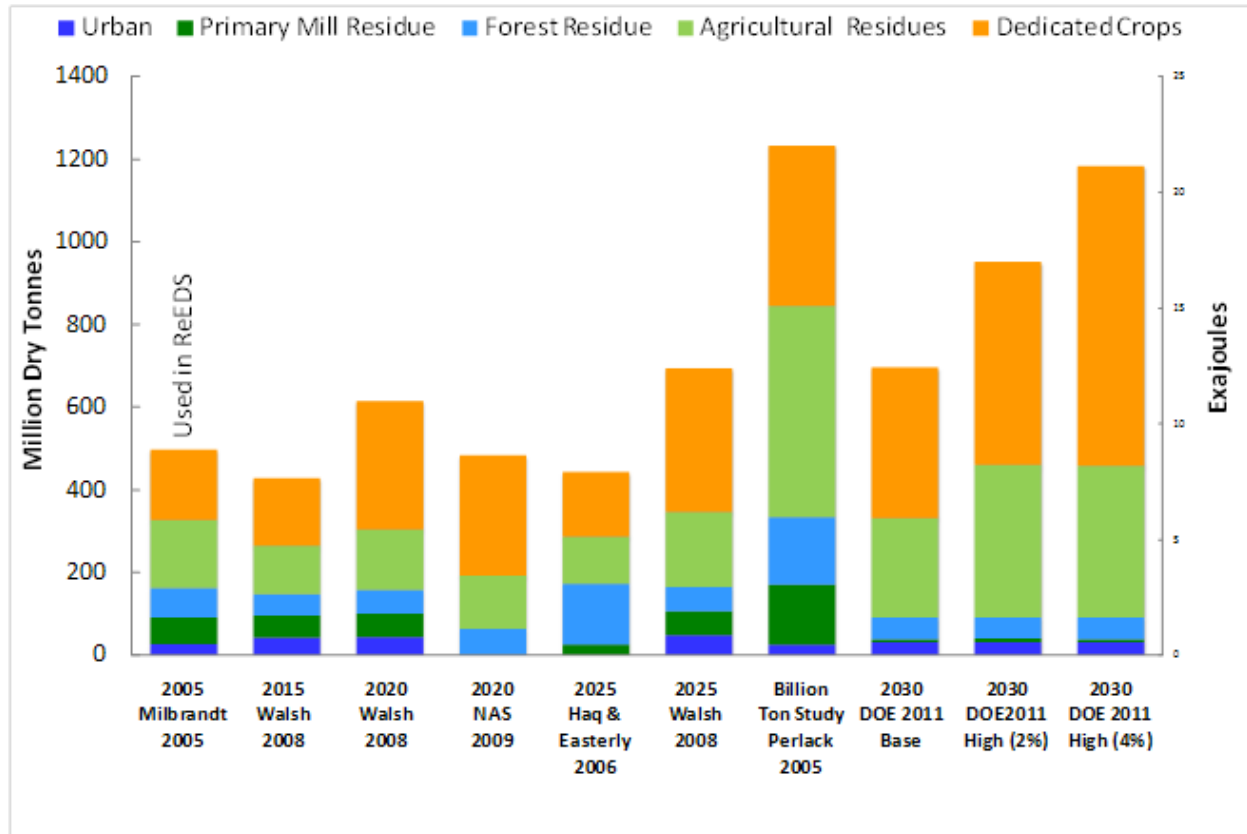
Figure 3-2 Potential Biomass Supply (Source: Augustine et al. 2012)

Exajoule = 10^{18} Joule
Quadrillion Btu (quad) = 10^{15} Btu
Quad = 1.055 Exajoule

Assumed dry biomass heating value (lower heating value basis)
Woody biomass = 18.6 GJ/tonne
Agricultural residues and biogenic MSW = 18.0 GJ/tonne where 1 tonne = 1.1023 short ton; MMBtu = 1.055 GJ
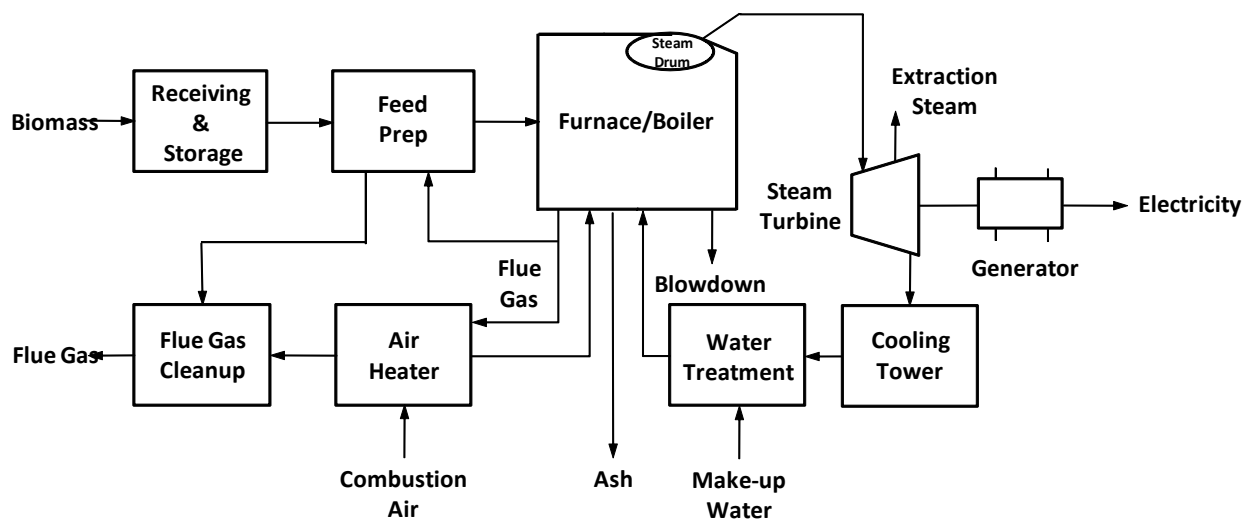
Figure 3-3 Schematic of a Direct-Fired Biopower Facility (Source: Augustine et al. 2012)

combustion of biomass is typically two-thirds of the volumetric heat released by coal combustion, because of the lower heat content and higher moisture content in biomass. Typical biomass combustion plants operate at lower steam conditions and thus lower energy efficiencies than modern coal plants.

Biomass-fired steam cycle plants typically use single-pass steam turbines. However, efficiency and design features previously found in only large-scale steam turbine generators have been transferred to smaller capacity units. These designs include multi-pressure, reheat, and regenerative steam turbine cycles as well as supercritical steam turbines.

The addition of dryers in the pretreatment of the biomass materials and the incorporation of more complex steam cycles can raise the efficiency of direct combustion systems (McGowin 2007).

Co-firing is the practice of introducing biomass as a supplemental source of energy or fuel in coal-fired boilers. Co-firing is a commercial technology that has been in use for decades in the pulp and paper industry and adopted by utilities in recent decades in high-efficiency coal-fired steam plants by supplementing the normal coal feed with available solid biomass fuels. Co-firing with coal in existing boilers is the lowest-cost biopower option because existing boilers and generating equipment are used, and the investment required is incremental as it is largely restricted to modifying storage, preparation, and feed systems. Investments are facility specific, and minor modifications of boilers may be required for separate injection of biomass into a coal boiler. In addition to the relatively limited capital investment required, the co-firing with coal achieves a higher efficiency than the typical dedicated biomass plant, since modern coal plants have efficiencies in the range of 32% to 38%. The disadvantage is that the supplemental biomass feed is limited to a small fraction of the fuel energy input (typically 3% to 15%).

3.1.5 Screening Factors

Screening factors relate to both the availability of the resource and specific needs of the energy conversion technology. For the purpose of this analysis, the screening factors used to screen areas for the specified biomass conversion technologies (in addition to the resource availability) are listed in Table 3-1. The specific default suitability criteria and ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4. Informational layers may also be useful for additional analysis by overlaying them onto the suitability model results. Appendix B includes the extensive list of EZ Mapping Tool informational layers.

Co-firing with coal is generally relevant to existing plants and future plants, including those that might use CCS. For existing coal plants, the feasibility of co-firing is very plant specific and depends on design details and the type of biomass material that is available in the local region. Many of the clean energy resource development areas and exclusion areas relevant to coal will be applicable to dedicated biomass plants with the recognition that the plant size will typically be far smaller.

Table 3-1 Biomass Technology Screening Factors

Biomass Technology	Screening Parameter
New biomass-fired plants with traditional combustion	Population density Slope Distance to rivers (>2,000-gpm) Distance to railroad Distance to major road 100-yr flood zone Distance to port (barge locations) Proximity to transmission (>220 kV) Protected Land Habitat Imperiled Species
Biomass co-fire with existing coal plant	Distance to coal plants suitable for co-firing Population density Slope Distance to rivers (>2,000-gpm) Distance to railroad Distance to major road 100-yr flood zone Proximity to transmission (>220 kV) Protected Land Habitat Imperiled Species

3.1.6 Data and Sources

The biomass resource data are from a recent update of "The Billion-Ton Study: Biomass Supply for a Bioenergy and Bioproducts Industry," a study led by ORNL and published in 2011 (DOE 2011). The models and reports are supplemented with resource data from the U.S. Environmental Protection Agency (EPA) and other sources listed in Table 3-2. Publicly available data to construct the screening factors for biomass technologies are available from a variety of sources listed in Table 3-3. The Protected Land, Habitat, and Imperiled Species screening layers are discussed in Section 4.

Landfill gas, wastewater treatment, and animal manure-processing-generated methane data are included as informational layers in the EZ Mapping Tool, and reports can be generated to summarize the availability of this resource data in an area of interest. The source of these data layers is listed in Table 3-2.

Table 3-2 Biomass Data and Sources[a]

Resource	Data and Source
Forest biomass, agricultural biomass and waste, dedicated energy crops	2011 U.S. Department of Energy (DOE), [https://bioenergykdf.net/; http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf]
Landfill gas	2013 U.S. Environmental Protection Agency (EPA), [http://www.epa.gov/lmop/]
Wastewater treatment methane	2012 EPA Wastewater Treatment Facility Capacity
Animal manure methane	Existing digesters: 2012 EPA, [http://www.epa.gov/agstar/projects/index.html#database] Potential resource: 2012 National Renewable Energy Laboratory (NREL), [http://www.nrel.gov/gis/data_biomass.html]
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

Table 3-3 Biomass Screening Factor Data and Sources[a]

Factor (Parameter)	Data and Source
Population density	LandScan™, http://www.ornl.gov/sci/landscan/
Slope	2012 National Geospatial-Intelligence Agency (NGA) Digital Terrain Elevation data/ calculated and resized for 250-m cells
Distance to rivers/surface water flow	2012 U.S. Geological Survey (USGS), National Hydrography data (Version 2)
100-yr flood zone	2011 Federal Emergency Management Agency (FEMA) National Flood Hazard data http:/www.msc.fema.gov
Distance to railroad	2012 Federal Railroad Administration (FRA) data
Distance to major road	2012 National Transportation Atlas Database
Distance to port	2012 U.S. Army Corps of Engineers (USACE)
Electric transmission data	2012 Bentek Energy/Platts
Coal plants for co-firing	2011 EPA
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

3.2 Clean Coal with Carbon Capture and Sequestration

3.2.1 Introduction

The United States has the largest demonstrated reserve base of coal in the world with recoverable reserves estimated at 258 billion tons out of a demonstrated resource base of 483 billion tons (EIA 2012c). Based on 2011 production levels of 1.1 million tons (including exports), U.S. supplies would last more than 200 years (EIA 2012a). However, growth in global demand may accelerate the point of peak production to an earlier year. Coal is currently mined in 27 states, though 90% of the confirmed coal reserves are concentrated in 10 states. Approximately 72% of current production originates in five states: Wyoming, West Virginia, Kentucky, Pennsylvania, and Montana (EIA 2012a). There are roughly 1,300 coal mines in the United States. Approximately 60% of the coal is mined at the surface, and the remaining 40% is

mined underground (EIA 2012b). Coal is readily available as a power resource from diverse supply locations.

Burning coal accounted for 45% of the electricity generated in the United States in 2010 at more than 1,400 coal-fired thermoelectric power plants (EIA 2012b). This is more than any other single power source and reflects the fact that coal is plentiful and relatively inexpensive in the United States. The use of natural gas as an electricity power source is expected to displace some use of coal in the future, with the amount of displacement dependent on fuel prices and the level of environmental controls required. With advanced environmental controls, coal-fired power plants can have a long-term role to play in the net energy production in the United States for the foreseeable future. Sections 3.2.2 through 3.2.7 discuss the clean coal with CCS technologies in scope for the EZ Study, describe clean coal technologies, describe conversion technologies, list screening factors considered, and provide data sources for the resources and screening factors.

3.2.2 Scope

Three types of advanced clean coal plants were considered in this study: (1) (PC oxycombustion power plants; (2) IGCC plants; and (3) coal fluidized bed (CFB) plants. In addition, the retrofit of existing coal plants with CCS technology is also included in this study. For this study, "clean coal" includes CO_2 capture, not just other pollutants.

Underground coal gasification technology was deemed to be out of scope for this study.

3.2.3 Resource Description

Coal is a combustible black or brownish-black sedimentary rock. A harder form of coal, such as anthracite coal, has the highest carbon content, the fewest impurities, and the highest calorific value of all types of coals. Bituminous coal is softer than anthracite coal and contains a tarlike substance called bitumen. Sub-bituminous coal has a somewhat lower heat content and higher moisture content than bituminous coal but can be lower in sulfur. Lignite, often referred to as brown coal, is the softest fuel with characteristics similar to peat and is considered the lowest rank of coal. Figure 3-4 is a resource map for the various varieties of coal in the United States. Because of the abundant availability, most coal-fired power plants use bituminous or sub-bituminous coal. All coal is composed primarily of carbon, along with variable quantities of other elements—chiefly hydrogen, sulfur, oxygen, and nitrogen. When coal is burned to produce electricity in a thermoelectric power plant without any controls or scrubbing of the stack gases, CO_2, carbon monoxide (CO), sulfur oxides (SO_x), nitric oxides (NO_x), particulate matter (PM), and trace metals (including mercury) are released to the atmosphere. Burning coal accounted for 37% of the total United States emissions of CO_2 in 2010 (EIA 2012a). Coal combustion produces higher amounts of CO_2 per unit of energy than either oil or natural gas combustion. By retrofitting existing coal plants with CCS technology, coal-related emissions can be greatly reduced.
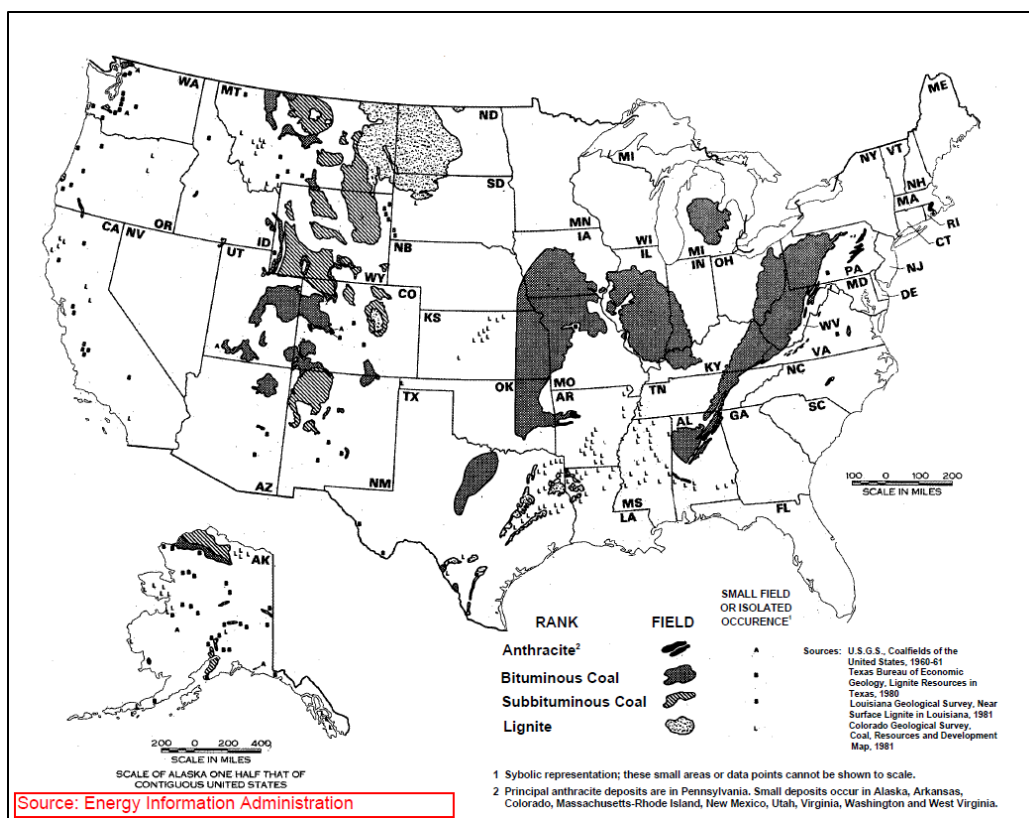
Figure 3-4 Coal Resource Map (Source: EIA undated)

3.2.4 Conversion Technologies

New PC oxycombustion, IGCC, CFB power plants, and retrofitted existing PC coal plants with sequestration equipment can convert coal resources into thermal energy.

In a PC power plant, raw coal is milled into a fine powder in a pulverizer that increases the surface area for combustion and allows the coal to burn faster. The powdered coal is blown into a boiler and burnt at a high temperature. Water circulating in tubes in the boiler is converted to high-pressure steam, which subsequently turns a turbine shaft at high speeds. The turbine shaft is connected to a generator, which produces electricity. A typical PC plant with pollutant control technologies uses limestone to capture the SO_x. Selective catalytic reduction reduces NO_x and fabric filters, or electrostatic precipitators control particulates and assist in the control of mercury (NETL 2008a).

A PC oxycombustion power plant uses oxygen diluted with recycled flue gases in the combustion process. This produces a flue gas stream of CO_2 and water. The water can be removed, leaving a nearly pure stream of CO_2. The CO_2 is compressed to approximately 2,200 pounds per square inch (psia) and transported via a pipeline to a geological formation where it is stored (NETL 2008a). Geological formations that are typically considered for storage are deep saline formations and partially depleted oil fields. Figure 3-5 is a schematic of a basic PC plant.
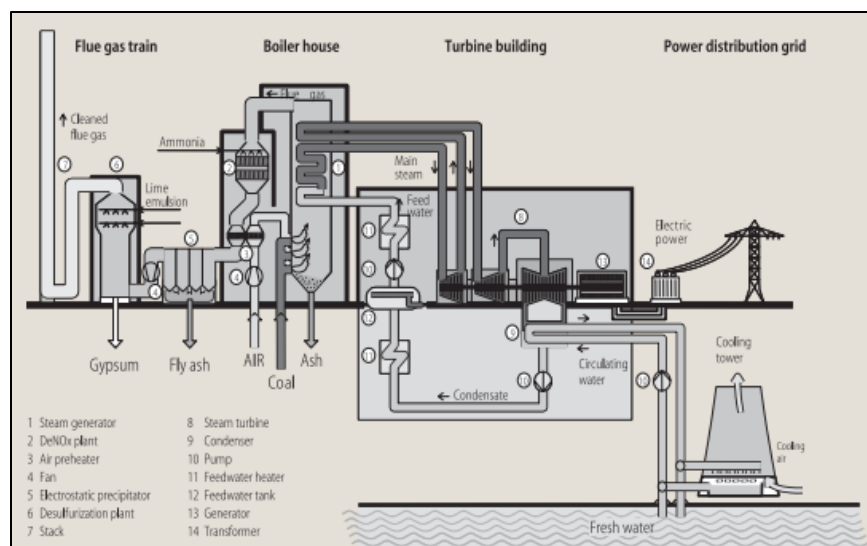
Figure 3-5 Basic Advanced, Low-Emissions PC Plant
(Source: Katzer et al. 2007)

In an IGCC power plant, coal is gasified in a high-pressure, high-temperature reactor called a gasifier. Under the low oxygen conditions in a gasifier, coal sulfur forms hydrogen sulfide (H_2S), which can be removed to extremely low concentrations by chemical-absorption processes. This is an advantage over conventional combustion, which forms SO_2 that must be removed by post-combustion scrubbing of the high volume of flue gas produced. Inorganic materials that form particulates and slag in a conventional furnace are removed from the gasifier as slag. The resulting raw gas product consists primarily of CO and steam, with small amounts of methane, hydrogen, and trace constituents. This synthetic gas has a very low heating value and is often upgraded by converting the CO in the raw syngas to CO_2 in a process called a shift reaction. The shift reaction simultaneously converts reagent steam to hydrogen, thus increasing the heating value of the synthetic gas. The CO_2 is separated from the syngas, pressurized, and sequestered similar to the PC plant process. However, the relatively high concentration of CO_2 in the syngas makes capture more economical in the gasification case. The raw syngas is typically burned locally as is or it may be methanized into substitute natural gas and subsequently fired in a gas turbine or introduced into the natural gas pipeline network. The heat of the gas turbine exhaust is used to create steam to run a steam turbine in a combined-cycle process that has a higher efficiency than a PC plant. Plant efficiencies of up to 60% are possible with IGCC plants compared to efficiencies of less than 40% in PC plants. By removing emission-forming constituents from the syngas before burning, the SO_2 and NO_x emissions are greatly reduced. Other IGCC feedstocks are possible as well, including biomass, petroleum coke, MSW, chemicals, and sludge (DOE 1999). Figure 3-6 is a schematic of a basic IGCC plant.

In a CFB power plant, a limestone or dolomite sorbent is mixed with the coal to capture the SO_2 released by the coal combustion process. Particulate and NO_x emission removal is similar to a PC plant. Air suspends the mixture of burning coal and sorbents in a combustion chamber such that the fluidized mixture can be circulated. The hot combustion gases with entrained solids exit at the top of the combustion chamber into a hot cyclone. The cyclone separates the solids from the combustion gases and returns the solids, including any unburned solid fuel, through a
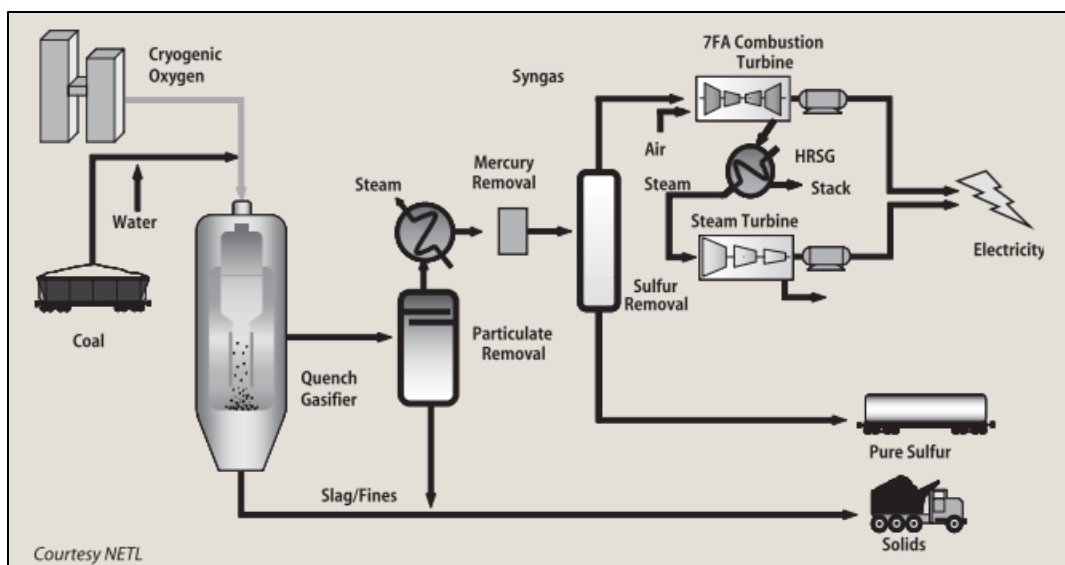
Figure 3-6 Basic IGCC Plant Coal and By-product Flow (Katzer et al. 2007)

non-mechanical loop seal to the combustion chamber where they mix with incoming fresh fuel. The long residence time of solids at combustion temperature and the continuous recirculation of the solids ensure high combustion efficiencies and sulfur capture. The heat of the combustion process is used to create superheated steam to run a steam turbine that has a higher efficiency than a PC plant. The CFB SO_2 and NO_x emissions are about one-tenth those of an uncontrolled PC plant and are comparable to those of a PC plant with a scrubber (http://www.power-eng.com/articles/print/volume-111/issue-3/features/comparing-emissions-pc-cfb-and-igcc.html). The CO_2 emissions can be sequestered similar to the PC plant process. Figure 3-7 is a schematic of a basic CFB plant.

Existing coal-fired power plants may be able to cut CO_2 emissions by retrofitting control and sequestration equipment onto an existing PC power plant. The carbon scrubbing and control equipment will require a substantial footprint on the plant site, which may preclude some sites from consideration. In addition, a net loss in power to the grid occurs to account for the parasitic loads associated with operating the emission control and sequestration equipment. This will eliminate the consideration of small coal plants for retrofit. In addition, the age or remaining life of an existing coal plant must be factored into any decision to retrofit a plant.

3.2.5 Screening Factors

Screening factors relate to both the availability of the resource and the specific needs of the energy conversion technology. For the purpose of this analysis, the screening factors used to screen areas for the specified coal conversion technologies (in addition to the resource availability) are listed in Table 3-4, and the specific default suitability criteria and specific ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4. Informational layers may also be useful for additional analysis by overlaying them onto the suitability model results. The extensive list of EZ Mapping Tool informational layers is included in Appendix B.
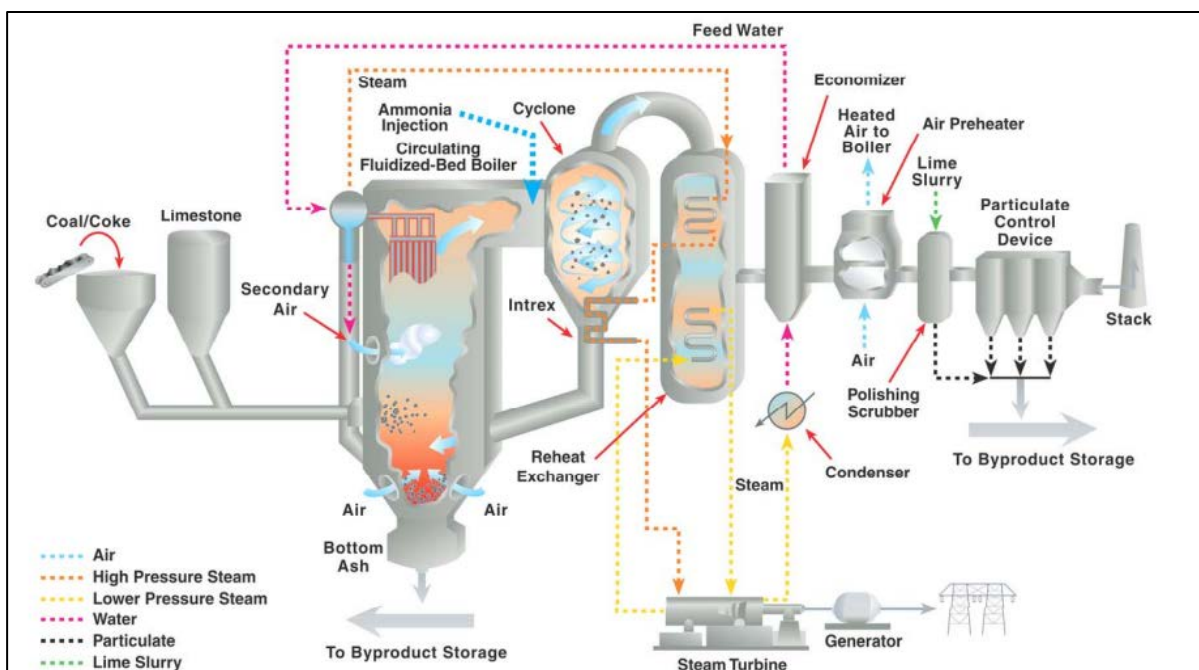
Figure 3-7 Basic CFB Plant Coal and By-product Flow (Source JEA 2003)

The screening factors for many thermoelectric power plants are similar, with varying values for the individual factors. While siting of advanced coal plants is not held to the same regulatory rigor as nuclear power plant siting, many of the screening factors are very similar between the two plant types.

ORNL has developed a tool, OR-SAGE (Oak Ridge Siting Analysis for power Generation Expansion) (Mays et al. 2012) for applying GIS and spatial modeling techniques for evaluating siting options for nuclear power and has extended that capability for other electric power plants, including, for example, solar and clean coal. A further description of the siting methodology is provided in Section 3.5.5, since the tool was originally formulated for evaluating nuclear plant siting. Its methodology for coal plants siting criteria is the foundation for the coal technology evaluation described below.

Since population density of greater than 500 people per square mile begins to transition into an urban setting, new advanced coal plants in these areas are excluded based on anticipated available space and zoning restrictions. However, there is no need to include a buffer for public safety as there would be for nuclear power plants. Engineering judgment indicated that screening factors, such as avoiding wetlands and open water, protected land, excessive slope, and floodplains, should be considered for areas suitable for clean coal technology development.

Available water for cooling is a common need for all thermoelectric power plants. A DOE/National Energy Technology Laboratory (NETL) report provided water consumption factors for IGCC, supercritical PC, and subcritical PC plants using carbon capture technology (NETL 2008b). The subcritical PC plant had the highest water consumption factor, including carbon capture technology; thus this plant type was conservatively used to establish the water

requirements for the PC plant. The IGCC plant uses less than half the water of the PC plant on a gallons per MWh basis. Water usage at a CFB plant is assumed to be similar to an IGCC plant, adjusted for differences in thermal power produced.

Expected PC plant parameters were provided in a DOE/NETL report (NETL 2008a). This report indicated that the expected average advanced PC plant is situated on 300 acres and that the gross output is 750 megawatts electric (MW(e)). This report also indicated that reasonable access to coal delivery was a necessary requirement. The expected average IGCC plant was assumed to be 600 MW(e) based on an Energy Information Administration report (EIA) (2010). Likewise, the expected average CFB plant was assumed to be 400 MW(e) based on a CFB plant demonstration project in Jacksonville, Florida. The plant output was factored into the advanced coal-fired plant water requirement calculation for each plant type. For an older coal-fired PC plant retrofitted with CCS technology, only the additional water requirements of the CCS technology would need to be factored. This would vary depending on the capacity of the plant to be retrofitted. In all cases, it is assumed that water can be economically piped up to 20 miles (mi) from an existing water source. As a general rule, no more than 10% of the available water supply at any given location is assumed to be available for a new power plant.

The report *Pulverized Coal Oxycombustion Power Plants* also indicated that CO_2 could be piped up to 50 mi to a saline aquifer formation (NETL 2008a). ORNL expertise indicated that this distance could be pushed to a higher value with certain provisions, such as avoiding high slopes, faults, and crossing of protected land. Consultations with Carnegie Melon University researchers in December 2010 confirmed this assumption. The distance to an acceptable geologic storage formation for carbon is a unique screening factor for the consideration of advanced coal plant siting. Saline formations assessed for storage are restricted to those where the following basic criteria for the storage are met: (1) pressure and temperature conditions in the saline formation are adequate to keep the CO_2 in dense phase (supercritical) or liquid phase, (2) a suitable seal is present to limit vertical flow of the CO_2 to the surface, and (3) salinity in the saline formation is >10,000 parts per million (ppm) total dissolved solids. For the purposes of this study, a depth of 2,500 feet (ft) below surface was accepted as a reasonable proxy for these criteria to be met (NETL 2010). Geological storage capacity and carbon injection rates are noted as issues for the use of advanced coal technology. However, no publicly available GIS data are currently available to permit the inclusion of these issues as additional advanced coal evaluation criteria.

Other informational data that may make one candidate area superior to another candidate area include access to transportation, access to the electrical transmission network and load centers, and EPA air pollution standards for a given area. These factors should not be used to initially factor out an area but provide useful additional knowledge about candidate areas.

Table 3-4 shows the screening criteria for the expected average clean coal technologies that include CCS positioned on 300 acres of land.

Table 3-4 Advanced Coal Technology Screening Factors

Clean Coal-Technology	Screening Parameter
Pulverized coal	Distance to saline formation for carbon storage Population density Slope Land cover area 100-yr flood zone Distance to rivers (>125,000 gpm) Distances to railroad Distance to port (barge locations) Proximity to electric transmission (>345 kV) Protected Land Habitat Imperiled Species
Integrated gasification combined cycle	Distance to saline formation for carbon storage Population density Slope Land cover area 100-yr floodplain Distance to rivers (>45,000 gpm) Distance to carbon storage Distance to railroad Distance to port (barge locations) Proximity to electric transmission (>345 kV) Protected Land Habitat Imperiled Species
Coal fluidized bed	Distance to saline formation for carbon storage Population density Slope Land cover area 100-yr flood zone Distance to rivers (>30,000 gpm) Distance to carbon storage Distance to railroad Distance to port (barge locations) Proximity to electric transmission (>345 kV) Protected Land Habitat Imperiled Species

3.2.6 Data and Sources

The coal resource data were obtained from the EIA (2007). Publicly available data to construct the screening factors for clean coal technologies that include CCS are available from a variety of sources listed in Table 3-5. The Protected Land, Habitat, and Imperiled Species screening layers are discussed in Section 4.

Table 3-5 Clean Coal Screening Factor Data and Sources[a]

Parameter/Information	Data and Source
Population density	LandScan™, http://www.ornl.gov/sci/landscan/
Slope	2012 NGA Digital Terrain Elevation data/calculated and resized for 250-meter (m) cells
Land cover area	2011 USGS
100-yr flood zone	2011 FEMA National Flood Hazard data
Distance to rivers/surface water flow	2012 USGS/National Hydrologic data (Version 2)
Saline aquifer data (carbon storage)	2013 NETL saline aquifers data
Distance to railroad	2012 FRA data
Distance to port	2012 USACE
Transmission data	2012 Bentek Energy/Platts
Potential retrofitted PC plant (existing PC plants)	2012 Bentek Energy/Platts
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

Existing PC plant data are included as an informational layer in the EZ Mapping Tool, and reports can be generated to summarize the inventory of existing PC plants (location and generation rate) for an area of interest. The source of this data layer is listed in Table 3-5.

3.3 Geothermal

3.3.1 Introduction

Geothermal energy resources exploit thermal energy of the Earth's core where geologic features bring these resources close to the surface. This thermal energy is a combination of that available when the planet was formed and the decay of radioactive elements that are a natural constituent of the materials which formed the planet. Consequently, geothermal energy, like solar energy, is broadly available. However, unlike solar, geothermal is a possible source of baseload electric generation because of its constancy as opposed to wind or solar, which has natural variability. Geothermal energy is widely used today in two forms: (1) hydrothermal resources, hot water or steam accessed through deep wells that tap naturally occurring reservoirs for the extraction and use of the heat and/or generation of electricity, and (2) ground-source heating and cooling technologies that use the shallow ground near the Earth's surface that maintains a relatively constant temperature in the range of 40 to 60 degrees Fahrenheit (°F) year round.

Current commercial geothermal power plants use thermal energy produced from reservoirs of steam or hot water found several thousand feet below the Earth's surface to produce electricity. As the hot water[7] or steam is available directly, they are referred to as hydrothermal. These hydrothermal reservoirs have sufficient naturally occurring thermal energy, in situ water, and permeability for development of geothermal electricity. Hydrothermal resources are localized

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[7] The water, or geothermal fluid, at a particular site may contain salts and minerals and should be more appropriately referred to as brine.

geologic anomalies that require site-specific characterization. As will be discussed later, no significant hydrothermal resources have been identified within the Eastern Interconnection. Hydrothermal is discussed here as it is the common commercial technology.

The three categories of commercial geothermal power plants are defined by a combination of the type of geothermal resource and the conversion technologies: dry steam, flash steam, and binary cycle. The dry and flash steam directly use the geothermal fluid in the power cycle, while the binary cycle uses a secondary fluid, thus the term binary (Figure 3-8).

To explore the potential for geothermal energy in the Eastern Interconnection, a broader range of geothermal resources and conversion technologies need to be considered. Research over the last decades has identified additional geothermal resources available within the footprint of the Eastern Interconnection, including enhanced geothermal systems (EGSs), geopressured reservoirs, and co-production of geothermal energy from oil and gas wells.

EGSs (Figure 3-9) are resources with a large amount of thermal energy but lack sufficient in situ water, permeability, or both, so that the reservoir must be engineered to extract the thermal energy. EGS resources are divided into (1) near-hydrothermal field EGS resources located near conventional hydrothermal fields, and (2) deep EGS resources, which in theory can be developed anywhere by drilling deep enough to access high-temperature reservoirs.[8] Because EGSs are still primarily in demonstration, estimates of the potential of this resource are subject to considerable uncertainty. The vast majority of the geothermal potential for EGSs within the contiguous United States is located in the western portion of the country. However, even the Eastern Interconnection has enormous potential for EGS development.

Geopressured resources are found in highly pressurized[9] shale and sandstone formations that contain high-temperature brine with dissolved methane; their energy potential includes both thermal energy and the methane stored in reservoirs. The best geopressured reservoirs are generally located along the Texas and Louisiana Gulf Coast (Figure 3-10).

It is estimated that about 20 billion barrels (bbl) of water is co-produced during onshore oil and gas operations annually (Veil and Clark 2009). Some of this water is at a high enough temperature that it could be used to generate electricity. Co-production of geothermal energy from oil and gas wells consists of electricity generated from geothermal energy contained in fluids co-produced with oil and gas (or from abandoned oil and gas wells) using binary (organic Rankine cycle) power plants.

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[8] "In theory" as temperature increases with depth, but is limited in practice to the current state of drilling technology and affordability.

[9] The geopressured reservoir pressures exceed the hydrostatic head, and both the mechanical and thermal energy can be utilized in generating electricity.
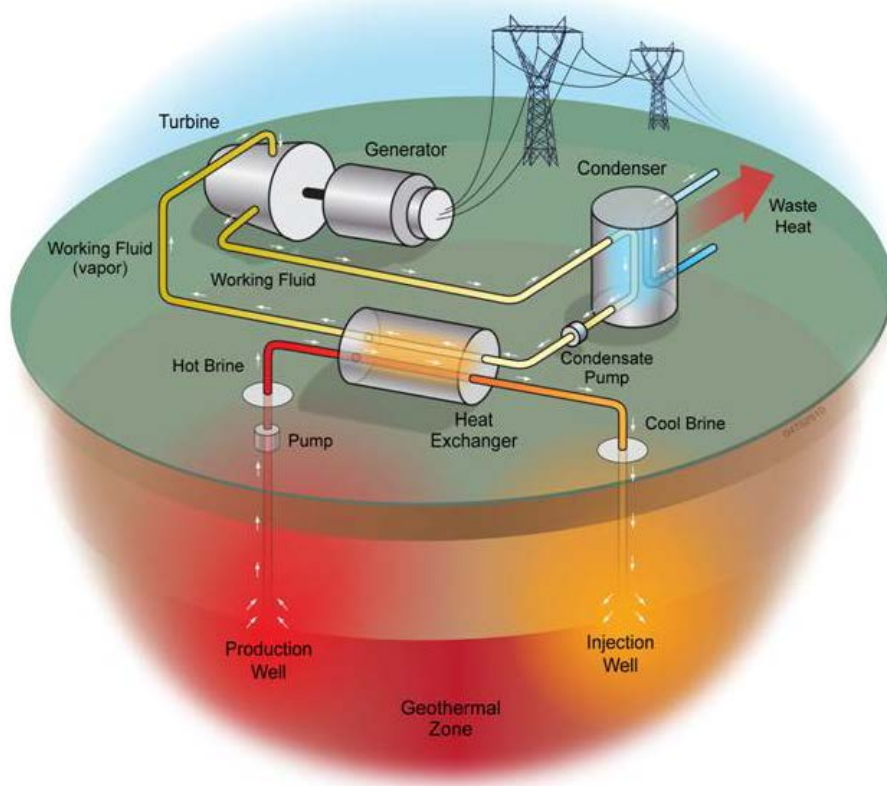
Figure 3-8 Schematic of a Hydrothermal Binary Power Plant
(Source: Augustine et al. 2012)

3.3.2 Scope

As the hydrothermal resource is not known to be available in the Eastern Interconnection, the EISPC EZ Mapping Tool focuses on EGS and geopressured reservoirs for production of electricity from these geothermal resources.

In addition to these geothermal resources, there is the potential to use the thermal energy in oil and gas reservoirs for the co-production of electricity. Because of the geographically distributed nature of oil and gas wells, co-production systems are expected to consist of small (<1 MW), modular units. However, these resources are more appropriately considered a distributed energy resource and are not included in the EISPC EZ Mapping Tool.

Although it is also possible to produce water from abandoned oil and gas wells, the additional costs to generate electricity from these wells, including well workover costs and transmission infrastructure costs, would result in less favorable economics than actively producing wells. These costs would be almost entirely allocated to geothermal electricity generation as little oil or gas would be expected to be recovered. In addition, since the wells are designed for oil and/or gas production, the maximum flow rate that can be achieved from these wells is limited to values lower than those typically achieved for geothermal electricity generation. It should be noted that
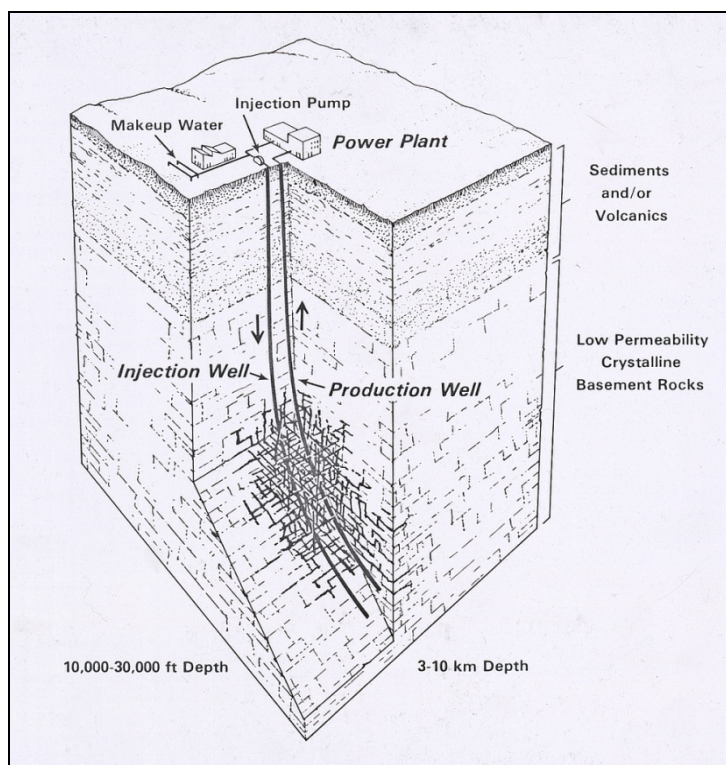
**Figure 3-9 Schematic of a Two-Well EGS in Hot Rock
(Source: MIT 2006)**

the EGS resource estimate essentially captures the geothermal resource potential in sedimentary basins, where oil and gas production originates. Since that estimate does not distinguish between the rock type at depth, whether it be in sedimentary basins or in granitic basement rock, the thermal resources that could be tapped from re-opening abandoned oil and gas wells is implicitly included in the EGS resource potential estimate.

3.3.3 Resource Description

EGS expands the potential of geothermal energy by orders of magnitude. The traditional geothermal approach relies on finding naturally occurring pockets of steam and hot water. The EGS process, by comparison, replicates these conditions by fracturing hot rock, circulating water through the system, and using the resulting hot fluid to produce electricity in a conventional flash or binary power cycle, depending on its temperature. The water is then re-injected back into the rock, where the cycle begins again in a closed loop (Figure 3-9).

Large zones of hot, highly pressurized fluids occur in deep strata under the Gulf Coast (Figure 3-11). This so-called "geopressured-geothermal" resource was studied extensively in the 1970s and 1980s, and DOE operated a test well near Houston, Texas. Typically, geopressured zones are at depths on the order of 15,000 ft and the fluid itself is a hot (about 300˚F), high-pressure brine with methane dissolved in it. Interest in the resource may be driven as much by the potential methane recovery as by its geothermal energy (Texas State Energy Conservation Office undated).
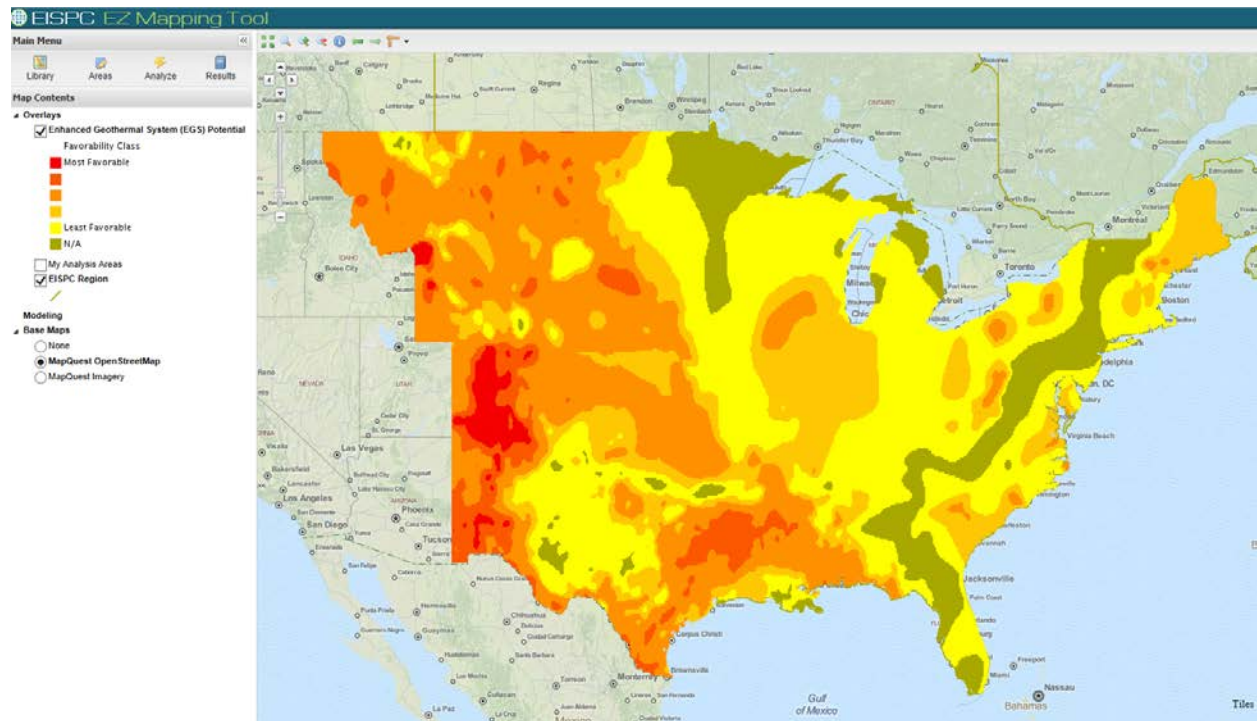
Figure 3-10 EGS Resources in the Eastern Interconnection (Source: EISPC EZ Mapping Tool)
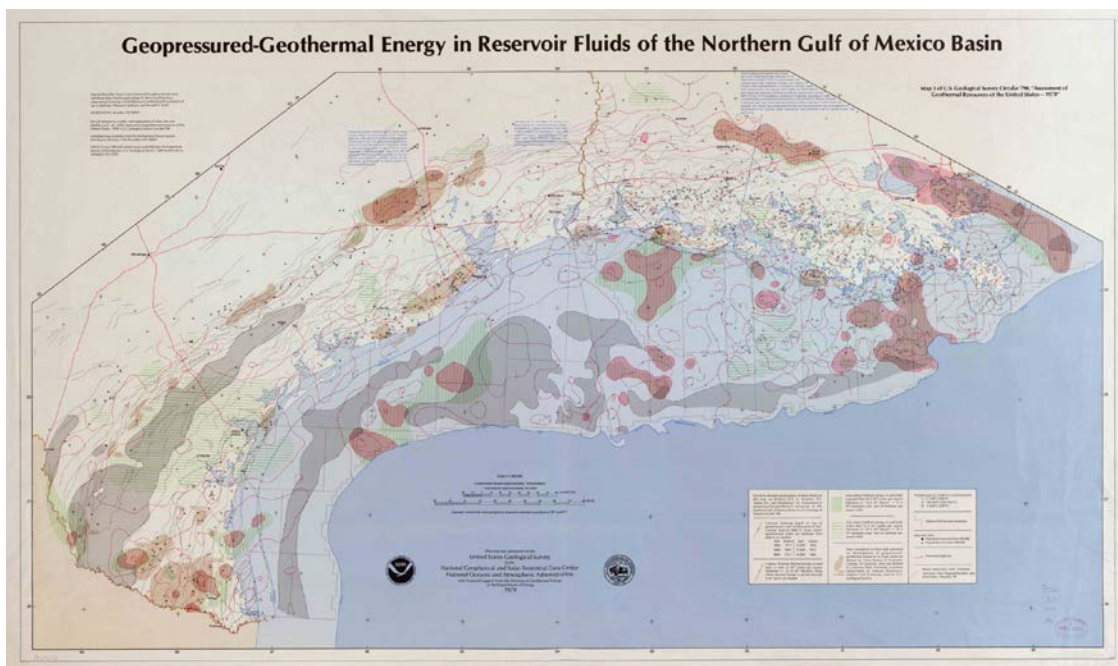
Figure 3-11 Geopressured Geothermal Resources in the Northern Gulf of Mexico (Source: National Geophysical and Solar-Terrestrial Data Center 1979)

3.3.4 Conversion Technologies

The conventional flash steam power plants used with hydrothermal resources use geothermal reservoirs of water with temperatures greater than 360°F (182°C). This hot water flows under its own pressure from the wells. As it flows upward, the pressure decreases and some of the hot water boils into steam. The steam is then separated from the water and used to power a turbine/generator. The water and condensed steam are injected back into the reservoir, making this a renewable resource. It is expected that most of the EGS resources will use binary cycle power plants. Binary cycle plants use the hot water resource to boil a working fluid, usually an organic compound with an appropriate boiling point. The water and the working fluid are kept separated during the whole process. The working fluid is vaporized in a heat exchanger and used to turn a turbine. The water is then injected back into the ground to be reheated.

Many of the technologies required for EGS, such as drilling and power plant technologies, are commercially available and already used in the hydrothermal or oil and gas industry. The technologies to create artificial geothermal reservoirs and manage these reservoirs over their lifetime are the major technical challenge. Technical feasibility of EGS concepts were first demonstrated at Fenton Hill in New Mexico in the late 1970s (MIT 2006, p. 4–5); however, the technology remains commercially immature. Key performance issues that must be addressed to enable commercialization include the techniques for creating the artificial reservoir of adequate size and flow characteristics so that significant thermal "drawdown" does not occur over the lifetime of the reservoir, achieving adequate flow connectivity to avoid excessive pressure losses in the reservoir, and preventing or repairing fluid circulation short circuits in the reservoir (MIT 2006). Demonstration projects are currently under way in the United States, Europe, and Australia.

Geopressured geothermal systems are closely related to the technology that can be used in co-production from oil and gas wells. They operate under the same principle but use wells drilled into naturally pressurized sedimentary reservoirs in which natural gas is dissolved in a high-temperature brine.[10] Although neither technology has been deployed on a commercial scale, both technologies have been successfully demonstrated by DOE-funded projects (Johnson and Walker 2010; Campbell and Hattar 1990), and there are no major technical barriers to either technology system. Because of the distributed nature of the resource, co-produced and geopressured power plants are expected to consist of small, modular units ranging in size from 0.25 to 10 MW. The larger geopressured systems may be aggregated into "geothermal farms."

3.3.5 Screening Factors

Screening factors relate to both the availability of the resource and specific needs of the energy conversion technology. For the purpose of this analysis, the screening factors used to screen areas for the specified geothermal technologies (in addition to the resource availability) are listed in Table 3-6, and the specific default suitability criteria and specific ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4. Informational layers may also be useful for

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[10] Not all geopressured reservoirs are necessarily at high temperatures.

Table 3-6 Geothermal Screening Factors

Geothermal Technology	Screening Parameter
Enhanced geothermal system	Population density Slope Land cover area Distance to rivers (>130,000 gpm) Proximity to electric transmission (>220 kV) Protected Land Habitat Imperiled Species
Geopressured geothermal	Slope Land cover area Protected Land Habitat Imperiled Species

additional analysis by overlaying them onto the suitability model results. The extensive list of EZ Mapping Tool informational layers is included in Appendix B.

3.3.6 Data and Sources

Table 3-7 lists the geothermal resource data and sources. Publically available data to construct the screening factor layers for geothermal technologies are available from a variety of sources and are listed in Table 3-8. The Protected Land, Habitat, and Imperiled Species screening layers and data sources are discussed in Section 4.

3.4 Natural Gas

3.4.1 Introduction

Natural gas is a highly abundant fuel. Exploration and the development of new extraction technologies have increased the potential supply. A well-developed pipeline system already exists to transport the fuel. Natural gas is essentially methane, a carbon compound, that releases CO_2 and water vapor when combusted. The CO_2 release from natural gas per million British thermal units (Btu) produced is approximately 55% of the release from coal combustion, and it does not contain the ash or sulfur content of coal, which eliminates the need for SO_2 scrubbers and material handling of collected pollutants. Technological developments have enhanced the efficiency of generation with natural gas to further reduce the carbon emission of gas-fired generation. Combined-cycle plants have nearly double the efficiency of conventional steam turbine plants.

Table 3-7 Geothermal Data and Sources[a]

Resource	Data and Source
Enhanced geothermal systems	NREL analysis of EGS favorability (Augustine 2011) based on temperature at depth maps from Southern Methodist University (SMU). Latest temperature-at-depth data could not be procured from SMU, thus analysis could not be updated.
Geopressured resource data	Data on the geopressured resource are available from Map 3 of USGS Circular 790 report, "Assessment of the Geothermal Resources of the United States – 1978," L.J.P. Muffler, Editor (1979). Map has been digitized, and shape files of the following information from the map have been created: Thermal energy in sandstone layers (contours) Depth to geopressured zones
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

Table 3-8 Geothermal Screening Factor Data and Sources[a]

Factor (Parameter)	Data and Source
Population density	LandScan™, http://www.ornl.gov/sci/landscan/
Slope	2012 NGA Digital Terrain Elevation data/calculated and resized for 250-m cells
Land cover area	2011 USGS
Distance to rivers/surface water flow	2012 USGS/National Hydrologic data (Version 2)
Electric transmission data	2012 Bentek Energy/Platts
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

3.4.2 Scope

The scope of this analysis focused on combined-cycle gas turbine (CCGT) central generating stations of at least 500-MW capacity, underground storage of compressed natural gas, and aboveground storage of liquefied natural gas (LNG).

The use of natural gas to displace the use of oil and coal in conventional generation is not in the scope of this study. Exclusion of plant fuel conversions does not exclude the concept of adopting sites of retired plants for construction of new combined-cycle plants.

3.4.3 Resource Description

In 2011, 22.9 trillion cubic feet (Tcf) of dry natural gas (about 94% of consumption) was produced in the United States (EIA 2013a). Texas produced the greatest percentage (30%), and the next highest states included Louisiana (13%), Wyoming (9%), and Oklahoma (8%). Gas was produced in 32 states plus the Outer Continental Shelf. The majority was recovered from conventional reservoirs (i.e., from natural gas wells [43%] or co-existing with crude oil [21%]) (Figure 3-12).

However, the lower 48 states also contain substantial amounts of gas in unconventional reservoirs such as shale formations, 470 Tcf (see Figure 3-13); coal bed formations, 90 Tcf (Figure 3-14); and tight gas formations, 357 Tcf (Figure 3-15). Future production profiles will be
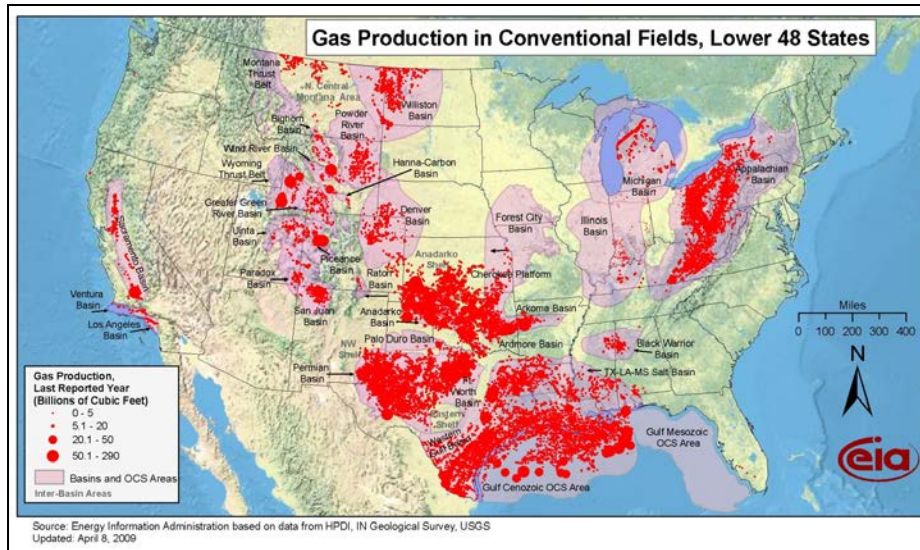
**Figure 3-12 Conventional Natural Gas Production Fields
(Source: EIA 2009a)**
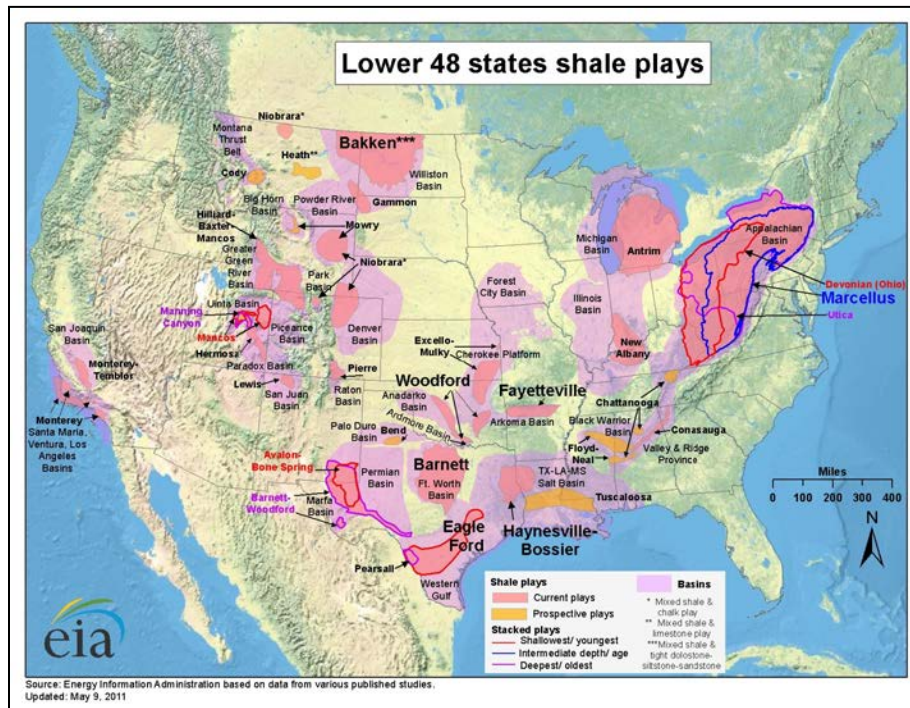
Figure 3-13 Shale Gas Plays in the Lower 48 States (Source: EIA 2011)
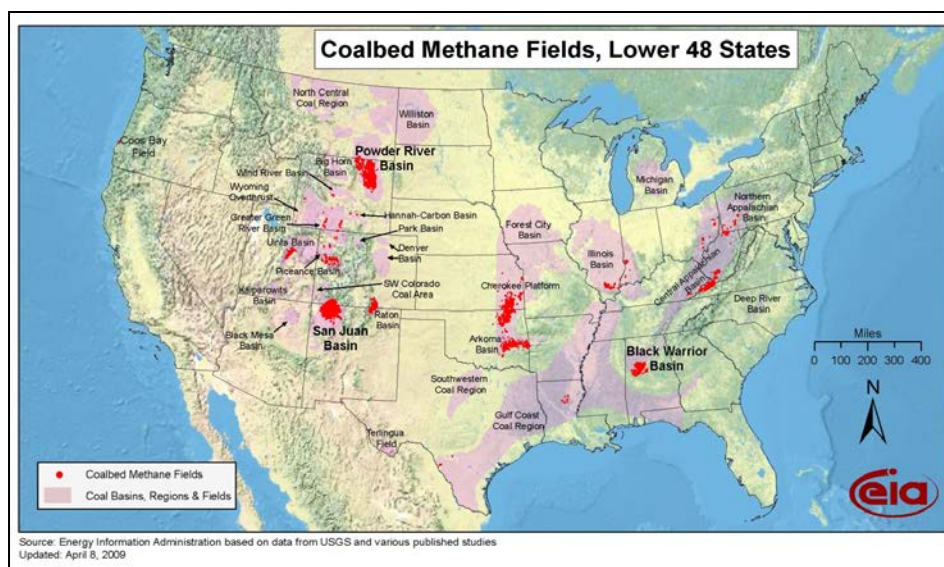
Figure 3-14 Coal Bed Methane Gas Fields in the Lower 48 States (Source: EIA 2009b)
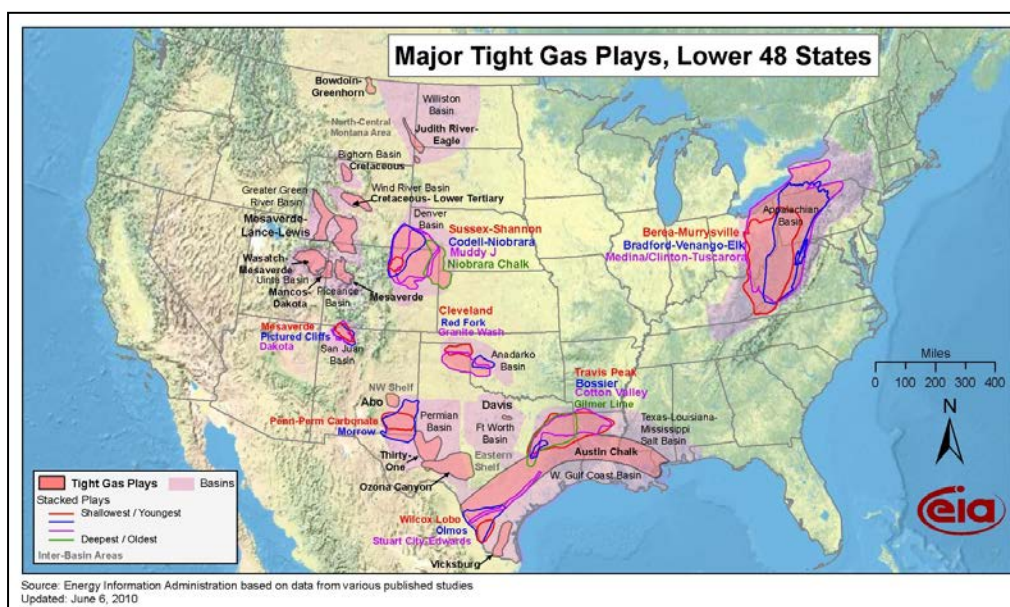
Figure 3-15 Major Tight Gas Plays in the Lower 48 States (Source: EIA 2010)

influenced greatly by the introduction of new unconventional supplies, including, for example, the initially estimated 500 Tcf of recoverable gas in the Marcellus Shale Gas Play, part of the Devonian Black Shale Succession (Figure 3-16). Shale gas production has grown from 0% in 2006 to 30% of total production in 2011 (EIA 2013a).

More recent estimates anticipating the application of technological advancements developed in gas recovery from shale formations in Texas place the total amount of recoverable gas as high as
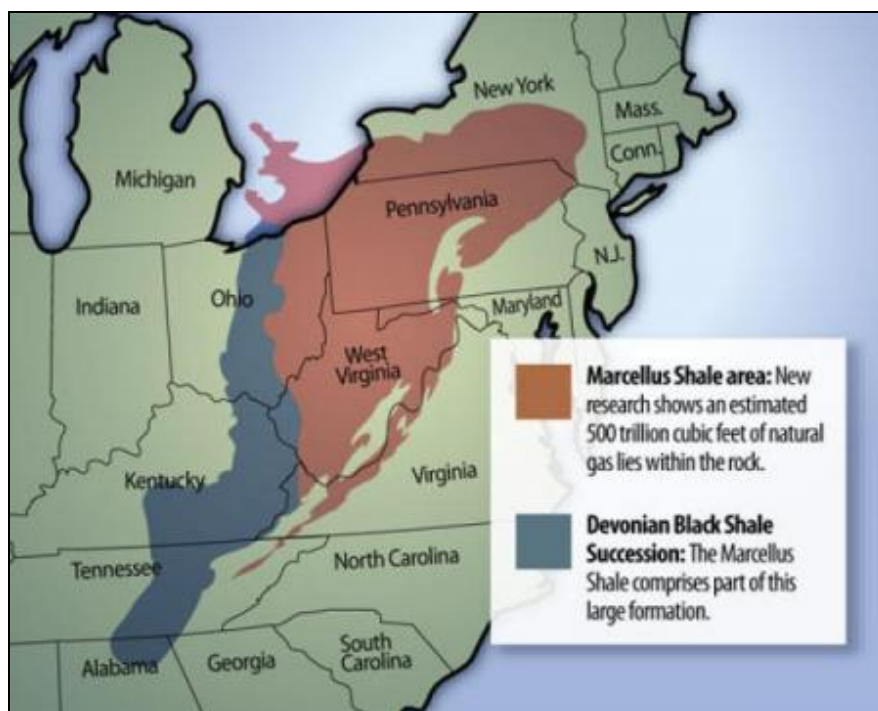
Figure 3-16 Marcellus Shale and the Devonian Black Shale Areas (Source: Weber 2010)

1.3 quadrillion cubic feet (Qcf). In response to these estimates, as many as 24 pipeline expansion projects have been announced by companies with existing pipeline infrastructures in the vicinity of the formation to bring gas from this formation to market (Weber 2010). The EIA, in its Annual Energy Outlook 2013 release overview, projects that production of gas from shale formations will increase from approximately 23.0 Tcf/yr in 2011 to 33.0 Tcf/yr by 2040 (EIA 2012a).

The U.S. natural gas pipeline network is a highly integrated transmission and distribution grid that can transport natural gas to and from nearly any location in the lower 48 states (Figure 3-17). For more details on the interstate and intrastate pipelines, state-to-state capacity, and pipeline projects, see the web links in the references in Section 9.

On the basis of data generated from the 2009 annual report to the Pipeline and Hazardous Materials Safety Administration (PHMSA) from pipeline operators (http://primis.phmsa.dot.gov/comm/PipelineBasics.htm?nocache=699), the network includes approximately:

- 321,000 mi of onshore and offshore gas transmission and gathering pipelines,

- 2,066,000 mi of gas distribution mains and service pipelines, and

- 114 active LNG plants connected to U.S. gas transmission and distribution systems.
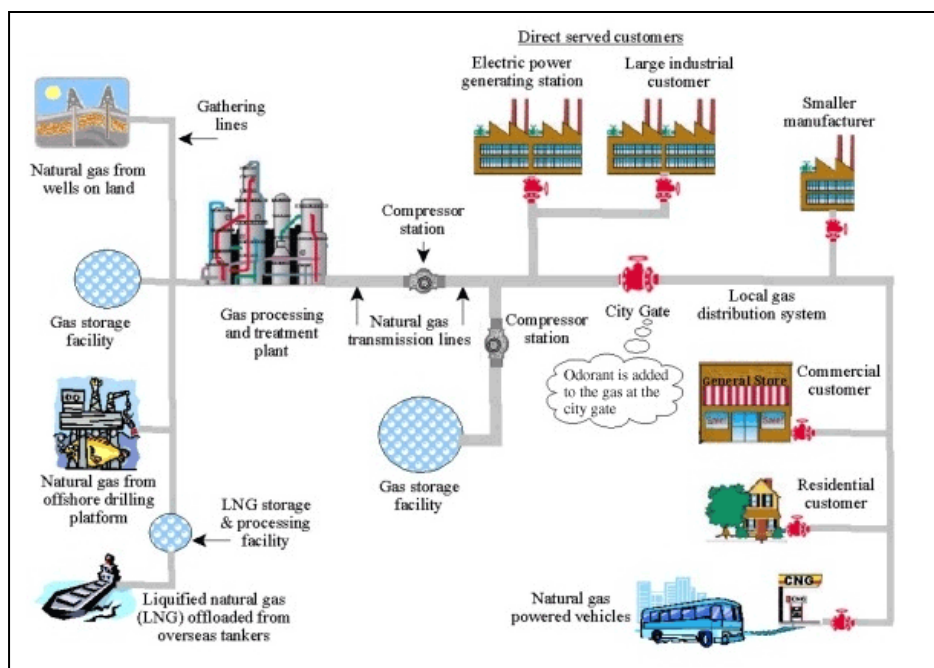
Figure 3-17 Natural Gas Pipeline System (Source: PHMSA 2005–2011)

The ability to transport natural gas from producing regions to consumption regions also affects the availability of supplies to the marketplace. The interstate and intrastate pipeline infrastructure in essence provides a "ceiling" for the amount of natural gas that can reach the market. The EIA estimates daily delivery capacity of the pipeline grid to be 148 billion cubic feet (Bcf) [http://www.naturalgas.org/business/supply.asp#liquifiedng]. Despite a relatively abundant supply of natural gas at the wellhead and shale gas play due to the proliferation of wells seeking to exploit unconventional resources, gas supply is still constrained by pipeline capacity. (For more information about these constraints, see Skutnik 2013 and EIA 2013b).

In addition, the U.S. Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) (formerly the U.S. Department of Interior's (DOI's) Minerals Management Service [MMS]) provided the forecast for Gulf of Mexico gas production during the period 2007 to 2016 based on existing shallow and deep water operator commitments. BOEMRE estimates that Gulf of Mexico gas production could exceed 9 Bcf/day (Karl et al. 2007).

3.4.3.1 Underground Storage

Natural gas can be stored underground or aboveground in a number of different ways. It is most commonly held in inventory underground and under pressure in three types of facilities: (1) depleted reservoirs in oil and/or gas fields, (2) aquifers, and (3) salt cavern formations. Each storage type has its own physical characteristics (porosity, permeability, and retention capability) and economics (site preparation and maintenance costs, deliverability rates, and cycling capability) which govern its suitability to particular applications. Two of the most important characteristics of an underground storage reservoir are its capacity to hold natural gas for future use and the deliverability rate at which the gas inventory can be withdrawn.

Most existing gas storage in the United States is in depleted natural gas or oil fields that are close to consumption centers. Conversion of a field from a production to storage state takes advantage of existing wells, gathering systems, and pipeline connections. Depleted oil and gas reservoirs are the most commonly used underground storage sites because of their wide availability and economics.

In some areas, most notably the Midwestern United States, natural aquifers have been converted to gas storage reservoirs. An aquifer is suitable for gas storage if the water-bearing sedimentary rock formation is overlaid with an impermeable cap rock. While the geology of aquifers is similar to depleted production fields, their use in gas storage usually requires more base (or cushion) gas and greater monitoring of withdrawal and injection performance. Deliverability rates may be enhanced by the presence of an active water drive.

Salt caverns provide very high withdrawal and injection rates relative to their working gas capacity. Base gas requirements are relatively low. The large majority of salt cavern storage facilities have been developed in salt dome formations located in the Gulf Coast states. Salt caverns have also been leached from bedded salt formations in Northeastern, Midwestern, and Southwestern states. Cavern construction is more costly than depleted field conversions when measured on the basis of dollars per thousand cubic feet of working gas capacity; however, the ability to perform several withdrawal and injection cycles each year reduces the per-unit cost of each thousand cubic feet of gas injected and withdrawn.

Efforts have been made to use abandoned mines to store natural gas, with at least one such facility having been in use in the United States in the past. Further, the potential for commercial use of hard-rock cavern storage is currently undergoing testing. None are commercially operational as natural gas storage sites at the present time. Figure 3-18 is a stylized representation of the various types of underground storage facilities, while Figure 3-19 shows the locations of underground storage facilities in the lower 48 states.

3.4.3.2 Aboveground Storage of LNG

LNG is natural gas that is cooled to -260°F until it becomes a liquid and then stored at essentially atmospheric pressure. Converting natural gas to LNG, a process that reduces its volume by about 600 times, allows it to be transported internationally by specialized tankers with insulated walls. It is kept in liquid form by auto refrigeration, a process in which the LNG is kept at its boiling point, so that any heat additions are countered by the energy lost from LNG vapor that is vented out of storage and used to power the vessel. Once delivered to its destination in the United States or abroad, the LNG is warmed back into its original gaseous state so that it can be used just like existing natural gas supplies, by sending it through pipelines for distribution to homes and businesses. The LNG supply chain includes natural gas exploration/production, liquefaction, shipping, and regasification/storage. Figure 3-20 shows an LNG storage and peak shaving facility, and Figure 3-21 shows the locations of U.S. LNG peak shaving and import terminal facilities.

Imported LNG accounts for slightly more than 1% of natural gas used in the United States. According to the EIA, the United States imported 0.41 Tcf of natural gas in the form of LNG in 2010. However, because of increased domestic production, LNG imports are expected to
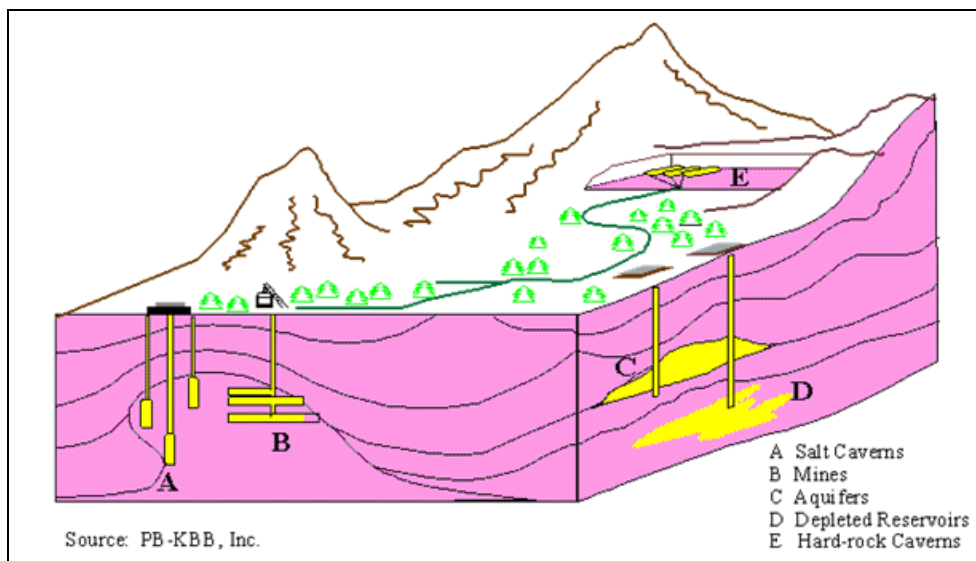
Figure 3-18 Types of Underground Natural Gas Storage Facilities (Source: EIA 2004)
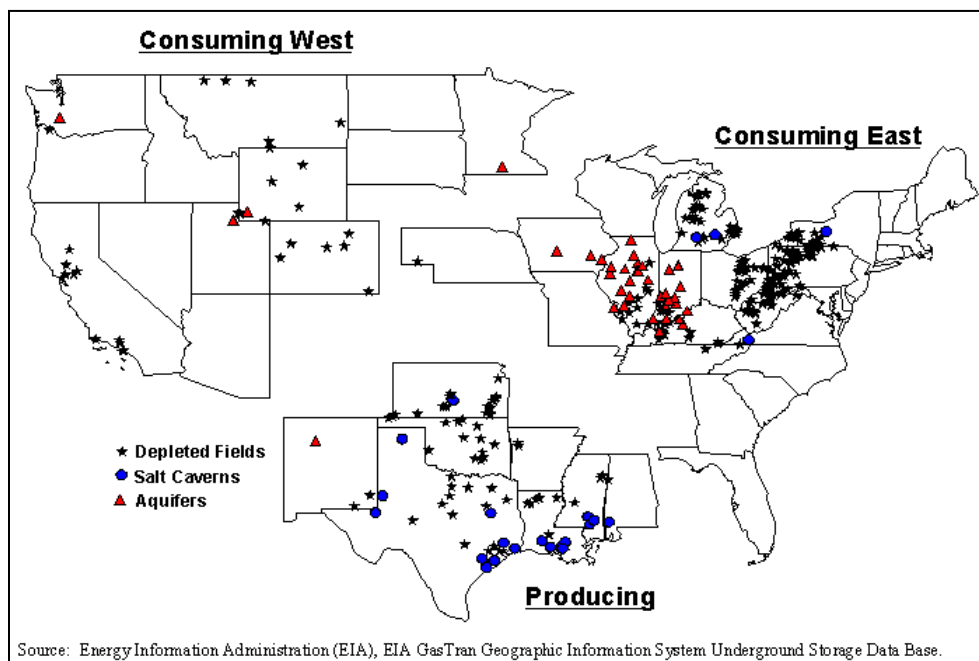
Figure 3-19 Underground Natural Gas Storage Facilities in the Lower 48 States (Source: EIA 2004)

Figure 3-20 LNG Storage and Peak Shaving Facility (Source: DOE 2005)

decrease by an average annual rate of 4.1%, to levels of 0.14 Tcf of natural gas by 2035. More recent EIA projections show a reversal in the market due to the availability of large amounts of unconventional natural gas. The United States is projected to be a net exporter by 2021 (EIA 2012a). LNG imports represent an important part of the natural gas supply picture in the United States. LNG takes up much less space than gaseous natural gas, which allows it to be shipped much more efficiently. The United States gets a majority of its LNG from Trinidad and Tobago, Qatar, and Algeria, and also receives shipments from Nigeria, Oman, Australia, Indonesia, and the United Arab Emirates (http://www.naturalgas.org/business/ supply.asp#liquifiedng).

As with any industry, LNG operators must conform to all relevant national and local regulations, standards, and codes. The four requirements for safety—primary containment (safe storage and isolation of LNG), secondary containment (leaks or spills contained and isolated), safeguard systems (minimize release of LNG and mitigate the effects of a release), and separation distance (LNG facilities must be sited at a safe distance from adjacent industrial, communities and other public areas)—apply across the LNG value chain, from production, liquefaction, and shipping, to storage and re-gasification (Michot Foss 2012). DOE helps to coordinate across federal agencies that have regulatory and policy authority for LNG, while the Federal Energy Regulatory Commission (FERC) is responsible for permitting new onshore LNG regasification terminals and ensuring safety at these facilities. The U.S. Department of Transportation (DOT) regulates offshore terminals and LNG tanker operations, and the United States Coast Guard (USCG) is responsible for assuring the safety of all marine operations at all LNG terminals and on tankers

Note: Satellite LNG facilities have no liquefaction facilities. All supplies are transported to the site via tanker truck.
Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division Gas, Gas Transportation Information System, December 2008.
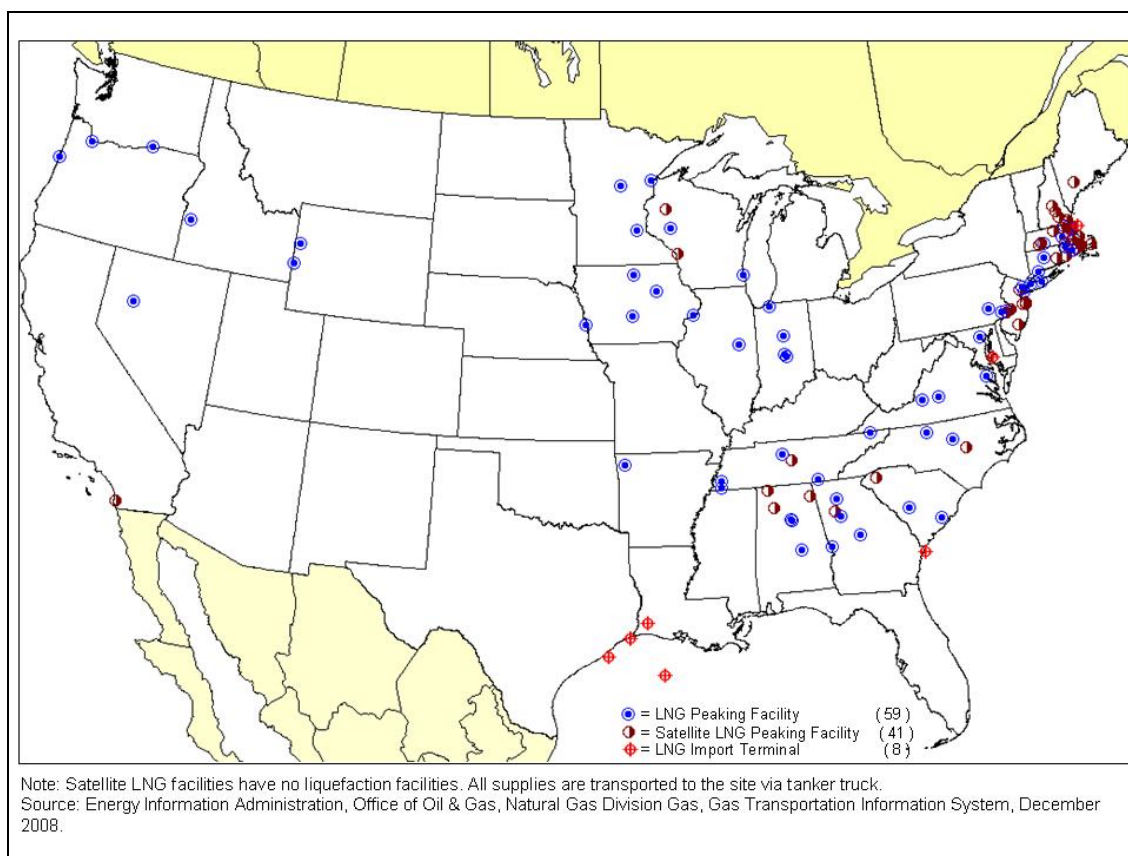
Figure 3-21 U.S. LNG Peak Shaving and Import Facilities (Source: EIA 2008)

in U.S. coastal waters. The EPA and state environmental agencies establish air and water standards with which the LNG industry must comply. Other involved agencies include the U.S. Army Corps of Engineers (USACE); U.S. Fish and Wildlife Service (USFWS); BOEMRE (formerly MMS is responsible for offshore activities); National Oceanic and Atmospheric Administration (NOAA); and state, county, and local (municipal) agencies. All have key roles in ensuring safe and environmentally sound construction and operation of LNG industry facilities (Delano 2004).

3.4.4 Conversion Technologies

CCGT is the dominant gas-based technology for intermediate and baseload power. A review of the Platts database revealed 194 operating combined-cycle plants greater than 500 MW in the Eastern Interconnection. Heat recovery steam generators (HRSGs) are usually built for horizontal gas flow, thus increasing the area required when compared to a conventional fossil-fueled steam plant. However, gas plants do not require acreage for coal storage and coal train unloading, nor for dewatering ponds for ash and slag, and do not need space for sulfur scrubbers and other types of pollution control technology. Assuming that the steam cycle would employ cooling towers for the steam condensers, a 500-MW plant would require about 100 acres.

A CCGT plant is a dual-cycle plant that consists of one or more gas turbine electricity generators; the second part of the CCGT is equipped with HRSGs to capture heat from the gas turbine exhaust (Figure 3-22). It takes advantage of the energy in the exhaust gases to create steam with recovered waste heat. The HRSGs may be equipped with a bypass damper that allows the gas turbine to operate independently from the steam cycle, which makes plant operation more responsive and flexible. Steam produced in the HRSG powers a steam turbine generator to produce additional electric power (WSU undated). The combustion turbine will produce 60% to 70% of the electric output, with the balance created by the steam turbine.

The efficiency of a simple cycle steam plant, based on current design technology, is approximately 35%. The hot gases of combustion in the steam boiler leave the smokestack at 300°F, accounting for 15% of the loss. The balance of the waste energy is lost during the phase change of the steam exhaust from the turbine. The combustion turbine combined cycle can achieve efficiency of 60%.

3.4.5 Screening Factors

Screening criteria for coal and nuclear technology were used as a basis for developing the natural gas screening factors (Table 3-9). The criteria were modified on the basis of the unique characteristics of natural gas technologies. The specific default suitability criteria and specific ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4.
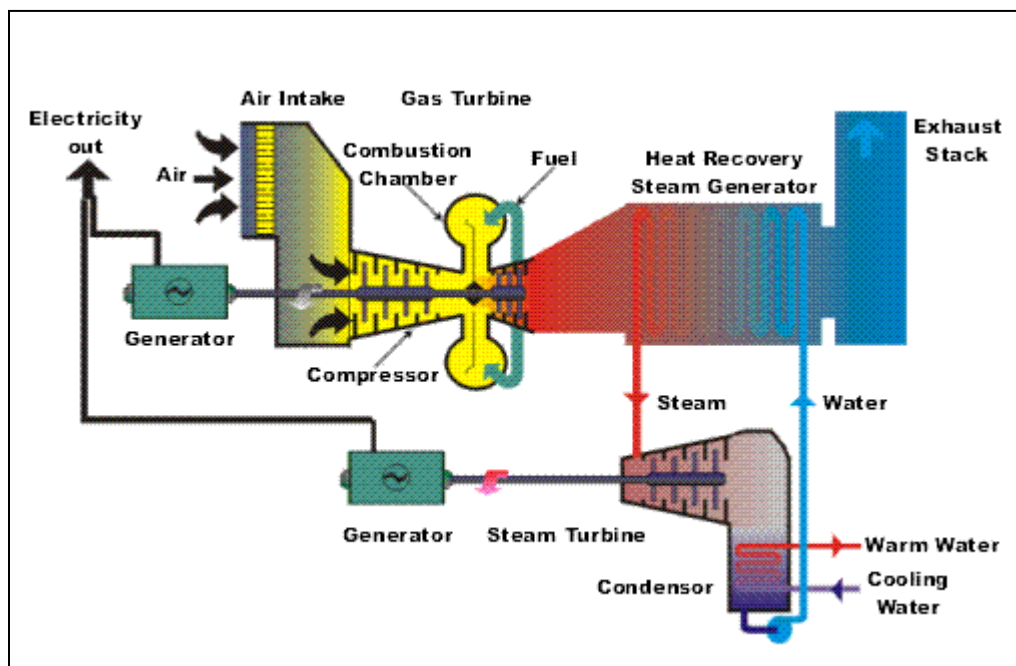
Figure 3-22 Schematic of Combined-Cycle Plant Process (Source: Nooter Eriksen undated)

Table 3-9 Natural Gas Screening Factors

Natural Gas Technology	Screening Parameter
Combined-cycle gas turbine power plant	Distance to natural gas transmission pipeline (≥12 in) Population density Slope Land cover area Distance to rivers (>100,000 gpm) 100-yr flood zone Distance to railroad Distance to port (barge locations) Proximity to electric transmission (≥100kV) Protected Land Habitat Imperiled Species
Underground natural gas storage	Distance to natural gas transmission pipeline (≥12 in) Aquifer area Distance to domal salt formation Population density Land cover area 100-yr flood zone Distance to railroad Distance to major road Proximity to electric transmission (>100kV) Protected Land Habitat Imperiled Species
Aboveground natural gas storage (LNG)	Distance to natural gas transmission pipeline (≥12 in) Population density Slope Land cover area 100-yr flood zone Proximity to electric transmission (>100kV) Protected Land Habitat Imperiled Species

Population density of greater than 1,000 people per square mile begins to transition into a highly urban setting, thus new combined-cycle power plants in these areas are not likely based on anticipated available space and zoning restrictions. Review of the inventory of existing CCGT plants of 500 MW or more confirms this conclusion. LNG facilities require a very low population density, since a buffer exclusion zone is required for safety reasons. Numerous overlapping jurisdictions must be addressed to develop an LNG storage site, based on federal, state, and local legislation. The criteria presented for LNG only provide a broad interpretation of these concerns.

Construction of a gas power plant requires building a lateral pipeline from a major natural gas pipeline in order to operate. For this reason, it is assumed that the gas power plant will interconnect with a pipeline. The same consideration is assumed to apply to both underground

storage and aboveground LNG storage. Access to high-voltage transmission for an outlet of the power produced is essential for the CCGT. It is also highly desirable to provide service to the storage facilities, even though they may self-generate.

Available water for cooling is a common need for all thermoelectric power plants. A report prepared by NETL for DOE provides water consumption factors (NETL 2008). Water is also required at storage facilities, but it is assumed that the much lower required volumes can be supplied from wells.

In all categories, protected land is excluded, including parks, schools, airports, wildlife, and conservation areas. In the case of underground storage, the footprint of the storage field belowground will vary. The identified zone will only address the storage access point and not the entire formation.

The application of ground slope is completely based on industry experience. Because there is a tradeoff between cost and the severity of terrain, mild slope is always desirable but not an exclusion criterion. However, locating tanks for LNG would seem prudent only in areas of mild slope.

The transportation of large components by rail, road, or barge is deemed an important practical consideration for the construction of a CCGT plant as well as storage facilities, with the associated compression, expansion, and treatment equipment needed.

Informational layers may also be useful for additional analysis by overlaying them onto the suitability model results. The extensive list of EZ Mapping Tool informational layers is included in Appendix B.

3.4.6 Data and Sources

Publicly available data to construct the screening factors for natural gas technologies are available from a variety of sources (Table 3-10). The Protected Land, Habitat, and Imperiled Species screening layers are discussed in Section 4.

3.5 Nuclear

3.5.1 Introduction

Currently, 65 commercial nuclear power plants with 104 reactors (nuclear units) are licensed by the U.S. Nuclear Regulatory Commission (NRC) to operate in the United States.[11] These plants represent a highly reliable baseload electric power source across several large regions of the country. They constitute nearly 20% of the electricity generated and more than 70% of the country's "zero-carbon" electricity capacity. For 2011, nuclear power plants generated approximately 790 billion kWh.

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[11] Utilities have recently opted to permanently shut down 4 of the 104 licensed reactors.

Table 3-10 Natural Gas Data and Sources[a]

Parameter/Information	Data and Source
Distance to natural gas transmission pipeline	2012 Bentek Energy/ Platts
Population density	LandScan™, http://www.ornl.gov/sci/landscan/
Slope	2012 NGA Digital Terrain Elevation data/calculated and resized for 250-m cells
Distance to rivers/surface water flow (>100,000 gpm)	2012 USGS/National Hydrography Data (Version 2)
Land cover area	2011 USGS
100-yr flood zone	2011 FEMA National Flood Hazard, http:/www.msc.fema.gov
Distance to railroad	2012 FRA data
Distance to port	2012 USACE
Distance to major road	2012 National Transportation Atlas Database, www.bts.gov/publications/national_transportation_atlas_database/2012
Electric transmission data	2012 Bentek Energy/Platts
Aquifer areas	2011 USGS
Salt caverns	2012, 2013 ORNL
[a]All metadata can be accessed via the EISPC EZ Mapping Tool.	

Five new plants are presently under construction—two in Georgia (Vogtle 3 and 4), two in South Carolina (Summer 2 and 3), and one in Tennessee (Watts Bar 2)—totaling approximately 5,000 MW(e) of new generation capacity.

Thirty-one states have one or more operating commercial nuclear power plants. For 2011, nuclear power composes the largest percentage of electric power generated for seven of these states:

- Vermont   72.5%

- New Jersey   52.1%

- South Carolina   51.2%

- Illinois   48.2%

- Connecticut   47.4%

- New Hampshire   41.5%

- Virginia   38.1%

These generating statistics and data were summarized from information contained at the Nuclear Energy Institute's website (NEI 2012). Figure 3-23 shows the location of each of the nuclear plants. The top five states for nuclear generation in 2011 were Illinois, Pennsylvania, South Carolina, New York, and North Carolina.

Sections 3.5.2 through 3.5.6 provide descriptions of the types of reactors that were considered for potential siting, illustrations of several reactor types, descriptions of the siting screening criteria employed for each type reactor, and data and sources for the screening factors.

3.5.2 Scope

The 104 operating commercial nuclear power units noted above are all light-water reactor (LWR) designs of varying power levels with 35 of them boiling-water reactors (BWRs) and 69 pressurized-water reactors (PWRs). For this study, three different types of reactors were considered: (1) large LWRs like those currently undergoing design certification and combined operating license reviews by the NRC; (2) small modular reactors (SMRs) based on PWR technology whose compact design features are expected to offer a host of safety, siting, construction, and economic benefits as well as ideal for small electric grids; and (3) high-temperature gas-cooled reactors (HTGRs) currently being considered for both electricity and process heat applications.

Advanced power reactor concepts (liquid-metal cooled reactors) and non-light water SMR concepts were considered out of scope for this study.
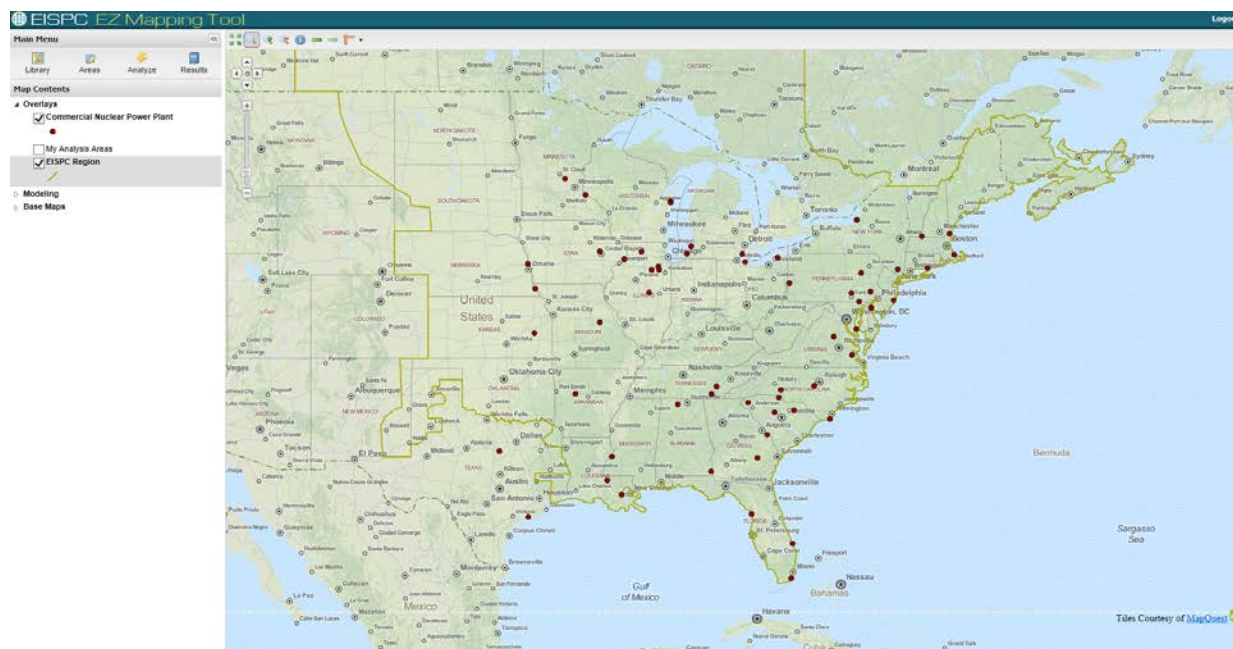
Figure 3-23 Locations of Existing Commercial Nuclear Power Plants in the U.S. Portion of the Eastern Interconnection (Source: EISPC EZ Mapping Tool)

3.5.3 Resource Description

Nuclear power plants, like plants that burn coal, oil and natural gas, produce electricity by boiling water into steam. This steam then turns turbines to produce electricity. However, nuclear plants do not burn anything; rather, they use uranium fuel, consisting of solid ceramic pellets, to produce electricity through a process called fission. Nuclear power plants obtain the heat needed to produce steam through the fission that involves the splitting of atoms of uranium in the fuel of a nuclear reactor.

The uranium fuel consists of small, hard ceramic pellets that are packaged into long, vertical tubes. Bundles of this fuel are inserted into the reactor. Nuclear fuel consists of two types of uranium, ^{238}U and ^{235}U. Most of the uranium in nuclear fuel is ^{238}U, but ^{235}U splits, or fissions Typical commercial nuclear fuel is enriched to about 5% ^{235}U to achieve a self-sustaining fission process. Figure 3-24 is a schematic of a current generation PWR that illustrates the major systems of PWR nuclear power plants.

Natural gas represents the largest share of electric power generation capacity, followed by coal, nuclear power, and conventional hydropower. Natural gas and coal capacity are each much larger than nuclear capacity. However, for cost and technical reasons, nuclear power plants are generally utilized more intensively than coal or natural gas units. In 2011, the nuclear share of electricity generating capacity was 9%, while nuclear's share of national power generation was 19%. The comparable values were 28% capacity to 42% generation for coal, and 41% capacity to 25% generation for natural gas (EIA 2012).

The above noted "intensity" factor is related to the extraordinarily high-energy density of nuclear fuel relative to fossil fuels and consequent low fuel cost. For example, 1 kilogram (kg) of firewood can produce 1 kWh of electricity. Comparable values for other fossil fuels and nuclear are as follows:

- 1 kg of coal => 3 kWh

- 1 kg of oil => 4 kWh

- 1 kg of uranium => 50,000 kWh

3.5.4 Conversion Technologies

"Large LWRs" are currently undergoing design certification and combined operating license reviews by the NRC and are commonly referred to as Generation III+ (Gen III+) designs, in the 1,100- to 1,600-MW(e) range. Those that are characterized as passive with regard to safety do not require active controls or operator intervention, but instead rely on gravity or natural convection to mitigate the impact of abnormal events and provide emergency cooling. These reactors (both PWRs and BWRs) represent the next evolution of designs beyond those 104 currently operating commercial nuclear power reactors. Examples include Hitachi-GE's Economic Simplified Boiling-Water Reactor (ESBWR), AREVA's European Pressurized Reactor (EPR), Mitsubishi's Advanced Pressurized-Water Reactor (APWR), and
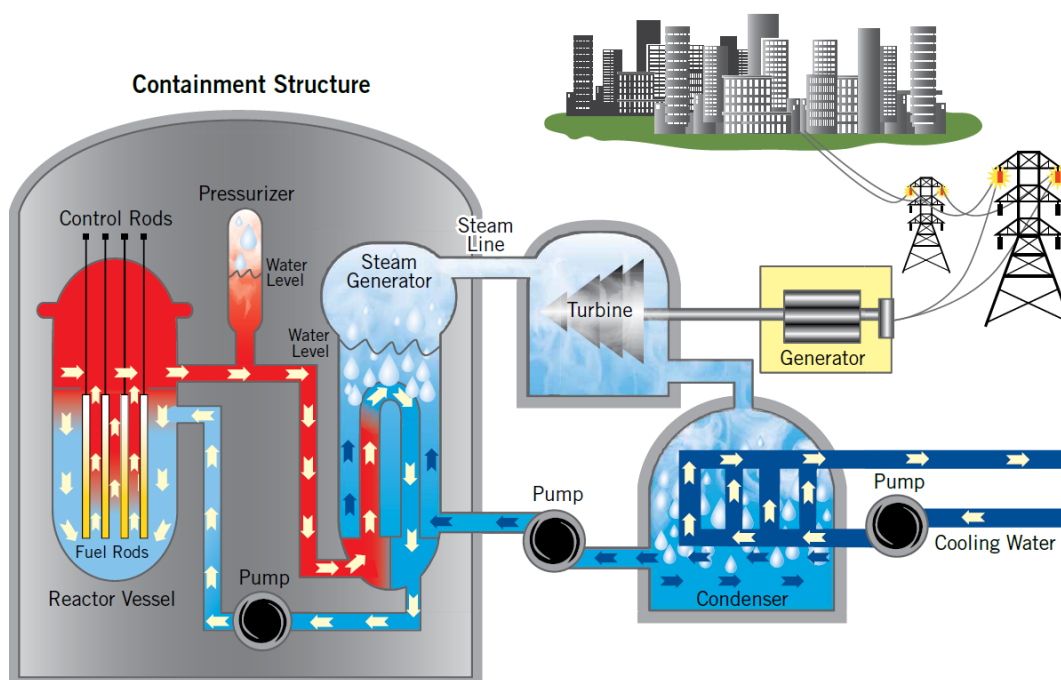
Figure 3-24 Schematic of PWR Illustrating Generation of Electrical Power (Source: ANS 2013)

Westinghouse's AP1000®PWR. The four reactors that recently received an approved combined operating license (COL) from the NRC and have initiated construction—two in Georgia (Vogtle 3 and 4) received their COL in February 2012 and two in South Carolina (Summer 2 and 3) received their COL in March 2012—are using Westinghouse's approved AP1000 standardized reactor design. Figure 3-25 illustrates the AP1000 PWR plant design.

SMRs have design features that will provide safety, siting, construction, and economic benefits. Furthermore, these smaller plants are ideally suited for small electric grids and for locations that cannot support large reactors, thus providing utilities with the flexibility to scale production as demand changes by adding more modules or reactors in phases. The near term SMR designs are based on existing PWR technology. They are characterized as "integral" PWRs (iPWRs), since these plants will have major equipment such as pumps, steam generators, and pressurizers, all located within the pressure vessel in an integrated, compact design. These designs are typically in the 25 to 250 MW(e) power range. In 2012, DOE initiated an "SMR Licensing Technical Support Program" through a funding opportunity announcement to accelerate the deployment and commercialization of SMR technologies. This program represents a 5-year cost-share industry partnership. In December 2012, the Babcock & Wilcox Generation mPower™ design was selected as part of this program.

Figure 3-26 is a simple illustration of the principal design differences between an iPWR SMR and a loop-type PWR, including the elimination of the two, three, or four loops (only one pictured) for the large PWR, piping diameter size difference, and the major equipment for the iPWR being located within the pressure vessel. Another distinguishing design feature that is not illustrated in Figure 3-26 is the elongated (taller) core design for the iPWR. The vessel height-to-

1. Fuel-handling Area
2. Concrete Shield Building
3. Steel Containment
4. Passive Containment Cooling Water Tank
5. Steam Generators (2)
6. Reactor Coolant Pumps (4)
7. Reactor Vessel
8. Integrated Head Package
9. Pressurizer
10. Main Control Room
11. Feedwater Pumps
12. Turbine Generator
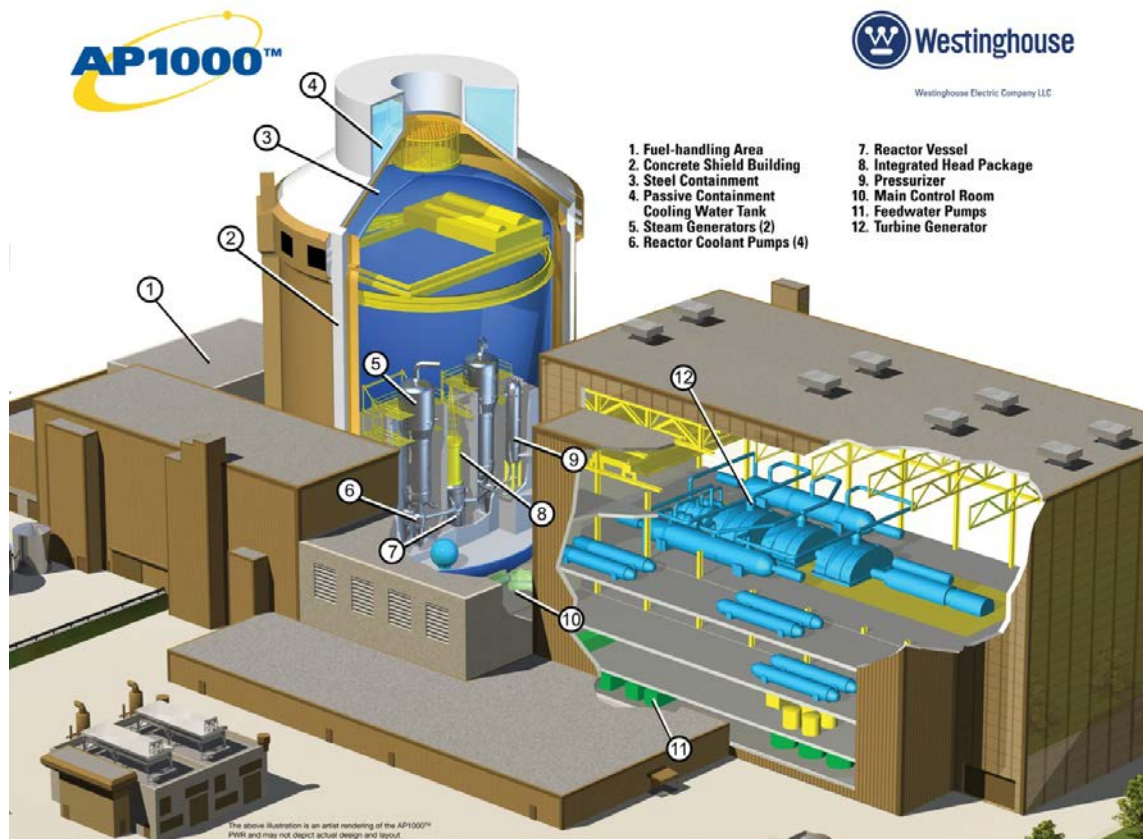
Figure 3-25 Plant Design and Layout of Westinghouse AP1000 PWR (Westinghouse Electric Company LLC 2013)
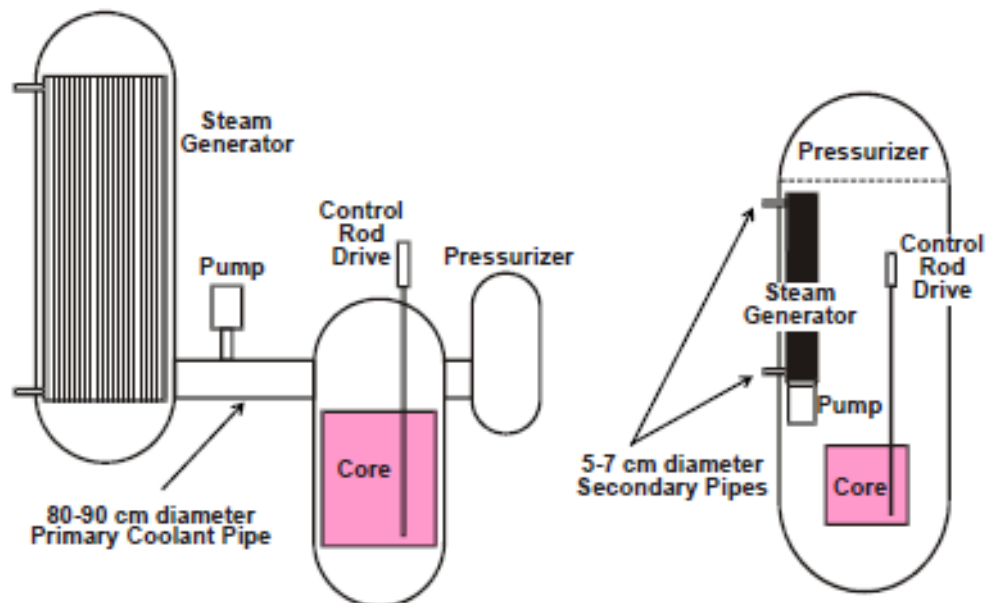
Figure 3-26 Comparison of Large PWR Design with iPWR Design for SMRs (Source: Ingersoll 2011)

diameter ratio for the near-term iPWRs will likely exceed 6.0, while that of a PWR and BWR are on the order of 2.5 and 2.0, respectively. This increase in the aspect ratio greatly facilitates the formation of gravity-driven natural convection circulation of the coolant, which enhances heat removal from the core and allows the plant to cool down safely in the event of a loss of off-site power without a requirement for emergency power (diesels or batteries) to drive circulation pumps (Ingersoll 2011).

The four SMR vendors whose integral designs are based on PWR technology include the following:

1. Babcock and Wilcox's m-Power SMR: 180 MW(e) per reactor module with the plan to deploy two 180-MWe modules/units at a time;

2. NuScale SMR: 45 MW(e) per reactor module with the plan to deploy 6 or 12 modules/units at a time;

3. Westinghouse SMR: 225 MW(e) per reactor with the plan to deploy one or more units individually; and

4. Holtec's SMR-160: 160 MW(e) per reactor with the plan to deploy one unit or multiple units individually.

All of these designs feature underground siting for safety and security reasons. All four vendors presently indicate submitting applications for design certification in the 2013 to 2015 time frame.

As previously stated, HTGRs are currently being considered for both electricity and process heat applications. DOE has been directed under the Energy Policy Act of 2005 (EPAct) to develop a high-temperature reactor under a cost-shared approach with industry. DOE's HTGR program is known as the Next Generation Nuclear Plant (NGNP). NGNPs do not require cooling water requirements like the LWRs and SMRs (some designs use a gas turbine power conversion technology) and could be located near other industrial plants that potentially could utilize the process heat produced by such a reactor. HTGRs in the small-to-medium-sized range are capable of high-temperature operation in excess of 700°C. These plants have the right combination of size, heat output, and passive safety features to make them favorable candidates for use in industrial settings. The referenced NGNP concept includes a helium-cooled, graphite-moderated, thermal neutron spectrum reactor. The reactor core technology will either be a prismatic block or pebble bed concept using multi-layered graphite coated particle fuel. The NGNP will produce both electricity and hydrogen using an indirect cycle with an intermediate heat exchanger to transfer the heat to either a hydrogen-production demonstration facility or a gas turbine. DOE is providing support through NGNP research and development ranging from fundamental nuclear phenomena research to advanced fuels development that could improve the economic and safety performance of these advanced reactors. Figure 3-27 illustrates an NGNP conceptual design deployed with industrial facilities.

In addition to the DOE-funded work in support of NGNP, there is an "NGNP Industry Alliance" composed of Dow, ConocoPhillips, AREVA, Entergy, and other companies that have organized
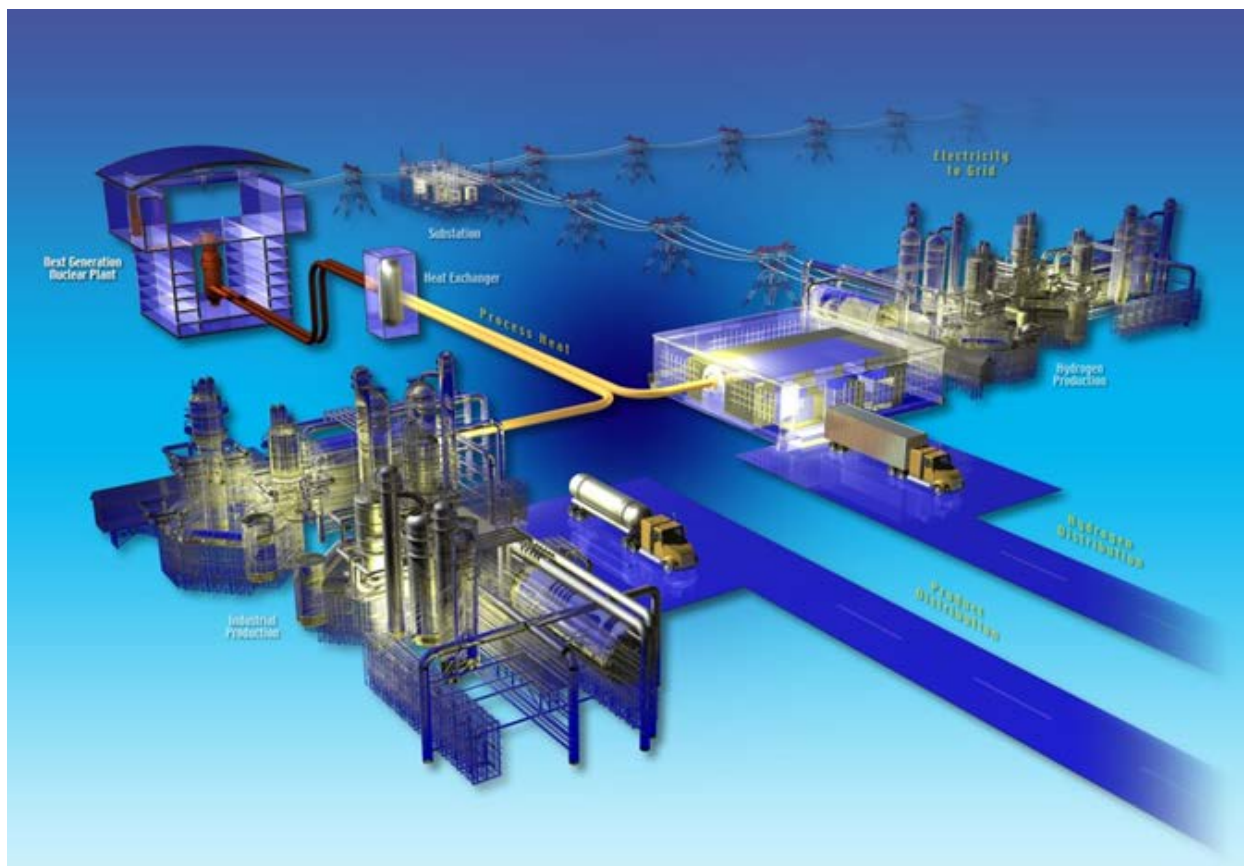
Figure 3-27 Conceptual Deployment of NGNP with Industrial Facilities (Source: NGNP Alliance 2013)

around the common objective of promoting the development and commercialization of HTGR technologies for high-temperature process heat applications. This group interacts with DOE and its NGNP program.

It is assumed that new large LWR and SMR plants will be deployed using closed-cycle cooling systems and cooling towers as opposed to once-through cooling. For the HTGR, it is assumed that the power conversion system is a gas turbine system and will not include cooling water for screening criteria. However, there would be some nominal water requirements as for any industrial facility.

3.5.5 Screening Factors

The screening factors used for nuclear power were based on work that ORNL conducted previously in support of work done for the Electric Power Research Institute (EPRI) (Mays et al. 2012).

ORNL developed OR-SAGE for applying GIS and spatial modeling techniques for evaluating siting options for nuclear power and has extended that capability for other electric power plants, including solar and clean coal. The earlier ORNL work and the screening criteria presented

herein are based on an EPRI document entitled *Siting Guide: Site Selection and Evaluation Criteria for An Early Site Permit Application* (EPRI 2002). This guide provides the framework for selecting potential sites. It includes approximately 60 categories of screening factors for consideration in developing an "environmental envelope" to support development of an early site permit application for a site pre-approval. Many of these factors are consistent with the information that would be contained in an Environmental Report as part of the full licensing process.

ORNL reviewed these parameters and identified those that were considered most important and would provide sufficient discrimination between and among potential areas suitable for nuclear resource development at an initial screening level. Table 3-11 presents the screening criteria for this study that were derived from this earlier effort. This table presents those factors common to all three types of reactors for determining which areas are most suitable for nuclear power generation. The specific default nuclear suitability criteria and specific ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4. Informational layers may also be useful for additional analysis by overlaying them onto the suitability model results. The extensive list of EZ Mapping Tool informational layers is included in Appendix B.

3.5.6 Data and Sources

The publicly available data sources used in formulating the screening factor layers for nuclear power were collected from a variety of sources listed in Table 3-12. The Protected Land, Habitat, and Imperiled Species screening layer and data sources are discussed in Section 4.

Table 3-11 Nuclear Technology Screening Factors

Nuclear Screening Parameters for Established Reactor Technologies	Large LWR	SMR (iPWR)	HTGR
Primary Screening Parameter			
Population density	✓	✓	✓
Slope	✓	✓	✓
Seismic hazard	✓	✓	✓
Quaternary fault exclusion	✓	✓	✓
Land cover area	✓	✓	✓
Distance to rivers (cooling water) (>200,000 gpm for large reactors/>50,000 gpm for small reactors)	✓	✓	NA
100-yr flood zone	✓	✓	✓
Distance to airports	✓	✓	✓
Distance to military bases	✓	✓	✓
Habitat, Protected Land, Imperiled Species	✓	✓	✓

✓ = include as parameter.
NA = not applicable.

Table 3-12 Nuclear Screening Factor Data and Sources[a]

Factor (Parameter)	Data and Source
Population density	LandScan™, http://www.ornl.gov/sci/landscan/
Slope	2012 NGA Digital Terrain Elevation data/ calculated and resized for 250-m cells
Seismic hazard	2012 USGS
Quaternary fault exclusion	2012 USGS
Land cover area	2011 USGS
Distance to rivers/surface water flow	2012 USGS/National Hydrography data (Version 2)
100-yr flood zone	2011 FEMA National Flood Hazard data
Distance to airports	2012 Federal Aviation Administration (FAA) and the Research and Innovative Technology Administration's Bureau of Transportation Statistics
Distance to military bases	2012 Defense Installation Spatial Data Infrastructure Program

[a] All metadata can be accessed via the EISPC EZ Mapping Tool.

3.6 Solar

3.6.1 Introduction

Solar energy can be used in a variety of ways to produce heat, light, fuel, or electricity. Solar energy is ubiquitous but is a variable energy source with strong diurnal, seasonal, inter-annual, and geographic patterns. In general, peak energy output for solar energy collectors corresponds well with high energy demand periods (Denholm and Margolis 2007) and can be more closely matched through the use of energy storage techniques. Utility-scale solar energy has been produced in the United States since the mid-1980s, and the EIA reported 987 MW of total solar nameplate capacity in 2010 (EIA 2011). Grid-connected solar capacity is growing rapidly in the United States, amounting to nearly 7,900 MW by the end of 2012 (Sherwood, 2012). Solar energy accounted for less than 1% of the electricity generated in the United States in 2012, excluding off-grid uses (EIA 2012).

Sections 3.6.2 through 3.6.6 discuss the solar technologies in scope for this study, describe solar energy resources, describe available conversion technologies, present screening factors used in the study, and provide data and sources. Section 3.6.4.3 provides details on the rooftop PV solar resource, which differs significantly from the utility-scale solar resources.

3.6.2 Scope

Conventional utility-scale PV and concentrating solar power (CSP) technologies were considered for the EZ Study along with distributed or rooftop PV. The CSP technologies included are parabolic troughs and solar power towers. Dish Stirling and linear Fresnel technologies are not currently proposed for any large-scale developments in the United States and are not included in the EZ Study, though similar considerations apply.

3.6.3 Resource Description

The three basic types of solar resources are direct normal (beam), diffuse (sky), and global (total) irradiance. The direct normal irradiance is the amount of radiation from the "solar disk" (generally defined by a 5.7° field of view) on a surface perpendicular to the Sun's location in the sky. Concentrating solar collectors are designed to capture this form of solar energy. The diffuse irradiance is the amount of solar radiation reaching the Earth's surface after being scattered from the direct beam. Diffuse irradiance data are useful for architectural daylighting applications and in photosynthesis. The global (typically global horizontal) irradiance is the geometric sum of the direct normal and diffuse irradiance components and represents the amount of energy available from the entire sky dome on a planar surface. The various collector types require design-specific models to convert the direct and diffuse components to estimates of solar radiation available to each collector type and orientation. Solar resource is typically reported in kilowatt-hours per square meter per day ($kWh/m^2/day$) when measured over longer time periods (more than a day), and watts per square meter (W/m^2) when reported at finer time scales.

Figure 3-28 presents the estimated annual average solar resource distribution for utility-scale PV, and Figure 3-29 presents the estimated annual average direct normal solar resource distribution for CSP.
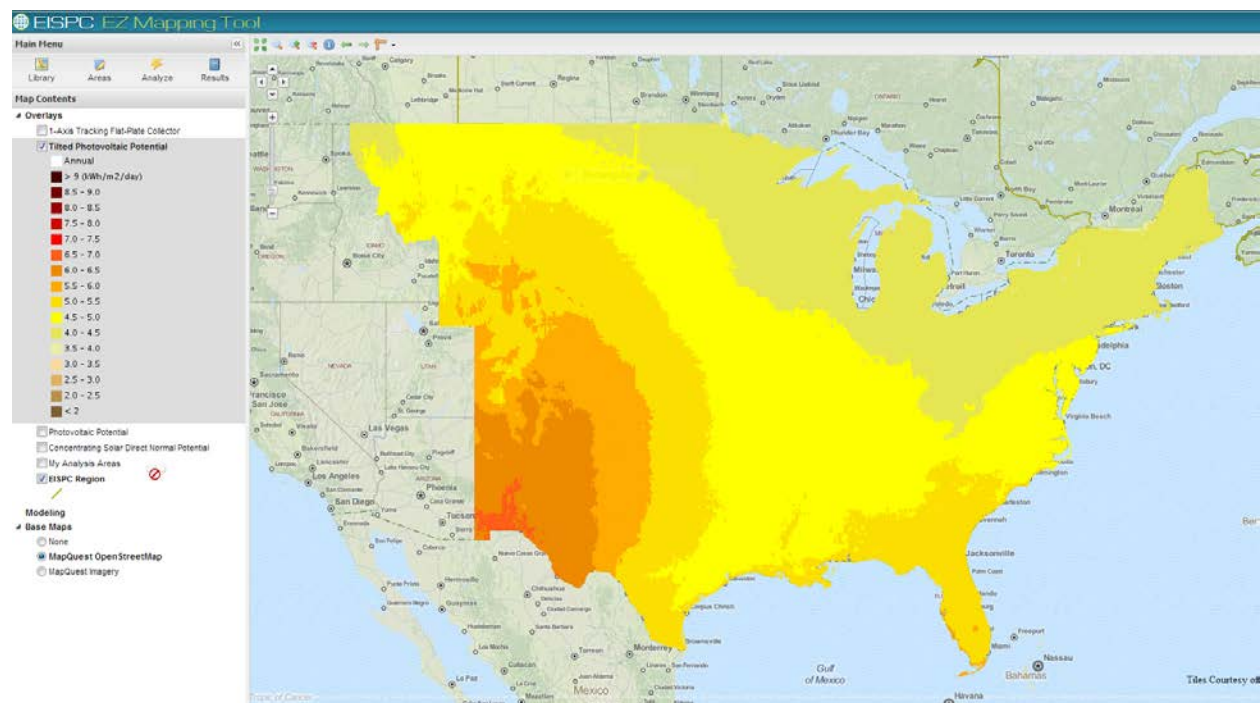
Figure 3-28 Estimated Average Daily PV Solar Resource Potential by Year in Wh/m²/day (Note: The insolation values represent the average solar energy available to a flat plate collector, such as a PV panel oriented due south at an angle from the horizontal equal to the latitude of the collector location.) (Source: NREL 2007 and EZ Mapping Tool)
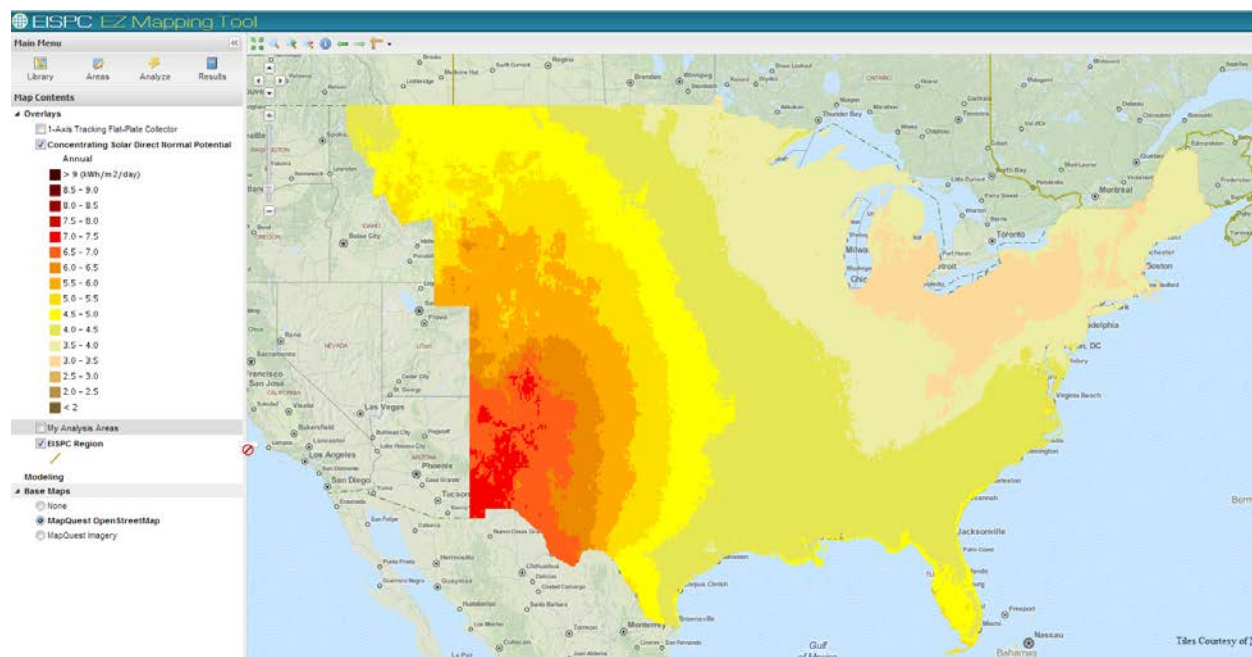
Figure 3-29 Estimated Average Daily CSP Solar Resource Potential by Year in Wh/m²/day (Note: The insolation values represent the average solar energy available to a concentrating collector on a 2-axis tracker, such as a dish or a power tower.) (Sources: NREL 2007 and EZ Mapping Tool)

The resource intensity for energy conversion is affected by factors such as site location (latitude, longitude, and elevation), time of day, season, cloud cover, atmospheric constituents that absorb or scatter solar radiation (e.g., water, dust, and ozone), and characteristics of the solar energy collector type. Short-term temporal variability of the solar resource can occur at a single location (Figure 3-30) due to rapid changes in these factors (i.e., passing clouds, storms, and fires) over a wide range of time scales (i.e., minutes to decades). For distances from 10 to 100 kilometers (km), the spatial variability can be relatively low but does increase in areas where terrain amplifies the physical effects, particularly in coastal or mountainous regions or near urban areas where pollutant levels can influence the solar radiation reaching the ground.

All regions of the United States have some solar resource available for power production, although the distribution and intensity vary based on atmospheric conditions and the collector type. The highest solar resource areas in the Eastern Interconnection are generally found in the south, with the most intense solar resource areas falling outside of the Eastern Interconnection in the southwestern portion of the United States. Factors such as the presence of clouds or aerosols in the atmosphere can also influence the regional distribution of a particular type of solar resource. This can be seen by comparing the two solar resource maps shown in Figures 3-28 and 3-29. The same general resource pattern is visible in both maps, but the pattern is stronger in the direct normal resource map because of its sensitivity to the influence of particulates in the atmosphere. The solar resource is lowest in Alaska, the Pacific Northwest, and New England.

The type of solar application also determines the distribution of useful solar resource. High solar resource is needed for cost-effective deployment of concentrating solar technologies (annual
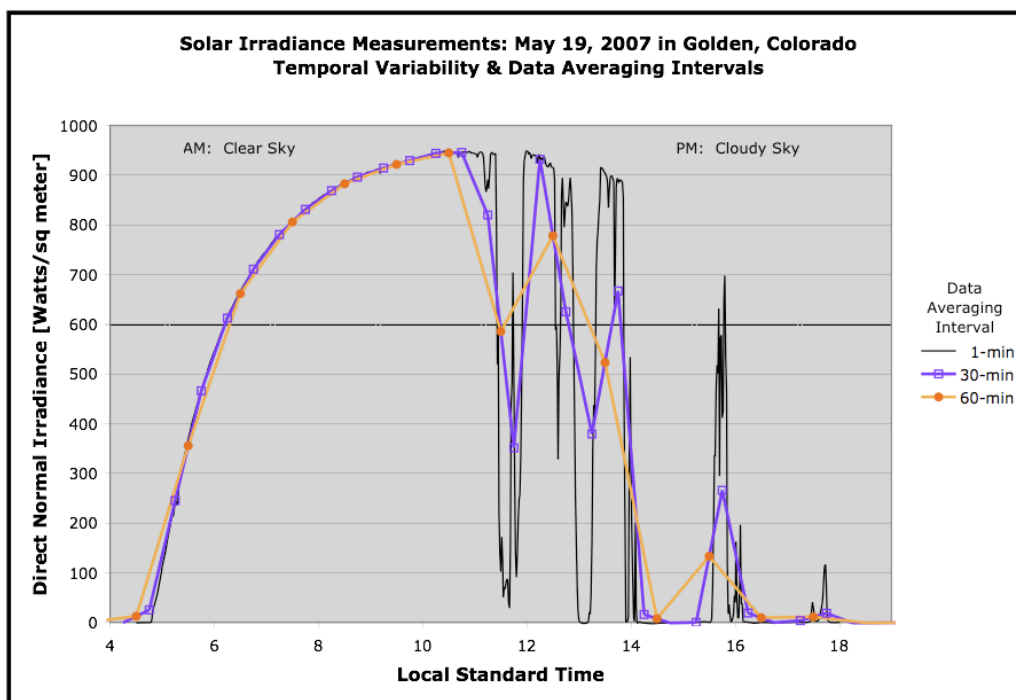
Figure 3-30 Example of Temporal Variability of Solar Irradiance under Clear and Cloudy Sky Conditions and the Effects of Time-Averaging Intervals Based on Measurements Collected Every 4 Seconds (Source: EPAct 2011)

average resource of 5 kWh/m^2/day and greater), which limits the applicable resource area in the Eastern Interconnection to its southwestern reach and small areas within Florida. Rooftop PV applications are not limited to high-resource areas and can be utilized throughout the United States, though with less productivity in northern latitudes.

3.6.4 Conversion Technologies

Utility-scale PV and CSP technologies convert solar resources into electricity. The two most common solar energy conversion technologies are PV and CSP. PV is a direct energy conversion technology that converts sunlight into DC electricity with semiconductor material usually fabricated in a flat panel. The DC is subsequently converted to AC or can be used directly. CSP uses mirrors or other highly reflective surfaces (solar collectors) to concentrate the sun's thermal energy into a small area. Electricity is generated from this concentrated solar thermal energy through a heat engine, commonly a Rankine cycle, which drives an electric generator. Many PV solar collector orientations and configurations are possible based on the parameters being optimized; however, typically fixed flat plate collectors are oriented south and tilted at an angle equal to the site's latitude.

The third conversion technology, rooftop PV, depends on the same fundamental technology as utility-scale PV; however, rather than being a separate facility, the solar panels or PV arrays are mounted on existing structures, primarily roofs of buildings.

3.6.4.1 Concentrating Solar Power

CSP uses reflective surfaces or lenses to concentrate the heat energy in sunlight over a large area to a small area. Different types of concentrators are used; the most common conventional utility-scale technologies are the parabolic trough and solar power tower (also referred to as a central tower or heliostat power plant). Other potential technologies include dish Stirling and linear Fresnel technologies, but these technologies are not currently proposed for large-scale development in the United States.

Parabolic trough collectors are arranged in long rows of curved reflective panel surfaces with a collector tube filled with a heat transfer fluid located at the focal point of the curved surface (Figure 3-31). The heated fluid is transported to a heat engine where the heat can be extracted. The longest operating CSP plants in the United States (solar electric generating system [SEGS] 1–9, totaling 350 MW) utilize this technology. The Solana plant currently under construction in Arizona will be one of the largest solar plants currently in existence (280 MW with 6 hours of thermal storage) when completed in 2013. Several other large parabolic trough projects are under construction or have been proposed. These systems typically cover large areas; Solana, with its oversized field to accommodate thermal storage, is being built on 1,920 acres (Abengoa Solar 2012).

Solar power towers arrange the reflective surfaces in a circular area around a tall central tower. The surrounding mirrored surfaces concentrate the solar beam on a receiver at the top of the tower (Figure 3-32). The heat transfer medium, a molten salt, is located in the tower itself. The molten salt flows into a storage tank where the heat can be efficiently stored. Solar power towers

Figure 3-31 Parabolic Trough Concentrating Solar Collector at Kramer Junction, California (Source: NREL 2012c)

Figure 3-32 Solar Power Tower Collector, Solar Two at Dagget, California (Source: NREL 2012d)

can operate at higher temperatures than parabolic trough systems, leading to higher system efficiencies and capacity factors. While only 5 MW is currently operational in the United States, construction is underway or under development for nearly 2 GW of additional capacity from solar power towers (NREL 2010).

The collected heat energy from both of these system types is then used to heat steam in a standard steam turbine generator similar to most conventional fuel sources. The heat energy can be stored to provide more flexibility in dispatching the energy produced to the grid and in increasing the overall capacity factor of the solar plant (Denholm and Mehos 2011).

3.6.4.2 Utility-scale Photovoltaics

Utility-scale PV uses arrays of solar panels that convert the solar energy received directly to electricity. The solar panels may be fixed-tilt, single-axis, or two-axis tracking collectors (Figure 3-33). Larger systems are typically ground mounted but may also occur on large commercial buildings or combinations of ground-mounted and rooftop systems. By 2012, the United States had more than 7,300 MW of installed PV capacity, with another 1,300MW under construction (Sherwood, 2012; EIA 2012a). This includes installations in the Eastern Interconnection such as the 32-MW BP Solar Long Island Solar Farm at Brookhaven National Laboratory, completed in 2011 (LIPA 2012).

Individual panels produce DC electricity and are linked in an array by electrical conduit. The DC electricity must be converted to AC electricity before it can be placed on the electricity grid.

Figure 3-33 Utility-Scale PV, Single-Axis Tracking Collector Totaling 2 MW at Prescott, Arizona (Source: NREL 2012e)

3.6.4.3 Rooftop PV

Rooftop PV solar as implemented in the EZ Mapping Tool differs significantly from the utility-scale solar resources, and the EZ Study treats rooftop PV separately.

Examples of rooftop installations are shown in Figure 3-34.

As a distribution-level resource, rooftop PV needs no transmission to connect it to the system. The two aspects that matter the most for system planning are the location of the urban load center on the network and the degree of rooftop PV penetration throughout the load center. More energy produced at the distribution level within the load center reduces what needs to be delivered to the load center via the transmission system.

Trees and other vegetation can obstruct sunlight, which affects the amount of electricity produced throughout the day. The height of neighboring buildings to the south can also limit PV output. The amount of rooftop space containing heating, ventilation, and air-conditioning (HVAC) equipment will also reduce the space available for solar panels. Buildings in warmer climates tend to have more tree shading and more HVAC, resulting in less area available for rooftop PV panels.

While utility-scale solar is a generation resource from the perspective of transmission planning, rooftop PV may be viewed as a load-reducing technology. Location is not the unknown variable. What affects system planning is how much load reduction might occur in a given urban area due to greater rooftop PV deployment.

Figure 3-34 Examples of Rooftop PV on Office Buildings and Residences (Source: NREL 2012f–h)

This analysis only deals with the *aggregate* amount of rooftop PV that might be available in a given load area. It does not address where rooftop PV might be located within the load area. The EISPC EZ Mapping Tool is not designed for analyzing the viability of specific sites or buildings. For a suite of publicly available site assessment tools, see http://www.nrel.gov/analysis/ analysis_tools_tech_sol.html.

How much electricity comes from a square meter of rooftop PV will depend on the technology. The efficiency of panels currently in use ranges widely, with silicon technologies—most commonly used in rooftop arrays—ranging between 14% and 21%.[12]

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[12] Monocrystalline silicon modules range from 14% to 16%; multicrystalline silicon modules range from 17% to 21%. (DOE 2012, p. 71).

3.6.4.3.1 Estimating Rooftop Area

Estimations of the amount of sunlight falling on rooftops in a given area were derived from the same detailed satellite and ground observation data used to estimate utility-scale solar potential in Section 3.6.3. Most rooftop PV installations are small scale and use fixed mounting. The raw solar potential for rooftop PV in a given area is therefore calculated on the basis of a fixed-mounted panel tilted at an angle equal to the latitude of where the panel is installed. This is the angle that generally captures the most sunshine over the course of a year.

Mapping rooftop solar PV potential involves two analytical components: population and buildings stock (residential, commercial, and industrial) and the amount of sunshine the area has during a typical year. The analysis method in the EZ Mapping Tool relies on a 2008 study by Denholm and Margolis that estimates the building stock rooftop area that is potentially available for rooftop PV (Denholm and Margolis 2008). For a discussion of the methodology used to estimate rooftop area for this analysis, see Section 2, Methodology and Appendix C.

3.6.4.3.2 Peak Load Reduction

As the penetration of rooftop PV increases in a given metropolitan area, county, or state, the reduction in peak demand will become more significant. This is especially true in hot climates where sunny days and high temperatures correlate with greater use of air-conditioning, leading to higher demand for electricity.

Summer electric demand peaks tend to occur in the mid- to late-afternoon hours. PV output peaks around noon and declines in the afternoon as the sun moves lower in the sky, which means that PV's effect on peak demand is actually less than its full rated capacity. It tends to push the net peak to later in the day, which also complicates the task of estimating PV's peak load reduction. The estimate of rooftop PV's impact on an area's annual peak load is based on the analysis of the building estimation methods and solar exposure discussed previously, and on the assumptions on the level of rooftop PV deployment. Details of this analysis are presented in Appendix C.

3.6.5 Screening Factors

Utility-scale PV and CSP have similar screening factors, though the different conversion technologies may mitigate the impact or range of values for specific screening factors. A list of those factors identified for this study is presented in Table 3-13. Some of the screening factors listed are more economic in nature rather than technical limits. As such, local incentives for installing solar systems may influence development decisions. As rooftop PV is installed on built structures, screening factors relate to very specific requirements associated with the building design. In some jurisdictions, local building codes may be the most important factors.

The specific default solar suitability criteria and specific ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4. Informational layers may also be useful for additional analysis by overlaying them onto the suitability model results. The extensive list of EZ Mapping Tool informational layers is included in Appendix B.

Table 3-13 Solar Technology Screening Factors

Solar Technology	Screening Parameter
PV Solar	Population density Slope Land cover area Proximity to electric transmission (>345 kV) Protected Land Habitat Imperiled Species
CSP	Population density Slope Land cover area Distance to rivers (>64,500 gpm) Proximity to electric transmission (>345 kV) Protected Land Habitat Imperiled Species

3.6.6 Data and Sources

Solar data were provided by NREL (2013). The data include monthly average and annual average daily total solar resource for areas of 0.1° in both latitude and longitude (~10 km in size). The data were developed using the State University of New York/Albany (SUNY) satellite radiation model developed by Dr. Richard Perez and collaborators at NREL and other universities for DOE (Perez et al. 2002). The SUNY model uses hourly radiance images from geostationary weather satellites; daily snow cover data; and monthly averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere to calculate the hourly total insolation (sun and sky) falling on a horizontal surface. A modified Bird model is used to calculate clear sky direct normal irradiance (DNI). This is then adjusted as a function of the ratio of clear sky global horizontal irradiance (GHI) and the model-predicted GHI. Where possible, existing ground measurement stations are used to validate the data. Nevertheless, there is uncertainty associated with the meteorological input to the model, since some of the input parameters are not available at a 10-km resolution. As a result, it is believed that the modeled values are accurate to approximately 15% of a true measured value within the grid cell. The annual average values are calculated using satellite data from 1998 to 2008.

Publicly available data to construct the screening layer for solar technologies are available from a variety of sources and are listed in Table 3-14. The Protected Land, Habitat, and Imperiled Species screening layer and data sources are discussed in Section 4.

Table 3-15 describes additional data needed for estimating the potential of rooftop PV. EZ Mapping Tool reports can be generated to summarize the potential of rooftop PV in an area of interest.

Table 3-14 Solar Technology Screening Factor Data and Sources[a]

Factor (Parameter)	Data and Source
Population density	LandScan™, http://www.ornl.gov/sci/landscan/
Slope	2012 NGA Digital Terrain Elevation data/calculated and resized for 250-m cells
Land cover area	2011 USGS
Distance to rivers/surface water flow	2012 USGS/National Hydrologic data (Version 2)
Electric transmission data	2012 Bentek Energy/Platts
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

Table 3-15 Rooftop PV Data and Sources[a]

Information	Data and Source
Average number of floors per building type	EIA 2005 Residential Energy Consumption Survey and the 2003 Commercial Building Energy Consumption Survey
Total floor space	McGraw-Hill, FW Dodge Building Stock Database
Solar resource	http://www.nrel.gov/gis/data_solar.html
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

3.7 Storage Technologies

3.7.1 Introduction

To assist in an increased penetration of clean energy technology, the deployment of energy storage infrastructure must control the flow of electricity, match energy supply to energy demand, and improve the economics of the energy supply chain. Storage technologies can be used to provide peaking generating capacity, load shifting, system support, operating reserves, and other ancillary services.

Pumped storage hydro (PSH) is by far the most common form of energy storage in the United States. There is currently about 18 GW of existing capacity, with facility sizes ranging from 28 to 2,800 MW. Proposed PSH plants range from 75 to 1,300 MW. Other energy storage technologies currently exist at a smaller scale in the United States. Batteries are also a common energy storage technology; however, no batteries currently exist for storing more than 10 MWh for a 1-day period and are little used at utility scale. Recent advances in plug-in hybrid electric vehicles are providing additional energy storage capability at the distribution level in a series of U.S. Department of Defense-sponsored demonstration projects. Non-battery-based storage technologies include superconductive magnetic energy storage (SMES), flywheel energy storage, electrochemical capacitors, CAES, and large PSH.

Sections 3.7.2 through 3.7.6 discuss the scope of the study, describe storage resources and available conversion technologies, detail the screening factors used in the EZ Study, and provide data and sources.

3.7.2 Scope

The scope of this study includes PSH and CAES technologies and covers the conventional cycles of these two technologies. Other storage technologies (batteries, flywheels, SMES, and capacitors) are outside the scope of this study because they are not mature enough for analysis and screening criteria development. This study only discusses basic screening criteria and does not discuss the individual CAES and PSH cycles and their differences or the plant parameter envelope for CAES and PSH technologies.

3.7.3 Resource Description

The use of energy storage is fundamental to the generation of electric power. However, to date, the application of energy storage technology for real-time and short-notice (less than a few minutes) support and optimization of the transmission and distribution system has been limited. One reason is the lack of cost-effective options (EPRI 2003). In the United States, large PSH facilities are the major energy storage technology applied for utility-scale applications. At present, about 99% of utility-scale storage capacity in the world is in PSH. A typical PSH plant has a capacity of several hundred megawatts and is typically designed to provide about 8 to 10 hours of generation at full power output. These facilities are primarily used for daily load shifting, but also for regulation control (short-term fluctuations) and spinning reserve applications. In addition, one CAES facility with a capacity of 110 MW for up to 10 hours is available in the United States. Another CAES facility with a capacity of 290 MW is operating in Germany. The benefits from energy storage for utility-scale applications include improved reliability of system operation and reduced customer financial losses due to poor power quality and power outages, better integration of variable energy resources such as wind and solar, load shifting or energy price arbitrage involving charging with low-priced "off-peak" energy for use later when cost is high, and various ancillary services necessary for electric power grid operation.

3.7.4 Conversion Technologies

For the EZ Study, the conversion technologies for CAES and PSH are limited to their respective conventional cycles. Within each technology, there are several variations. For example, in addition to the conventional CAES cycle, there is a recuperated cycle, combined-cycle, steam-injected cycle, compressed air with humidification, and adiabatic CAES cycle. The technical descriptions of the conversion technologies that follow are intentionally abbreviated. Additional information about storage technologies is available from the EPRI (2008).

3.7.4.1 Pumped Storage Hydro

PSH is the longest established technology for utility-scale applications that have been commercially deployed since the late nineteenth century. A PSH facility is typically equipped with pumps and generators connecting an upper and a lower reservoir. Figure 3-35 is a diagram of the Tennessee Valley Authority (TVA) PSH facility at Raccoon Mountain. The pumps use cheap electricity from the power grid during off-peak hours to move water from the lower reservoir to the upper reservoir in order to store energy. During periods of high electricity demand (peak hours), water is released from the upper reservoir to turn the turbines and generate power as it flows back into the lower reservoir.
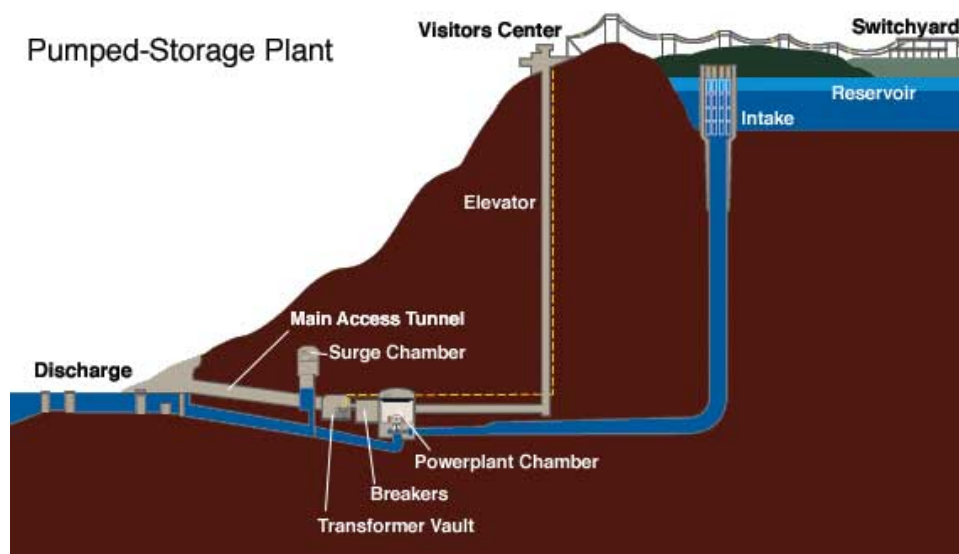
Figure 3-35 Diagram of TVA Pumped Storage Facility at Raccoon Mountain PSH Plant (Source: TVA 2013)

There are two types of PSH facilities—off-stream (closed loop) PSH and pump-back PSH. Off-stream or pure PSH rely entirely on water that was previously pumped into an upper reservoir as the source of energy; whereas, pump-back or combined PSH uses both pumped water and natural streamflow water to generate power. Any site utilizing streamflow water must meet regulations concerning water quality and fish protection. The efficiency of PSH varies significantly because of the long history of the technology and the long life of a facility. At present, the total PSH cycle efficiency is typically between 70% and 85%.

There are currently 26 existing PSH plants in the Eastern Interconnection (16.5 GW capacity); another 16 have been issued preliminary permits (12 GW), and 8 have permits pending (4.7 GW). Figure 3-36 shows the location of these facilities.

3.7.4.2 Compressed-Air Energy Storage (CAES)

For CAES systems that use underground caverns, the suitable geologies can be classified into salt (bedded and dome salt), aquifer, and rock. In general, the geological formation suitable for underground air storage must have sufficient depth to allow safe operation at the required air pressure and must be sufficiently porous to provide the required storage volume at the desired pressure. The formation must also be sufficiently permeable to permit the desired airflow rates, and requires a mineralogy that does not result in rapid chemical consumption of the oxygen in the stored air through oxidation reactions.

Figure 3-37 is a general diagram of a CAES system. In this example, air is compressed and injected into the cavern during times when energy is to be stored. When power is needed, compressed air is released. When the gas expands during release, it cools, and thus a recuperator is used to transfer waste heat from the exhaust of the turbines into the cooled air. In addition, natural gas fuel is added and ignited to increase the temperature and pressure prior to the turbines. The various types of CAES cycles may or may not include, for example, injection of
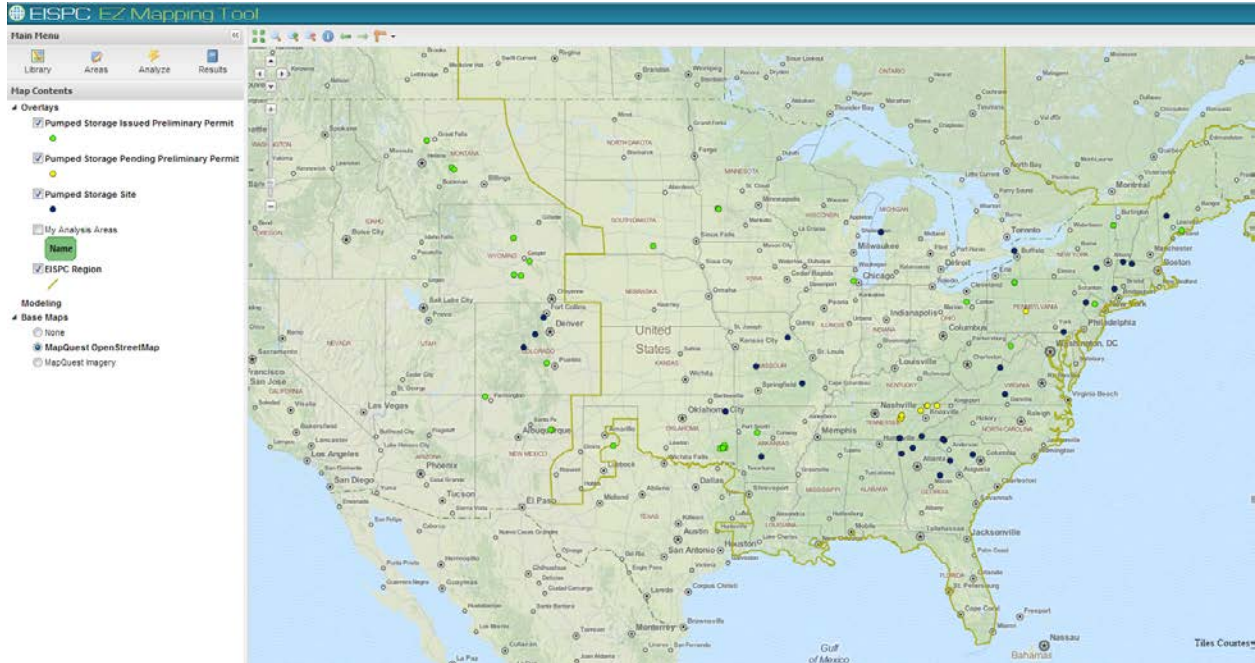
Figure 3-36 Map of Existing Preliminary Permitted and Pending Preliminary Permitted PSH Plants (Source: EZ Mapping Tool)
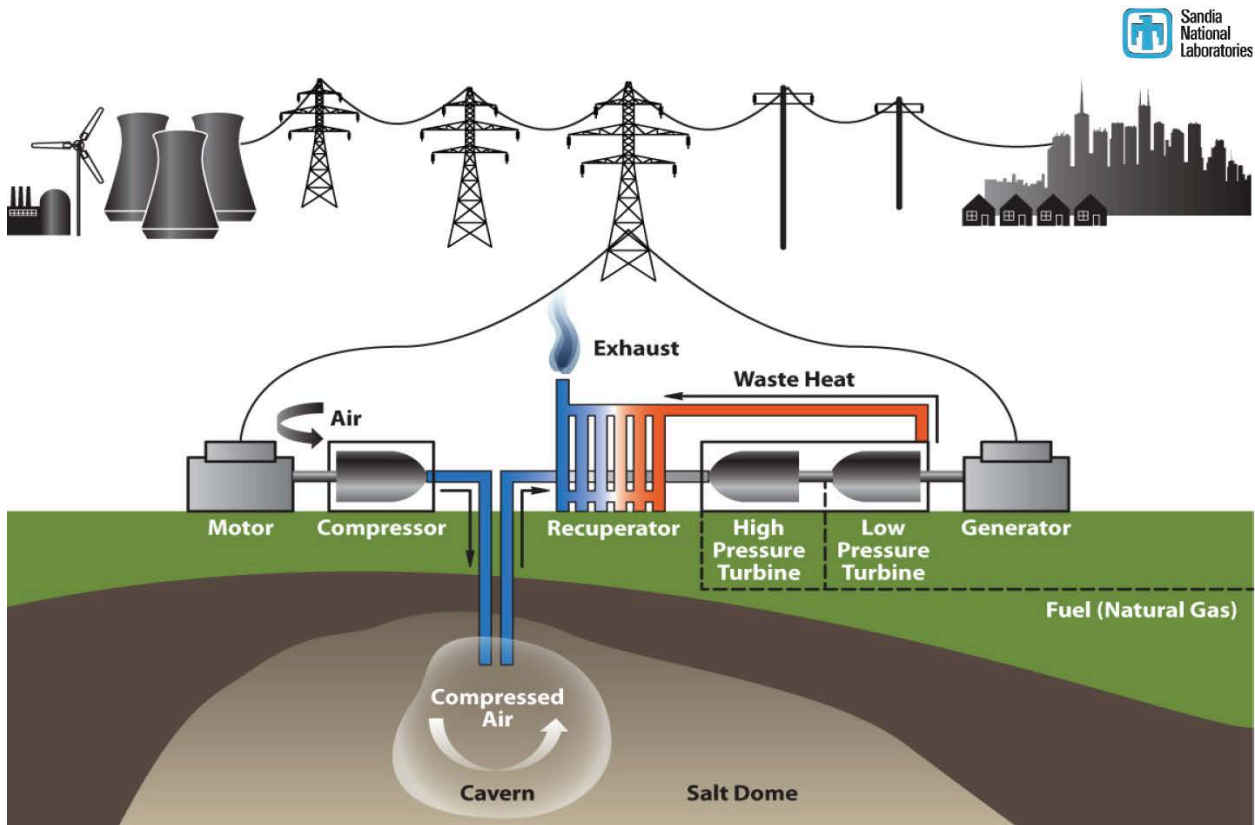
Figure 3-37 Diagram of CAES Operation (Source: Sandia National Laboratory 2013)

natural gas, water, and recuperation of waste heat. This diagram shows a salt dome as the cavern used for the compressed air; however, storage within an aquifer or rock (such as depleted gas wells) is also feasible.

3.7.5 Screening Factors

Many of the screening factors for nuclear power plants were the starting point to establish screening criteria for storage technologies even though storage technology siting is subject to a different regulatory process. For CAES, the technology demands the presence of underground caverns for storing compressed air; therefore, CAES siting is a function of geology. Consequently, suitable areas for CAES could allow for some limited vertical and/or horizontal drilling access to the storage vessel. On the other hand, PSH technology demands an upper and a lower reservoir, which is a function of difference in elevations. Therefore, these facilities will be more closely influenced by the surface features of the area. For screening factors such as seismic and earthquake fault restrictions, it was decided that these facilities do not have any issues beyond what local codes cover. Therefore, factors such as proximity to hazardous facilities and fault lines are not considered applicable to CAES and PSH plant screening.

Because CAES plants generate noise, highly populated areas are excluded from consideration for CAES siting. Similarly, to minimize the risk of a potential PSH reservoir accident on a population, the same factor is applicable to PSH siting. On the basis of engineering judgment, factors such as wetlands and open water, protected land, landslide hazards, and 100-year floodplain areas, should also be excluded for new CAES and PSH plant screening. Table 3-16 lists the final screening factors for CAES and PSH.

The specific default CAES suitability criteria and specific ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4. Informational layers may also be useful for additional analysis by overlaying them onto the suitability model results. The extensive list of EZ Mapping Tool informational layers is included in Appendix B.

3.7.6 Data and Sources

Data used to construct the screening factors for the CAES technology are available from various sources listed in Table 3-17. The Protected Land, Habitat, and Imperiled Species screening layers are discussed in Section 4.

PSH data are included as an informational layer in the EZ Mapping Tool, and a report can be generated to summarize the availability of this resource data in an area of interest. The sources of these data layers are listed in Table 3-18.

Table 3-16 Storage Technologies Screening Factors

Storage Technology	Screening Parameters
Compressed-air energy storage	Aquifer area Distance to domal salt formation Distance to bedded salt formation Population density Slope Land cover area Landslide hazards 100-yr flood zone Land cover area Proximity to electric transmission (all lines) Distance to natural gas pipelines Protected Land Habitat Imperiled Species

Table 3-17 Storage Technologies Data and Sources[a]

Factor (Parameter)	Data and Source
Aquifer area	2011 USGS
Geological formations	CAES: the underground portion, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4113158
Salt caverns	2012, 2013 ORNL
Population density	LandScan™, (http://www.ornl.gov/sci/landscan)
Slope	2012 NGA digital terrain elevation data/calculated and resized for 250-m cells
Land cover area	2011 USGS
Landslide hazard	2001 USGS
100-yr flood zone	2011 FEMA National Flood Hazard data
Electric transmission data	2012 Bentek Energy/Platts
Natural gas lines	2012 Bentek Energy/Platts

[a] All metadata can be accessed via the EISPC EZ Mapping Tool.

Table 3-18 PSH Data and Sources[a]

Information	Data and Source
Pumped storage site	2011 Argonne
Pumped storage pending preliminary permit	2011 FERC
Pumped storage Issued preliminary permit	2011 FERC

[a] All metadata can be accessed via the EISPC EZ Mapping Tool.

3.8 Water

3.8.1 Introduction

The largest renewable energy resource in the United States is hydropower. There are more than 96 GW of hydropower projects operating in the United States, including conventional and pumped storage. Of this installed capacity, about 78 GW is conventional hydropower, which generated 260 TWh of electricity in 2010. Conventional hydropower projects consist of both federal and non-federal projects.

Sections 3.8.2 through 3.8.7 discuss the scope of the study, describe water technologies and conversion technologies, detail screening factors used in the study, and provide data and sources for the water resources and screening factors.

3.8.2 Scope

The technologies included in the EZ Study are additional electrical output from existing hydropower dams, new output from current NPDs, river and tidal hydrokinetic energy, marine tidal hydrokinetic energy, and wave energy.

Metropolitan energy-water systems and irrigation power energy are out of scope because of the lack of available data for GISs on the potential sites in the Eastern Interconnection. New hydropower site development is out of scope due to unreliable data. Hydrokinetic (river and tidal) are too immature technologically to be able to establish adequate screening criteria. However, information layers are provided.

3.8.3 Resource Description

Three available resources that potentially could be used for hydroelectric generation are river systems, ocean tidal currents, and coastal wave action. Currently, only the river systems are used across the United States. Figure 3-38 shows those rivers that have average streamflows greater than 35 cubic feet per second (cfs). Much of the resource is unusable for hydropower because land use surrounding the stream precludes building impoundments, or the possible differential in water height between a high and low pool (the "head") is too low for economic development.

Another potential source of hydroelectric generation is ocean tidal currents. These provide consistent flows in and out of bays or estuary channels. Technologies are being developed that can exploit the changes in sea level from tides or the currents from tidal forces.

The third hydropower resource is wave action along the coastlines. Waves are largely generated through ocean winds but are much more consistent than onshore wind resources. The eastern United States has relatively low power density from waves; <10 kW/m as shown in Figure 3-39.

The total available wave energy resource along the Outer Continental Shelf (national 200-m depth contour) is presented in Table 3-19, broken down by major coastal region. These results
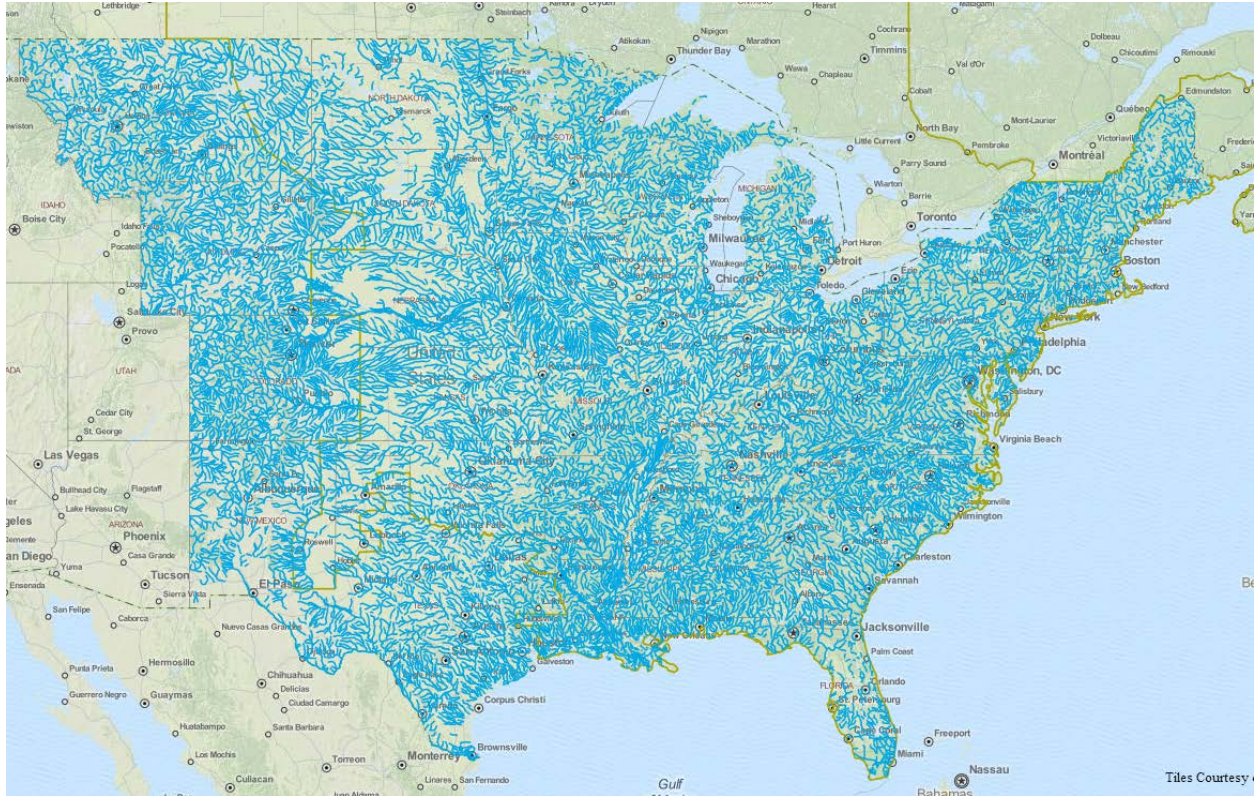
Figure 3-38 Composite Streamflow > 35 cfs (Source: EZ Mapping Tool)
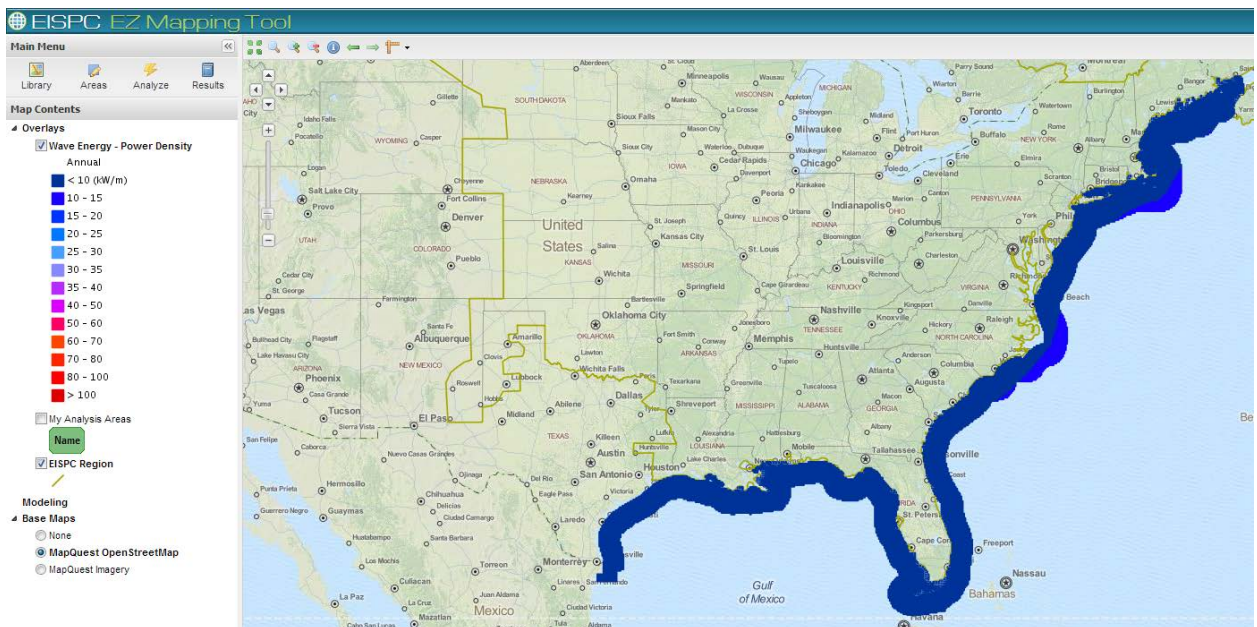
Figure 3-39 Wave Energy Power Density along the Eastern United States (Source: EZ Mapping Tool)

Table 3-19 Total Available Wave Energy Resource Breakdown by Region

Coastal Region	EPRI 2004 Estimate	EPRI 2011 Estimate Outer Shelf[a]
West Coast (WA,OR,CA)	440 TWh/yr	590 TWh/yr (34% greater)
East Coast (ME thru NC)	110 TWh/yr	200 TWh/yr (82% greater)
East Coast(SC thru FL)	Not estimated	40 TWh/yr
Gulf of Mexico	Not estimated	80 TWh/yr
Alaska (Pacific Ocean)	1,250 TWh/yr	1,360 TWh/yr (9% greater)
Alaska (Bering Sea)	Not estimated	210 TWh/yr
Hawaii	300 TWh/yr	130 TWh/yr (not comparable[b])
Puerto Rico	Not estimated	30 TWh/yr
Total =	**2,100 TWh/yr**	**2,640 TWh/yr (26% greater)**

[a] Rounded to nearest 10 TWh/yr for consistent comparison with EPRI 2004 estimate.

[b] EPRI's 2004 estimate for Hawaii was along the northern boundary of the U.S. Exclusive Economic Zone, as far west as the Midway Islands. The present estimate extends only as far west as Kauai and encompassed the entire islands (not just their northern exposures).

(EPRI 2011) are compared with an early preliminary estimate made by EPRI during its first offshore wave energy conversion feasibility study in 2004.

3.8.4 Conversion Technologies

3.8.4.1 Additional Output from Existing Hydropower Dams

Conventional hydropower refers to traditional project designs that utilize a combination of hydrostatic head and flow through turbines to generate electricity. There are significantly more non-federal projects than federal projects, but federal projects are on average larger in size. Some of the smaller, lower-impact, non-federal projects are exempt from FERC licensing but are still subject to mandatory permitting from state and federal resource agencies. Approximately 80 FERC-licensed projects are located at USACE dams but consist of powerhouses built and operated by non-federal developers.

Federal hydropower consists of projects built and operated by three agencies: USACE, DOI's Bureau of Reclamation (Reclamation), and the TVA. The USACE has the most projects, followed by Reclamation and then TVA. USACE currently owns and operates 75 power plants with a total rated capacity of 21.5 GW. In addition to those federally owned power plants, there are another 90 non-federal power plants located at USACE dams that have an additional 2.3 GW of capacity.

Non-federal hydropower is regulated by FERC under authority defined in the Federal Power Act. Ownership of non-federal projects is very diverse, ranging from large, public utilities to small rural electric cooperatives and independent power producers.

More than 50% of the hydropower equipment (turbine, generator, rotors, stators, etc.) are older than 40 years. The efficiency and capacity of aging turbine units have declined as their physical conditions have deteriorated over time. Advances have been made in materials and hydro-

mechanical designs that improve efficiency and performance of turbines and other components of hydropower systems since these aging plants and equipment were commissioned. Many plants in the United States hydropower fleet are operating under a different set of constraints than those existing at the time of commissioning, resulting in reduced energy production and services for the electric power system. DOE recognized a significant opportunity to increase the capacity, annual generation, and value of hydropower at existing U.S. hydropower facilities through the identification and implementation of improvements and developed the Hydropower Advancement Project (HAP) with ORNL.

The main objective of HAP is to demonstrate the potential increases in U.S. hydropower asset performance and value. Performance in this broad context includes hydropower asset reliability, availability, production, capacity, and water-use efficiency. The specific objectives of the HAP are as follows:

- Provide a fact-based quantitative estimate of additional energy available through improvements and expansions of all U.S. hydropower assets.

- Identify barriers to implementation of hydropower asset improvement and expansions.

- Prioritize research that would accelerate increases in hydropower asset performance and value.

- Develop and disseminate Best Practices, Assessment, and Analysis Tools to stimulate and accelerate increases in hydropower asset performance and value.

The overall potential increase in power generation efficiency is about 5% for units with Francis turbines built before the 1980s. An adequate estimate for total potential power generation increase should be obtained from meaningful statistics based on more sample assessments for the representative plants in the nationwide existing hydropower fleet.

The websites for the National Hydropower Asset Assessment Program and HAP are http://nhaap.ornl.gov/ and http://hydropower.ornl.gov/HAP.

3.8.4.2 New Output from Existing Non-powered Dams

The United States has produced clean, renewable electricity from hydropower for more than 100 years, but hydropower-producing facilities represent only a fraction of the infrastructure development that has taken place on the nation's waterways. In contrast to around 2,500 dams which provide 78 GW[13] of conventional and 22 GW of pumped-storage hydropower, the United States has more than 80,000 NPDs. These are dams that do not produce electricity but provide a variety of services ranging from water supply to inland navigation. The monetary costs and environmental impacts of dam construction have already been incurred at NPDs. Adding power to the existing dam structure can be achieved at lower cost, with less risk, and in a shorter

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[13] 1 gigawatt (GW) = 1,000 megawatts (MW). On an annual basis, 1 MW of hydropower produces enough electricity to power nearly 400 U.S. homes. Each gigawatt could power up to 400,000 homes.

time frame than development requiring new dam construction. Their abundance, cost, and environmental favorability, combined with the reliability and predictability of hydropower, make NPDs a highly attractive source for expanding the nation's renewable energy supply.

To better characterize this unique national resource, the DOE Water Power Program has undertaken a national-scale analysis of U.S. dams to determine the ability of NPDs to provide hydroelectric power (Hadjerioua et al. 2012). ORNL quantified the potential capacity available from powering U.S. NPDs. A thorough quality control and review process ensured that NPDs suitable for power production were accurately characterized. Figure 3-40 demonstrates the spatial and capacity potential distribution of the nation's NPDs with potential capacity greater than 5 MW. Electric generating capacities were calculated assuming that all water passing a facility would be converted to electrical energy and that hydraulic head at the facility would remain constant.

Adding power to U.S. NPDs has the potential to add up to 12.1 GW of new renewable capacity, a potential equivalent to increasing the size of the existing conventional hydropower fleet by 15%. A majority of this potential is concentrated in just 100 NPDs, which could contribute 8 GW of clean, reliable hydropower; the top 10 facilities alone could add up to 3 GW of new hydropower. Eighty-one of the 100 top NPDs are USACE facilities, many of which, including all of the top 10, are navigation locks on the Ohio, Mississippi, Alabama, and Arkansas Rivers. Dams owned by Reclamation hold the potential to add 260 MW and are also attractive options for adding clean power to existing dams.
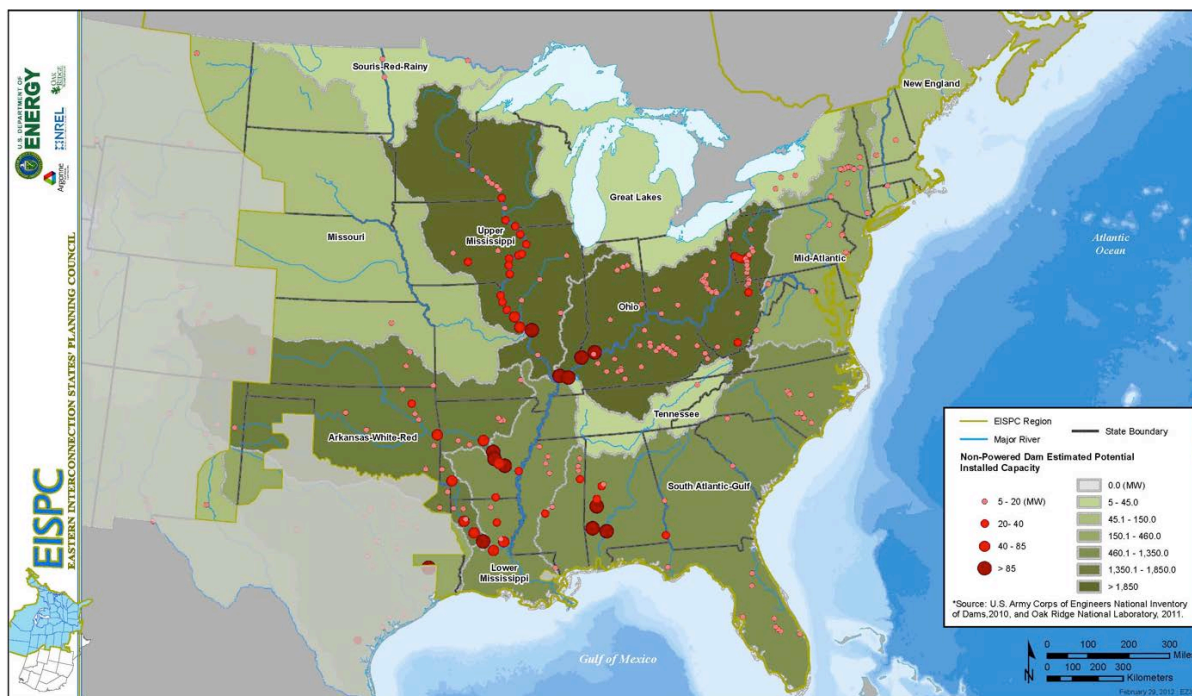
Figure 3-40 Hydropower Resources: Non-Powered Dam Resource Assessment by Hydrologic Region (Source: EZ Mapping Tool)

The national hydropower assessment is mainly targeted toward providing preliminary information for stakeholders who can further evaluate the potential to increase hydropower production at NPD sites. Developers could use the information provided in this assessment to focus on more detailed analysis of sites that demonstrate a reasonable potential for being developed. The availability and enhancement of national-scale datasets, such as the National Inventory of Dams (NID) and National Hydrography Dataset (NHD), provide a foundation for rigorous estimates of NPD potential for production for the entire country. Previous assessments, including Hall et al. (2004), DOI et al. (2007), and Reclamation (2011), have also been consulted in preparing the estimates reported herein.

3.8.4.3 River Hydrokinetic Energy

River hydrokinetic energy is the kinetic energy contained in non-tidal water currents. This energy is captured through turbines activated by the naturally flowing water in natural or constructed waterways. The turbines require a minimum current velocity referred to as "cut-in" speed to begin operation. Based on individual turbine design and performance, various water speeds correspond to optimal energy extraction.

With funding from DOE, EPRI conducted an assessment of the total available and technically recoverable in-stream hydrokinetic resources for the United States (excluding Hawaii). The assessment encompasses non-tidal rivers with a mean annual discharge exceeding 1,000 cfs. Table 3-20 summarizes the results from EPRI's assessment (EPRI 2012).

Table 3-20 Theoretical and Technically Recoverable River Hydrokinetic Energy Estimates for the Continental United States

Hydrologic Region	Theoretical Power (Annual Energy, TWh/yr)	Technically Recoverable Power (Annual Energy, TWh/yr)
New England	14.4	0.2
Mid-Atlantic	33.5	1.0
South Atlantic Gulf	38.5	1.2
Great Lakes	6.2	0.01
Ohio	79.2	6.9
Tennessee	20.4	1.0
Souris Red-Rainy	1.8	0.03
Upper Mississippi	47.0	5.1
Lower Mississippi	208.8	57.4
Texas Gulf	8.9	0.05
Arkansas Red	45.1	1.3
Lower Missouri	79.8	5.6
Upper Missouri	74.3	2.8
Rio Grande	29.5	0.3
Lower Colorado	57.6	3.9
Upper Colorado	46.9	1.1
Great Basin	6.9	0.0
California	50.9	0.7
Pacific Northwest	296.7	11.3
Alaska	235	20.5
Total	**1,381**	**119.9**

3.8.4.4 Marine Tidal Hydrokinetic and Wave Energy

DOE released two assessments on January 18, 2012, revealing that waves and tidal coastal currents could contribute significantly to U.S. electricity production. The first was produced by EPRI (2011) and the second by Georgia Tech Research Corporation (2011). The West Coast, including Alaska and Hawaii, has especially high potential for wave energy development, while significant opportunities for wave energy also exist along the East Coast. In addition, parts of both coasts have strong tidal currents that could be utilized to produce energy. Combined with other analyses, these assessments show that water power, including conventional hydropower, could provide 15% of U.S. electricity by 2030.

The United States uses about 4,000 TWh of electricity per year. DOE estimates that the maximum theoretical electric generation that could be produced from waves and tidal currents is approximately 1,420 TWh per year, about one-third of the nation's total annual electricity use. Though not all of the resource potential identified in these assessments can be realistically developed, the results still represent major opportunities for new water power development by highlighting specific opportunities to expand on the 6% of the nation's electricity already generated from hydropower resources.

3.8.4.5 Other

In addition to the wave and tidal resource assessments, DOE plans to release additional resource assessments for ocean current, ocean thermal gradients, and new hydropower resources in 2012. To support the development of technologies that can tap into these vast resources, DOE's Water Power Program is undertaking a detailed technical and economic assessment of a wide range of water power technologies in order to more accurately predict the opportunities and costs of developing and deploying these innovative technologies. The program is sponsoring more than 40 demonstration projects that will advance the commercial readiness of these systems, providing first-of-a-kind, in-water performance data that will validate cost-of-energy predictions and identify pathways for large cost reductions.

3.8.5 Screening Factors

Two of the categories examined, increasing production at existing dams and conversion of existing NPDs to power, are only valid at specific sites with existing resources. Screening factors are not needed for them. For the purpose of this analysis, the marine tidal hydrokinetic screening factors are listed in Table 3-21. The other technologies evaluated are not mature enough to establish definitive screening factors. Rather, information layers are provided that give an overall sense of where possible resources may become available if technologies improve.

The specific default suitability criteria and ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4. Informational layers may also be useful for additional analysis by overlaying them onto the suitability model results. The extensive list of EZ Mapping Tool informational layers is included in Appendix B.

Table 3-21 Hydropower Technology Screening Factors

Water Technology Type	Screening Factors (for established resources/technologies)
Marine tidal hydrokinetic energy	Tidal current speed (cm/s) Tidal power density Unexploded ordinance Navigable waterways Distance to port Proximity to electric transmission (all lines) Bathymetry Protected Land Habitat Imperiled Species

3.8.6 Data and Sources

Publicly available data to construct the screening factors for marine tidal hydrokinetic energy are available from a variety of sources listed in Table 3-22. The Protected Land, Habitat, and Imperiled Species screening layers and data sources are discussed in Section 4.

Added output from existing hydropower dams, new output from existing NPDs, in-stream hydrokinetic energy, and wave energy data are included as informational layers in the EZ Mapping Tool. Reports can be generated to summarize the inventory of these dams and their power potential, or the availability of in-stream hydrokinetic energy and wave energy data in an area of interest. Table 3-22 lists the sources of these data layers.

3.9 Wind

3.9.1 Introduction

Wind deployment has increased significantly over the last decade and has been the fastest growing renewable technology market in the United States over that time. The EIA reported almost 40 GW of installed wind capacity in 2010 (EIA 2011); Wind Powering America and the American Wind Energy Association report that an additional 7 GW of wind was installed in 2011 (WPA 2012). Almost half of the total U.S. wind power capacity is installed in the Eastern Interconnection; more than half of the Eastern Interconnection's installed wind capacity is in the Midwest Independent Transmission System Operator, Inc. (MISO) or Southwest Power Pool (SPP) control areas. To date, all of the installed capacity in the United States is land based, but several offshore wind farms have been proposed.

Wind turbines use the kinetic energy in the wind to turn a large rotor and convert that rotational energy to electricity. Land-based wind resource data is available at 80-m and 100-m height above ground. These heights are the typical hub height of current wind turbine technology being installed in the United States and has been steady for the past several years (Wiser and Bolinger 2011). Figure 3-41 shows average wind potential at 80-m hub height. New installations are

Table 3-22 Marine Tidal Hydrokinetic Data and Sources[a]

Resource/Factor	Data and Source
Tidal current speed (cm/s)	2012 Georgia Institute of Technology
Tidal power density	2012 Georgia Institute of Technology
Unexploded ordnance	2012 Department of Commerce (DOC), NOAA, National Ocean Service (NOS), Costal Services Center (CSC)
Navigable waterways	2012 Research and Innovative Technology Administration
Distance to port	2012 USACE
Electric transmission data	2012 Bentek Energy/Platts
Bathymetry	2013 NOAA
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	
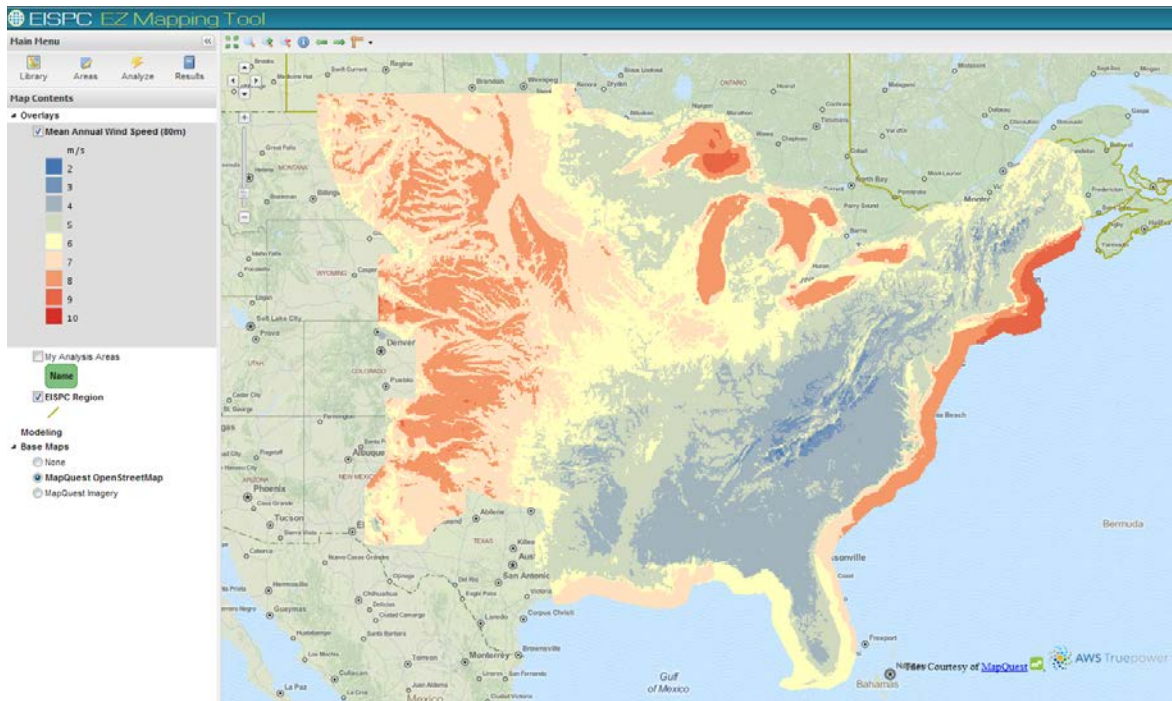
Figure 3-41 Estimated Annual Average Land-Based and Offshore Wind Resource at 80-m Height Above Ground (Source: EZ Mapping Tool)

seeking higher hub heights to capture more wind energy. Offshore wind resource data is at 90-m hub heights.

Sections 3.9.2 through 3.9.7 outline the scope of the investigation and describe wind energy resources and available conversion technologies, screening factors used in the study, data and sources, and synergistic factors with other technologies.

3.9.2 Scope

This research effort considered conventional utility-scale land-based and offshore wind technologies. Distributed wind (turbines 100 kW or smaller in size) was considered out of scope

for this study, as was siting of less prevalent wind conversion technologies such as vertical-axis wind turbines. Potential offshore wind turbines are considered, but only those that would be anchored in shallow waters (30-m depths or less) as anchoring methods in deeper waters are not yet well developed.

3.9.3 Resource Description

Wind is produced due to the uneven heating of the Earth; the poles receive less solar energy than the equatorial regions, and land masses warm and cool more quickly than water bodies. The uneven heating creates temperature gradients in the atmosphere as air moves from cold (high-pressure) to warm (low-pressure) areas. In general, the stronger the pressure gradient, the harder the wind blows between the regions in order to equalize the pressure gradients (EPAct 2011). Wind resource intensity varies spatially both horizontally along the ground and vertically into the atmosphere. Local terrain features can significantly impact wind resource intensity over short distances. For instance, a small elevated feature can be well exposed to wind resource and have high intensity, while a short distance down slope the land is sheltered and has low wind resource. There can also be local heating and cooling impacts on resource intensity over very short distances and time frames; that is, wind resource increases due to sea-breeze effects may dissipate within a few hundred meters of shore due to friction from surface vegetation. In general, wind resource increases with height above ground, but the rate of increase varies due to local terrain and meteorology. Offshore wind resources, moderated by the thermal cushioning of the surrounding water, generally display less spatial and temporal variability, though seasonal differences can still be significant.

The continental United States is characterized by a large-scale westerly flow (winds from the west) at higher levels of the atmosphere. The jet stream, located about 6 to 10 km above the surface, strongly influences weather systems across the country. Its influence is strongest in the northern states but can influence the entire continental United States. Regional wind climates in the United States are caused by the interplay of jet-stream-induced storm tracks, meteorological factors that occur closer to the surface, and regional and local terrain features. In the EZ Study area, land-based wind resources are present in the mountainous areas in the east; less intense but more consistent wind resources are in the central Great Plains. Resource is lowest in the southeast, but some suitable areas may be found along the coast or on elevated features. Offshore, considerable shallow areas suitable for development occur all along the eastern seaboard and Gulf Coast. Resource intensity is strongest in the northern portion, with lower offshore resource in the southern portion. However, offshore resource is noticeably stronger and more ubiquitous than land-based wind resource in the southern states.

Other parameters that can affect siting and performance of a wind farm include prevailing wind direction, frequency distributions of speed and direction, and wind shear (change of wind speed with height). Wind speeds are typically expressed in meters per second (m/s), and wind power density values are expressed as watts per square meter (W/m^2).

Public, high-resolution wind resource data were not available for the EZ Study area at the 80-m height above surface desired for this study. Therefore, a solicitation process was used to acquire a modeled wind resource dataset from a commercial source. AWS Truepower, LLC (AWST)

was the vendor selected, and it provided annual average wind speed and gross capacity factor estimates for the EZ Study area at 80- and 100-m heights above surface for land-based and offshore wind. The wind speed estimates are the result of AWST's MesoMap system (AWST 2012), a combination of mesoscale and microscale atmospheric models using a top-down approach for estimating wind near the surface. The microscale model then refines the wind estimates from the mesoscale model to capture the local influences of topography and surface roughness changes, and incorporates available surface observations when possible. The gross capacity factor estimates are the result of incorporating finer temporal resolution model estimates of wind speed with power curves from Class II IEC wind turbine power curves. Class II wind turbines are typical of wind turbines installed in the United States. However, Class III turbines, which utilize larger rotors at the same hub height to capture more energy at lower wind speeds, are increasingly being installed (Wiser and Bolinger 2011).

3.9.4 Conversion Technologies

For this study, the same conversion technology was used for both land-based and offshore wind energy extraction. The most common conversion technology is the horizontal axis wind turbine (Figure 3-42) which utilizes a tall tower upon which a spinning rotor is attached. There are variations on this design (i.e., two blades or three, size of the rotor blades, passive vs. active yaw systems), but these designs convert energy according to the same basic principles. The rotor at the top of the tower faces into or away from the wind, and the wind turns the rotor blades. Within

Figure 3-42 Maple Ridge Wind Farm in Lewis County, New York (Note: The wind farm contains a total of 195 1.65-MW wind turbines.) (Source: NREL 2013)

the turbine nacelle, the rotor is attached to a shaft which attaches to a generator, which generates electricity.

Offshore wind turbines utilize the same horizontal axis wind turbine structure but need to be anchored or supported to operate stably at a fixed location. The majority of offshore wind installations in the world have been sited in relatively shallow waters (30-m depths or less) where the turbines can be anchored directly into the seabed. Deployment of wind turbines in deeper waters through the use of floating platforms or other methods is still in the early stages of development (Musial and Ram 2010).

3.9.5 Screening Factors

Screening factors for land-based wind (Table 3-23) are well defined because of the number of wind installations over the last decade and are drawn in large part from national wind potential estimates generated by NREL (WPA 2011; Lopez et al. 2012). Offshore screening factors (Table 3-23) have been defined based on limits of the current technology, information from global offshore installations, and extrapolation of land-based screening factors. The specific default suitability criteria and ranges for each screening parameter are listed in Appendix A. The Protected Land, Habitat, and Imperiled Species screening parameters are discussed in Section 4. Informational layers may also be useful for additional analysis by overlaying them onto the suitability model results. The extensive list of EZ Mapping Tool informational layers is included in Appendix B.

Table 3-23 Wind Technology Screening Factors

Wind Technology	Screening Parameter
Land-based	Wind turbine gross capacity factor Population density Slope Land cover area Distance to major road Distance to airport runway Proximity to electric transmission (>345 kV) Protected Land Habitat Imperiled Species
Offshore	Wind turbine gross capacity factor Population density Bathymetry Distance to substation Unexploded Ordnance Distance to shore Navigable waterways Protected Land Habitat Imperiled Species

3.9.6 Data and Sources

Land-based and offshore wind resource data were obtained from AWST through a competitive solicitation. The data include average annual wind speeds at hub heights of 80 m and 100 m, based on a 200-m grid covering the entire Eastern Interconnection. Simulated temporal data provide estimates of hourly gross capacity factors for the same territory, but at a 20-km resolution.

Publicly available data used to construct the screening factor layers for the wind technologies are available from a variety of sources and are listed in Table 3-24.The Protected Land, Habitat, and Imperiled Species screening layers and data sources are discussed in Section 4.

3.10 Synergistic Considerations

The EZ Mapping Tool provides a means to find regions of higher energy potential from the different individual technologies described above. An important additional factor that the user must consider is the inter-relationships among the technologies. Close co-location of some technologies may provide synergies where one technology provides benefits for the other. In other situations, the technologies may be compatible, so that a region can support a greater density of electricity capacity than if only one were deployed. Lastly, the two may compete for the same resources or disrupt each other in other ways so that the combination of technologies has lower total capability than the sum of each by themselves.

A user of the EZ Mapping Tool should consider these synergy effects when analyzing the potential capacity for possible EZs. The discussion below and Table 3-25 provide some examples of possible synergistic impacts among different clean energy resources and the co-location compatibility of different technologies, as well as the incidence of competing

Table 3-24 Wind Technology Screening Factor Data and Sources[a]

Factor (Parameter)	Data and Source
Population density	LandScan™, (http://www.ornl.gov/sci/landscan)
Slope	2012 NGA digital terrain elevation data/calculated and resized for 250-m cells
Land cover area	2011 USGS
Distance to major road	2012 National Transportation Atlas Database, www.bts.gov/publications/national_transportation_atlas_database/2012
Distance to airport runway	2012 FAA
Transmission data	2012 Bentek Energy/Platts
Bathymetry	2013 NOAA
Distance to substation	2012 Bentek Energy/Platts
Unexploded ordnance	2012 DOC, NOAA, NOC, CSC
Distance to shore	2012 Argonne
Navigable waterways	2012 Research and Innovative Technology Administration
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

Table 3-25 Synergies among Clean Energy Resources

	Water	Land	Operations
Biomass/coal-CCS	Compete for cooling		Dual fuel use through co-firing
Biomass/wind		Dual use (except forests)	
Coal-CCS/geothermal	Compete for cooling		
Coal-CCS/gas	Compete for cooling		
Coal-CCS/nuclear	Compete for cooling	Similar site resources	
Coal-CCS/solar			CSP augments feedwater heating
Coal-CCS/storage		Compete with CAES for underground space	
Coal-CCS/hydro	Dual use of reservoir		
Geothermal/nuclear	Compete for cooling		
Storage/nuclear	Dual use of reservoir		
Storage/solar			Firms electricity delivery
Storage/wind			Firms electricity delivery
Storage/hydro	Dual use of reservoir		

Positive synergy or compatibility   Negative synergy or competition

technologies. Energy planners can use the information on possible synergistic impacts to evaluate potential co-location of technologies where an overlap of two or more highly suitable clean energy resources has been identified.

The main categories for synergy or competition are in the use of water resources, land (above or below ground), and operational synergies based on the characteristics of the technologies. For example, limited water resources create competition among thermal technologies because they require water for cooling. In some cases, there can be synergy, such as the creation of a reservoir that provides both cooling water for thermal plants and a storage pool for hydroelectric or pumped storage hydroelectric power.

Land resources can provide synergy when a technology (such as wind) is compatible with other energy technologies such as farming of biomass resources. Wind turbines in a wind farm are spaced far apart and have a small, dedicated footprint per wind turbine, which allows for mixed use within a wind farm's boundaries. Synergy exists with biomass fuel development activities since they can readily be grown and harvested between turbine sites. This multiple use of the land increases the resource density and improves justification of infrastructure improvements for an EZ. Table 3-25 does note that tree-based (forest) biomass resources may conflict with wind due to the tree-height reducing some fraction of the wind resource. Solar and wind co-location is

also possible, but more problematic with likely shading effects from the turbine structures that would affect solar production. Similarly, utility-scale PV can be co-located with other types of power plants if sufficient land area is available. Siting would need to be carefully conducted to avoid shading from large structures.

Underground resources can also be a factor. The surface footprint of a geothermal power plant is only a fraction of the underground footprint. Similarly, CAES facilities are very small on the surface but utilize large underground space under high pressure. Carbon sequestration may also use deep underground storage of CO_2. These three technologies may conflict with each other if located in the same area.

Operational characteristics may create opportunities for synergy. Biomass resources can be co-fired with coal, thereby promoting a renewable resource while having a firm capacity available regardless of the variation in biomass fuel availability. In general, CSP energy production is compatible with fossil plants that utilize steam turbine generators, so long as they have sufficient land area available to support installation of the solar field. NREL and EPRI have conducted a study examining synergies between CSP and existing coal or natural gas power plants (Turchi et al. 2011). It is possible that hybrid geothermal and CSP plant designs might be jointly developed as both technologies advance.

Storage technologies provide a system-wide operational benefit by allowing the operators to smooth generation, make up for intermittent or lost production, or take advantage of system cost differences over differing time scales. Many of these system benefits do not require that the storage be co-located or close to generation technologies, but there can be synergies if they are. For example, variable generation, such as wind or solar, will often operate at only a fraction of their full power, but transmission capacity may be needed for their peak production. Co-located storage may allow the operators to better utilize this transmission capacity during times of low wind or solar output (Sullivan et al. 2008; Parsons et al. 2006). Aggregation of variable generation, relative cost of transmission capacity, and other factors will all play a role in determining the best location for storage. Baseload plants, such as nuclear, would see less gain from co-locating storage since they provide a relatively constant level of power.

As a distributed resource, rooftop PV has little direct synergy or conflict with any generation technology at transmission-level voltages. However, it does have a high potential for synergy with future "smart grid" technologies. Some of the potential synergy is economic. If smart grid facilitates time-of-use retail electricity rates, then customers would have a greater incentive to install rooftop PV systems. Rates for on-peak usage would be higher than for off-peak usage, which would make the value of on-peak load reduction greater.

A number of technologies may compete for similar land and water resources. Many of the technologies in the EZ Mapping Tool have similar screening criteria (e.g., population, protected lands, and flood zones), thus regions suitable for one may be suitable for others as well. This is most apparent for technologies of similar size and resource needs. For example, advanced coal plants, gas-fired combined cycle, and nuclear plants being thermally driven have somewhat similar land and water criteria. Sites suitable for nuclear plants (generally the most restrictive) would also be suitable for coal and natural gas facilities.

4 Environmental Considerations

4.1 Background

Including environmental screening layers in the EZ Mapping Tool allows environmental factors to be incorporated at the beginning of the planning process to reduce the risk of public opposition, regulatory intervention, and litigation later in the planning or development process. In the EZ Mapping Tool, environmental screening factors related to energy development were grouped into three model input layers: Protected Lands, Habitat, and Imperiled Species. These environmental screening layers were included in models for all nine clean energy resource types. Each environmental screening layer is a composite made up of several individual datasets (tables are provided in Appendices D and E).

An Environmental Focus Group (EFG) was created to determine the appropriate environmental spatial data to include in each composite environmental screening layer. The EFG included subject matter experts from federal and state agencies, environmental non-governmental organizations (NGOs), and industry stakeholders, including the following:

- American Transmission Company

- Argonne National Laboratory

- Association of Fish and Wildlife Agencies

- Bureau of Ocean Energy Management, Regulation and Enforcement

- The Conservation Fund

- Defenders of Wildlife

- Eastern Interconnection States' Planning Council

- Eastern Interstate Planning Council

- EPA Region 4

- Exelon Corporation

- Michigan Public Service Commission

- National Audubon Society

- The Nature Conservancy

- NatureServe

- New York Independent System Operator

- Oak Ridge National Laboratory

- Southern Regional Energy and Environmental Office

- Western Governors' Association

- The Wilderness Society

- Xcel Energy

4.2 Composite Environmental Screening Layer Development Methods

The majority of the datasets included in the habitat and protected lands screening layers were compiled by NatureServe and an NGO caucus of the Eastern Interconnection Planning Collaborative (EIPC) as an initial set of data layers to be considered during the assessment of zones suitable for clean energy development in the Eastern Interconnection. The EFG then identified several additional datasets to augment the initial list while attempting to prevent redundant data. When identifying additional datasets to include in the composite screening layers, the EFG focused on identifying high-quality regional environmental datasets and Green Infrastructure Data that identified core conservation areas and emphasized connectivity among them at a landscape scale, rather than focusing on species-specific habitat or datasets that cover small areas. The EZ Mapping Tool is not designed for project siting, thus more detailed information is necessary for that level of analysis. The resulting habitat and protected lands composite screening layers consist of a wide range of state, regional, and national datasets which collectively cover the Eastern Interconnection.

In order to create composite environmental screening layers, a four-tier sensitivity categorization utilizing red, yellow, orange, and background was applied to each individual dataset. These sensitivity categorization levels for clean energy resource development are defined below:

- Red (Exclude from development): Areas where development is already precluded by statute or regulation (federal, state, and local).

- Orange (Develop with extreme caution): Areas where development would likely pose a high risk to natural resources but development is not precluded, or where development would likely pose a high risk to important habitat or imperiled species (G1, G2, T1, T2, S1, ESA-E, ESA-T, ESA-C, ESA-P, State-E, and State-T).

- Yellow (Develop with caution): Areas where development would likely pose a moderate risk to protected lands (development has not already been precluded) or where development would likely pose a moderate risk to important habitat or imperiled species (G3, T3, ESA-SAT, ESA-SC, and S2).

- Background (Likely low conflict area): Areas where development would have the lowest impact on habitat, imperiled species, and protected lands based on the included data. Additional data may provide information to increase the sensitivity in these areas. Further research at the project level would provide a more comprehensive categorization of sensitivity in these areas.

Each sensitivity categorization level was assigned a different default suitability value for the default model runs ranging from 0 (unsuitable) to 100 (most suitable): red = 0, orange = 20, yellow = 40, and background = 95. In the EZ Mapping Tool, the default suitability values can be adjusted. The creators or data managers for each dataset were contacted and asked for feedback about the categorization of their data and their advice was incorporated. The EFG conducted webinars (approximately one a month) to discuss data needs as well as the categorization of the individual datasets. The composite screening layers were then created by combining the individual datasets, and the highest sensitivity level was retained in any overlapping regions. The imperiled species composite screening layer was created by and procured from NatureServe. NatureServe obtained data from state natural heritage programs and created a species-blind dataset categorized according to the four-tier sensitivity levels based on the Element Occurrences of imperiled plant and animal species and their federal and state listing status, as well as their NatureServe conservation status ranks: Global conservation status rank (G-rank), Subnational conservation status rank (S-rank), and Infraspecific taxon status rank (subspecies, varieties, and other designations below the level of the species) (T-rank). Species status ranks are defined as follows:

- G1 – Globally critically imperiled species

- G2 – Globally imperiled species

- G3 – Globally vulnerable species

- T1 – Critically imperiled subspecies

- T2 – Imperiled subspecies

- T3 – Vulnerable subspecies

- S1 – State critically imperiled species

- S2 – State imperiled species

- ESA-C – Candidate species for federal listing

- ESA-P – Proposed species for federal listing

- ESA-PDL – Proposed for delisting

- ESA-E – Federally endangered species

- ESA-T – Federally threatened species

- ESA-SAT – Federally threatened species due to similarity of appearance

- ESA-SC – Federal species of concern

- ESA-XN – Nonessential experimental population

- State-E – State endangered species

- State-T – State threatened species

4.3 Data Caveats

Areas not identified as sensitive to energy development in any of the three composite environmental screening layers are not determinedly low impact areas; they may represent areas not surveyed during the studies used to create the individual datasets contained in the composite layers. In addition, the availability of environmental data varied extensively within the Eastern Interconnection. Several regional datasets that cover the southeastern and northeastern United States were included in the habitat composite screening layer; however, no regional datasets were available for the Midwestern states. Environmental sensitivity development may appear to be greater in the eastern EISPC region than the western EISPC region due to a greater number of available data layers. Site-specific surveys must still be conducted at the project-level to ensure avoidance of highly sensitive environments.

5 Policy, Demand Response, and Smart Grid Considerations

The earlier sections of this report describe the possible technologies that may be in place within an EZ and the criteria used to establish highly suitable areas. There are other considerations, including policy, demand response (DR), and smart grid technologies, that play a role in determining areas for potential EZs, even though they do not directly identify technologies, groups of technologies, or areas of concentrated resources. Policy considerations assist in the determination of viable EZs within the Eastern Interconnection by providing either positive or negative incentives to certain regions. DR is a technology that has the potential to reduce electricity demands at key times so that less capacity is needed on the grid and can be a substitute for the resources described in Section 3 of this report. In addition, smart grid is an enabler for some types of DR, as well as for energy efficiency, emergency response, and improved reliability of the electricity grid.

5.1 Policy

Policy considerations are a crucial aspect for the advancement of clean energy. The incentives are less likely to be geographically based, except for the associated political boundaries. For most policies, the appropriate mapping representations are simply the political boundaries where the policies are in effect. For example, some states have RPSs that provide incentives for the development of certain clean energy technologies. Some of these RPS laws have additional incentives if the technology is located within the state. Other policies may include prohibitions on nuclear plant construction, local fuel supply preferences, or incentives for job development. At finer detail, smaller political subdivisions may have their own policy incentives or disincentives, down to zoning regulations. However, these levels of detail are beyond the present scope of the EZ Mapping Tool.

The EISPC contracted with CESA to create an inventory of the clean energy laws, regulations, incentives, and other policies in the different states and Canadian Provinces across the Eastern Interconnection that can be accessed from the EZ Mapping Tool. Rather than develop a static report, CESA collaborated with EZ Mapping Tool developers and helped create a database displayed within the EZ Mapping Tool website that also connects to other online databases through NREL's OpenEI.

To populate the inventory, CESA began with DSIRE, which is funded by DOE and has been implemented by the North Carolina Solar Center and the Interstate Renewable Energy Council (NCSU 2013). It is "the most comprehensive source of information on incentives and policies that support renewables and energy efficiency in the United States." However, DSIRE does not cover some of the clean energy resource categories included in the EISPC EZ Mapping Tool, such as nuclear, natural gas, or geothermal. DSIRE also does not cover some types of policies (e.g., environmental regulations, state economic development incentives, climate action plans, and forestry policies) that can be relevant when making decisions about clean energy resource development. CESA therefore expanded its database to incorporate these technologies and policies.

CESA worked with NREL to create the database as a wiki in the OpenEI website <http://en.openei.org/wiki/EZPolicies> and populated it with available information. All states and provinces were invited to review the data and provide additional information. There are currently 2,360 policies in the database, including federal, state, and local policies. These are assigned to the different political entities as shown in Table 5-1. The database can be easily updated as new information is made available.

The EZ Mapping Tool incorporates the database with a tab that allows the user to search for policies and regulations by any combination of political entity, policy type, implementation sector, and affected technologies, as shown in Figure 5-1.

Table 5-1 Relevant Energy Policies in the EZ Mapping Tool Database as of April 19, 2013

All EZ Policies (2,360)	New Jersey (44)
United States Federal Policies (18)	New Mexico (53)
Canada Federal Policies (9)	New York (79)
	North Carolina (62)
State Policies	North Dakota (57)
Alabama (36)	Ohio (60)
Arkansas (31)	Oklahoma (45)
Connecticut (85)	Pennsylvania (72)
Delaware (38)	Rhode Island (48)
District of Columbia (22)	South Carolina (50)
Florida (74)	South Dakota (43)
Georgia (58)	Texas (91)
Illinois (58)	Tennessee (38)
Indiana (77)	Vermont (50)
Iowa (98)	Virginia (85)
Kansas (38)	West Virginia (49)
Kentucky (49)	Wisconsin (56)
Louisiana (43)	
Maine (61)	**Canadian Province Policies**
Maryland (119)	Manitoba (15)
Massachusetts (55)	Newfoundland and Labrador (10)
Michigan (47)	New Brunswick (12)
Minnesota (107)	Nova Scotia (13)
Mississippi (38)	Ontario (21)
Missouri (56)	Prince Edward Island (15)
Montana (95)	Quebec (14)
Nebraska (65)	Saskatchewan (15)
New Hampshire (33)	

Figure 5-1 EZ Mapping Tool Search Parameters

Table 5-1 lists the political entities; the policy types that can be searched are listed in Table 5-2. The five implementation sectors are shown in Figure 5-1, while the affected technologies are listed in Table 5-3.

Search results include state-level summaries providing an overview of the state's policy context and a summary description of each policy with a number of key characteristics; clicking on the name of the policy takes the user to more details on that policy provided within the OpenEI database.

5.2 Demand Response

FERC defines demand response as "the changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" (FERC 2009). DR tariffs and incentive programs are offered by utility companies, system operators, utility companies, electricity cooperatives, municipal power agencies, and other load-serving entities, and they incentivize consumers to reduce their electricity consumption over a specific period of time (Isser 2009; FERC 2009; PLMA 2002). DR programs are quite diverse in the means through which they offer energy-consumption-reduction incentives.

As part of its development of white papers and studies, the EISPC contracted with Navigant to conduct a survey and analysis of a broad range of demand-side resources for electrical energy end-uses within the Eastern Interconnection (Navigant 2013). These analyses considered six categories of resources:

- Study #1: End-use energy efficiency programs (EE),

- Study #2: Demand response programs (DR),

- Study #3: Distributed energy storage systems (ES),

Table 5-2 Searchable Policy Types in the EZ Mapping Tool Database as of April 19, 2013

Bond Program	Climate Policies
Corporate Tax Incentive	Enterprise Zone
Environmental Regulations	Equipment Certification
Equity Investment	Fees
Generating Facility Rate-Making	Generation Disclosure
Grant Program	Green Building Incentive
Green Power Purchasing	Industry Recruitment/Support
Interconnection	Leasing Program
Line Extension Analysis	Loan Program
Mandatory Utility Green Power Option	Net Metering
PACE Financing	Performance-Based Incentive
Personal Tax Incentives	Property Tax Incentive
Public Benefits Fund	Rebate Program
Renewables Portfolio Standards and Goals	Safety and Operational Guidelines
Sales Tax Incentive	Siting & Permitting
Solar/Wind Access Policy	Solar/Wind Contractor Licensing
Training/Technical Assistance	Utility Rate Discount
Workforce Development	

Table 5-3 Clean Energy Technologies in the EZ Mapping Tool Database as of April 19, 2013

Biomass/biogas	Coal with CCS	Concentrating solar power
Energy storage	Fuel cells	Geothermal electric
Hydroelectric	Natural gas	Nuclear
Solar photovoltaic	Tidal energy	Wave energy
Wind energy		

- Study #4: Distributed generation powered by fossil fuels (DG-F),

- Study #5: Distributed renewable resources (DG-R), and

- White Paper #1: Other programs and initiatives enabled by the smart grid (SG).

Study #2 focused on an analysis of DR programs across the Eastern Interconnection. The primary sources of data were the independent system operator/regional transmission organization (ISNO/RTO) forecasts in states that allow DR to participate in capacity markets and utility Integrated Resource Plans (IRPs) for all other states. Roughly three-fourths of the states in the Eastern Interconnection require utilities to file IRPs or other long-term plans. In addition, data were available through FERC and the EIA surveys and reporting forms. NERC also provided data through its Long-Term Reliability Assessment.

Navigant conducted a study of existing (2012), near-term (2013–2015), and long-term (2016–2030) forecasts of DR resources. Their results show a recent expansion of DR capacity with continued growth through the near-term. Long-term, it expects DR growth to roughly parallel overall growth in demand so that the percentage of capacity from DR will stay roughly constant.

Tables 5-4 and 5-5 show the base case results for Navigant's analysis. The DR Resource Capacity is the total amount of DR that could be called upon, while the Peak Load Impact reflects that not all DR can or should be called upon at the same time. Some types of DR are only available at certain times, such as air-conditioning during hot days or water heating when heating is most in use such as winter mornings. Many may have limits on the amount of time they can be used, either as number of events per year and/or amount of time per event. Optimized utilization may mean that some resources are reserved for other peak periods to better equalize peaks.

Furthermore, some fraction of DR suppliers may not have their resource available when the capacity is called upon. Navigant summarizes all of these reasons by using what it refers to as the *realization rate* for DR. Navigant used the data from the FERC 2012 DR survey (FERC 2012) to find the ratio of potential peak reduction to actual peak reduction. Separate ratios were calculated for the different regions and for the different types of DR programs.

Figure 5-2 shows a breakdown of the project DR capacity by the different types of programs that Navigant modeled. Emergency/Reliability DR represents capacity that will respond to an emergency event (such as system or local constraints) in exchange for an incentive or rate discount. This includes interruptible load, load procured as a capacity resource, and emergency demand response programs. It is mainly provided by commercial and industrial customers. Another contributor is direct load control (DLC), where the program sponsor remotely shuts off or reduces the load of specific equipment at a customer's site, such as air-conditioning or water heating. Time-based rates are expected to play an increasing role as more utilities provide this option.

Lastly, Navigant created four alternate scenarios to its base case, with varying policies in support of DR and level of economic growth. With more aggressive policies, the amount of DR

Table 5-4 Projected DR Resource Capacity by U.S. Census Region

U.S. Census Division	U.S. Census Region	Projected DR Resource Capacity (MW)						
		2012	2013	2014	2015	2020	2025	2030
Northeast	New England	1,253	1,435	1,460	1,462	899	957	1,025
	Middle Atlantic	6,767	8,416	9,539	9,706	10,230	10,800	11,427
Midwest	East North Central	6,694	7,352	9,981	10,298	10,848	11,439	12,080
	West North Central[a]	6,035	6,670	7,252	7,569	7,969	8,362	8,779
South	South Atlantic	11,657	13,033	15,638	16,032	17,002	18,078	19,232
	East South Central	4,785	4,993	5,420	5,494	5,881	6,286	6,730
	West South Central[a,b]	1,931	2,035	2,409	2,586	2,746	2,877	3,026
Total		39,123	43,933	51,698	53,148	55,574	58,799	62,298

[a] Portions of both Montana and New Mexico fall within Eastern Interconnection territory. However, even though they are part of the Mountain Census Region, they are grouped into West North Central and West South Central, respectively, due to the proximity and small service area.
[b] Excludes the Electric Reliability Council of Texas (ERCOT) portion of Texas.
Source: Navigant (2013).

Table 5-5 Projected DR Peak Load Impact by U.S. Census Region

U.S. Census Division	U.S. Census Region	Projected DR Resource Peak Load Impact (MW)						
		2012	2013	2014	2015	2020	2025	2030
Northeast	New England	792	907	923	925	572	609	653
	Middle Atlantic	4,346	5,411	6,134	6,240	6,577	6,944	7,347
Midwest	East North Central	4,291	4,707	6,418	6,614	6,968	7,349	7,761
	West North Central[a]	3,759	4,151	4,509	4,704	4,953	5,198	5,457
South	South Atlantic	7,314	8,181	9,828	10,069	10,678	11,353	12,077
	East South Central	2,747	2,867	3,125	3,170	3,392	3,627	3,882
	West South Central[a,b]	1,194	1,260	1,492	1,604	1,703	1,784	1,877
Total		24,443	27,484	32,429	33,327	34,844	36,863	39,054

[a] Portions of both Montana and New Mexico fall within Eastern Interconnection territory. However, even though they are part of the Mountain Census Region, they are grouped into West North Central and West South Central, respectively, due to the proximity and small service area.
[b] Excludes the ERCOT portion of Texas.
Source: Navigant (2013).
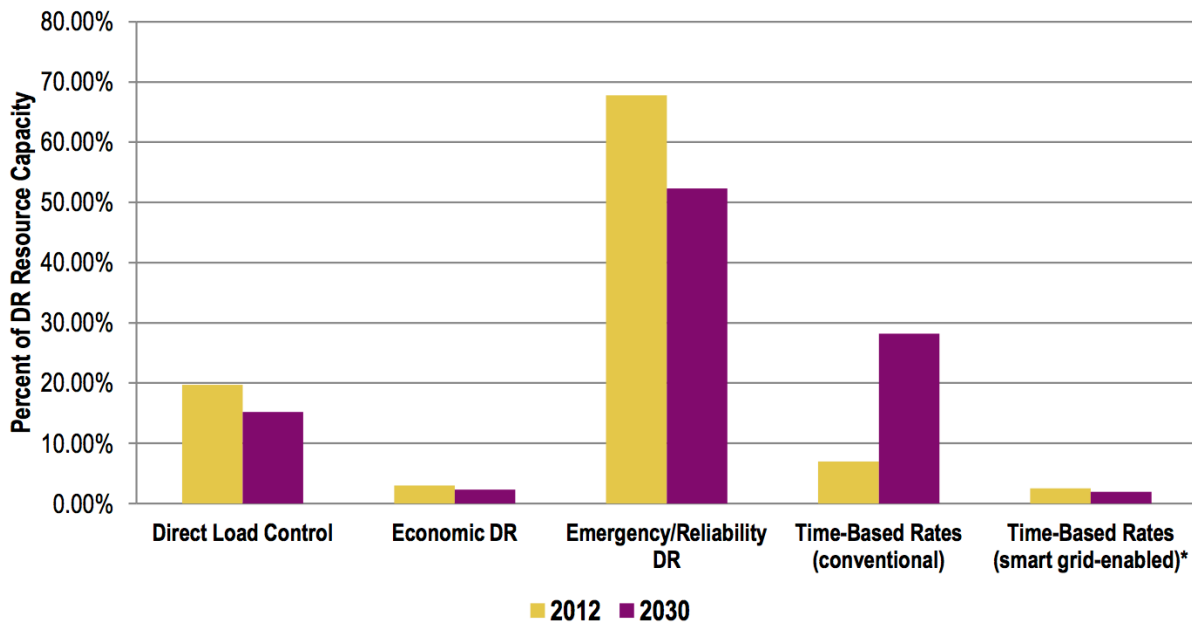
* Includes time-based rate programs that require AMI meters with two-way communication capability.

Figure 5-2 Percentage of DR Resource Capacity by Sub-Resource Category (Source: Navigant 2013)

increased over the base case, and higher economic growth accelerated DR as grid capacity demand increased.

In addition to Navigant's study, DOE funded ORNL to conduct a separate study on the potential for DR in the Eastern Interconnection (Baek et al. 2012). This study focused on the potential for DR using a modified version of the National Assessment of Demand Response (NADR) simulator made available by FERC. The assessment covered each state within the Eastern

Interconnection through 2030. It involved four separate scenarios: Business As Usual (BAU) that kept current DR programs ongoing but with little expansion; Optimistic BAU that expanded the current programs to utilities that currently do not have them but did not change technologies or types of programs; Aggressive Deployment that increased the DR pricing programs available and utilized smart grid technologies; and Full Deployment where all potential DR participants joined in the programs.

Five types of DR programs were utilized, similar to the Navigant programs but with slight regroupings of sub-programs. The NADR model also allowed further breakdown of resources by customer type, disaggregating by residential, and small, medium, and large commercial and industrial customers. Figure 5-3 shows the amounts of DR projected in the different scenarios by the ORNL study. According to 2030 DR potential analysis by scenario, program type, and end-use sector, under the BAU and Optimistic BAU scenarios, the largest gains come through interruptible tariffs and other DR. A significant growth in pricing programs (with and without enabling technologies) is noticed under the Aggressive and Full Deployment scenarios. DLC has a significant impact on the residential and small commercial and industrial (C&I) sectors. The majority of DR comes from large C&I customers primarily through interruptible tariffs (rates) and capacity and load bidding. In the residential sector, the most untapped potential for DR comes from the pricing programs.

5.3 Smart Grid

According to DOE:

> "Smart grid" generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries. They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the consumers of electricity in homes and businesses. They offer many benefits to utilities and consumers -- mostly seen in big improvements in energy efficiency on the electricity grid and in the energy users' homes and offices (DOE 2013).

Figure 5-4 is a schematic of the energy and information flow in a smart grid. The key characteristic of a smart grid is the frequent (up to continuous) two-way communication between devices in the field and the utility's network operations. Information on electricity usage, voltage, and even key equipment status can be sent from customers to the operators, while data such as varying prices and critical power problems can be transmitted to customers. This extra information can help both customers and operators to better manage the electricity grid.

Customers can respond to high prices or critical power needs by reducing demand during those periods. Operators can remotely modify the line voltage or operating characteristics of equipment as well.
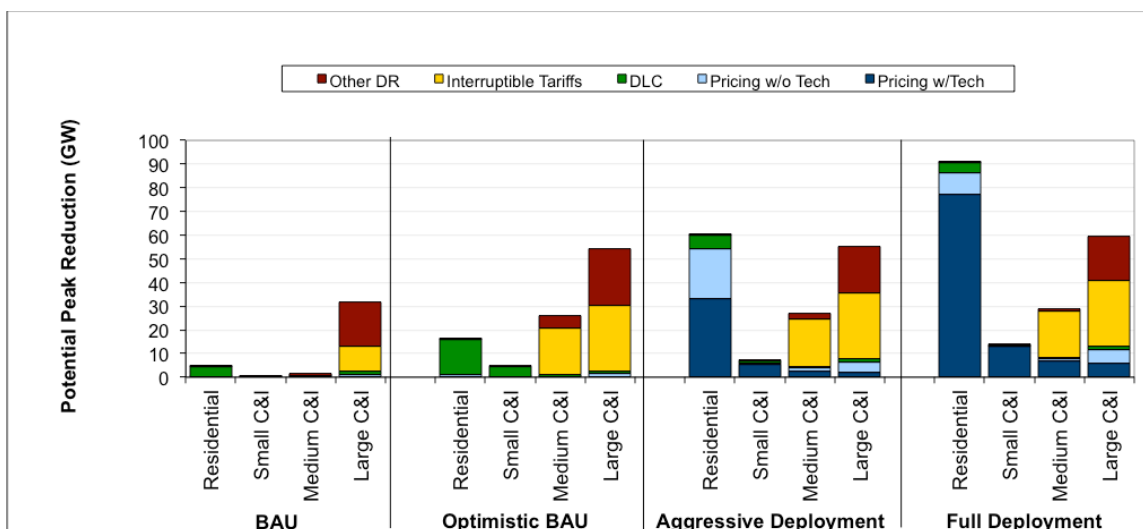
Figure 5-3 Potential Peak Reduction from DR in the Eastern Interconnection, 2030 (Source: Baek et al. 2012)

The smart grid by itself does not reduce demand. Rather, it is an *enabler* of demand response by providing additional, up-to-date information to consumers and system operators so they can make informed decisions on how to best use or make power. Automating the decision making (such as through smart appliances and thermostats) helps increase utilization of the information to make the savings more persistent and consistent.

The two main DR programs that the Navigant study (Navigant 2013) identified as most directly dependent on the existence of a Smart grid are:

- Automated Metering Infrastructure (AMI) and Time-Based Rate (TBR) programs that are enabled by AMI and,

- Conservation Voltage Reduction (CVR) programs.

An AMI requires not only smart meters installed at customers premises but also a communication system and large computing and data storage hardware systems, due to the large increase in data flow to and from consumers. TBRs may either change on an ongoing basis or only during critical times, depending on the design of the program.

CVR is a strategy used by utility operators to lower the voltage on a feeder during peak times while maintaining minimum voltage levels along its length. The smart grid provides information on the voltage all along the line so the utility operator can drop voltages closer to the minimum level without causing equipment damage from under-voltage. The utility needs to deploy dispatchable load-tap transformers in order to take advantage of this information.

Tables 5-6 and 5-7 show the projected resource capacity and peak load impact from the two smart grid-related DR resources combined for each of the major census regions. Since CVR is
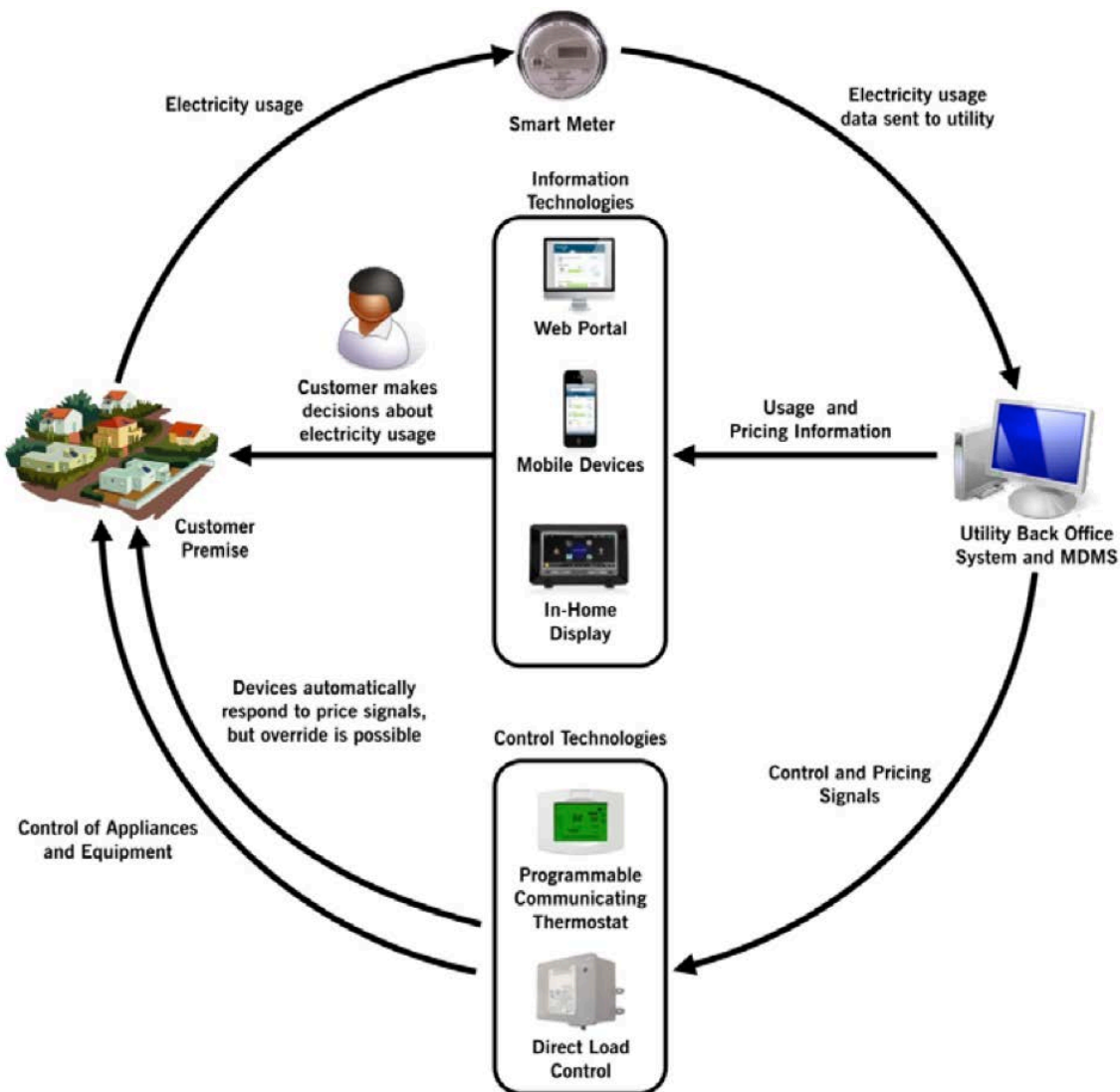
Figure 5-4 Overview of Consumer Devices and Systems for Managing Electricity Consumption and Costs (Source: DOE 2012)

controlled by the utilities, it is only dispatched during peak time, and the realization rate is 1.0. Its contribution to peak load is the same as its capacity.

The Navigant report (Navigant 2013) gives a further disaggregation into each category, as well as the energy impact from each. It also shows the expected impact under the scenarios with higher or lower economic growth and DR policies.

Lastly, it is worthwhile to show the results from Navigant's combined analysis of different demand-side resources analyzed, some of which are not included in the EZ Mapping Tool. Table 5-8 shows the potential resource capacity under the base case for each category, and Figure 5-5 presents the information in graphical form. Table 5-9 presents the Peak Load Impact from each category, along with Navigant's estimate of peak demands. Note that the full range of programs combined represents roughly 20% of peak demand by 2030.

Table 5-6 Smart Grid (TBR + CVR) Capacity by U.S. Census Region

U.S. Census Division	U.S. Census Region	Projected Smart Grid Capacity (MW)						
		2012	2013	2014	2015	2020	2025	2030
Northeast	New England	33	36	37	241	479	824	1,034
	Middle Atlantic	157	211	272	305	1,117	1,879	2,503
Midwest	East North Central	335	552	624	757	1,485	2,270	2,838
	West North Central[a]	105	124	138	169	509	896	1,361
South	South Atlantic	1,398	1,477	1,614	1,966	3,678	5,046	5,879
	East South Central	18	19	32	49	576	1,146	1,620
	West South Central[a,b]	370	433	526	575	815	1,107	1,372
Total		**2,417**	**2,851**	**3,243**	**4,061**	**8,659**	**13,168**	**16,607**

[a] Portions of both Montana and New Mexico fall within Eastern Interconnection territory. However, even though they are part of the Mountain Census Region, they are grouped into West North Central and West South Central, respectively, due to the proximity and small service area.
[b] Excludes the ERCOT portion of Texas.
Source: Navigant (2013).

Table 5-7 Smart Grid (TBR + CVR) Peak Load Impact by U.S. Census Region

U.S. Census Division	U.S. Census Region	Projected Smart Grid Peak Load Reduction (MW)						
		2012	2013	2014	2015	2020	2025	2030
Northeast	New England	15	16	17	219	361	611	768
	Middle Atlantic	72	98	125	149	538	952	1,275
Midwest	East North Central	192	378	413	479	837	1,311	1,622
	West North Central[a]	53	62	69	90	292	576	852
South	South Atlantic	774	810	890	1,187	1,980	2,970	3,470
	East South Central	8	9	20	36	294	670	929
	West South Central[a,b]	166	217	262	286	411	637	798
Total		**1,282**	**1,589**	**1,796**	**2,446**	**4,711**	**7,727**	**9,714**

[a] Portions of both Montana and New Mexico fall within Eastern Interconnection territory. However, even though they are part of the Mountain Census Region, they are grouped into West North Central and West South Central, respectively, due to the proximity and small service area.
[b] Excludes the ERCOT portion of Texas.
Source: Navigant (2013).

Table 5-8 Total Demand-Side Resource Capacity by Resource Category

		Projected Total Demand-Side Resource Capacity (MW)						
		2012	2013	2014	2015	2020	2025	2030
Energy Efficiency		3,016	5,650	8,567	11,542	25,956	40,106	53,369
Demand Response	*Conventional Programs*	36,739	41,270	48,613	49,535	47,469	48,007	48,790
	Smart Grid-Enabled[a]	2,384	2,662	3,086	3,613	8,105	10,793	13,508
Energy Storage		88	93	125	149	1,118	2,180	3,479
DG-Fossil		17,811	17,725	17,718	17,671	18,107	18,832	19,909
DG-Renewables		6,126	7,150	8,333	9,744	19,974	33,603	50,091
Smart Grid (CVR)		353	557	612	1,124	1,481	3,276	4,075
Total		**66,517**	**75,109**	**87,053**	**93,378**	**122,209**	**156,796**	**193,221**

[a] Includes time-based rate programs that require AMI meters with two-way communication capability.
Source: Navigant (2013).
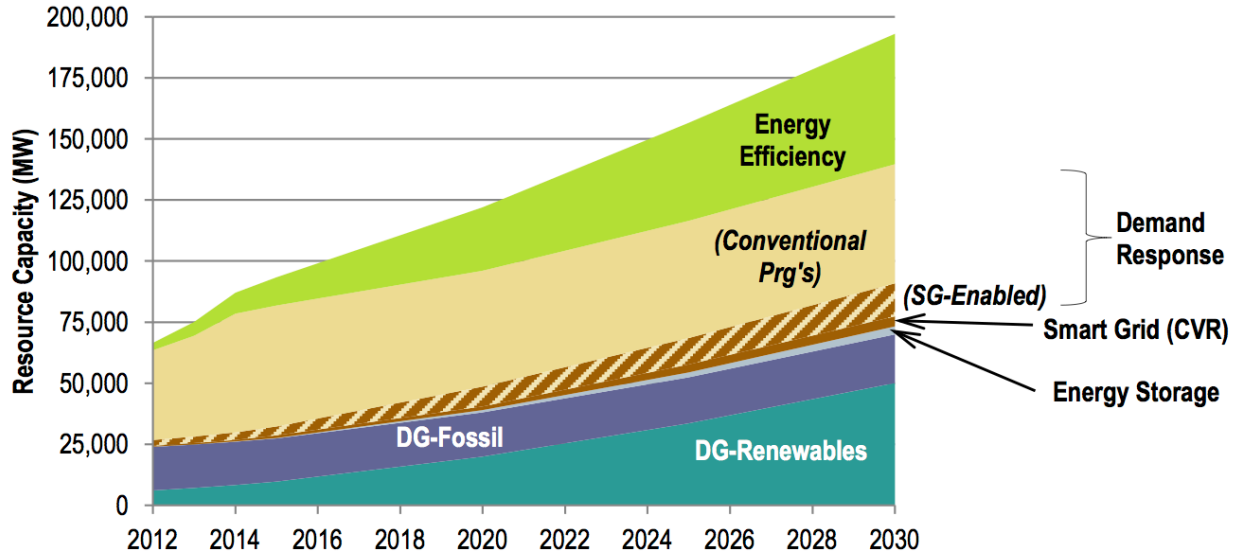
Figure 5-5 Total Demand-Side Resource Capacity by Resource Category (Source: Navigant 2013)

Table 5-9 Total Demand-Side Resource Peak Load Impact by Resource Category

		Projected Total Demand-Side Resource Capacity (MW)						
		2012	2013	2014	2015	2020	2025	2030
Energy Efficiency		3,016	5,650	8,567	11,542	25,956	40,106	53,369
Demand Response	*Conventional Programs*	23,370	26,286	31,041	31,701	31,197	32,007	32,976
	Smart Grid-Enabled[a]	1,073	1,198	1,389	1,626	3,647	4,857	6,079
Energy Storage		64	68	76	79	629	1,253	2,040
DG-Fossil		16,030	15,953	15,946	15,904	16,296	16,949	17,918
DG-Renewables		4,198	4,713	5,289	5,972	10,745	17,007	24,516
Smart Grid (CVR)		353	557	612	1,124	1,481	3,276	4,075
Total		48,103	54,424	62,918	67,948	89,950	115,454	140,972
Total Annual Peak Load		*577,087*	*585,752*	*596,594*	*604,471*	*640,249*	*677,684*	*718,217*
% of Peak Load Supported by Demand-Side Resources		8.30	9.30	10.50	11.20	14.00	17.00	19.60
[a] Includes time-based rate programs that require AMI meters with two-way communication capability. Source: Navigant (2013).								

6 EISPC EZ Mapping Tool Overview and Tutorial

This section provides an overview of the EZ Mapping Tool and describes the following: navigating the homepage, registering for and launching the tool, explaining the default layout, adding and removing mapping layers, using the map tools, creating analysis areas, creating corridors, copying and revising analysis areas and corridors, running models and reports, and exiting the system. This information and supplemental help videos are available to users on the website.

6.1 Navigating the Homepage

The URL for the EISPC EZ Mapping Tool is http://eispctools.anl.gov. That URL will bring you to the homepage.

The EISPC EZ Mapping Tool homepage includes eight links at the top of the screen: *Home*, *About the Study*, *Energy Resources*, *Data*, *Policies & Regs*, *Maps*, *Documents*, and *Links*

- The home icon ( ) will return you back to the main homepage.

- *About the Study* describes the purpose as well as the participants of the EISPC EZ Study.

- *Energy Resources* lists the resource categories and the technologies within each resource. You can click on a resource category and read a summary describing the basics about that resource. There are also references listed at the bottom of the page if you are interested in reading more about a particular energy resource.

- *Data* provides a list of all of the datasets available in the *Map Layer catalog*. To access metadata for a given dataset, click on the plus (+) next to the layer thumbnail and then click the *Metadata File* link. A PDF of the metadata will open in a new window. The metadata provide additional information about a dataset such as a summary of the dataset, the credits for who created the dataset, and information about the attributes contained within the dataset.

- *Policies & Regs* provides a searchable database of clean energy policy and incentive information. To search the database, choose at least one field from the *Country/State/Province*, *Policy Type*, *Implementation Sector*, or *Affected Technologies* scroll menus and then click the *Search* icon. A list of all of the policies and incentives matching your search will be generated.

- *Maps* provides a list of static maps available for viewing and printing. PDF maps have been created for technology resource data that are available in the EISPC catalog.

- *Documents* contains links for important documents such as white papers.

- *Links* contains a list of other helpful resources such as other available mapping tools and more information about EIPC and EISPC.

6.2 Registering for and Launching the EZ Mapping Tool

(1) In order to use the EISPC EZ Mapping Tool, you must create a login, which uses your email address and a password. Your activities within the mapping tool will be saved to your account so that your work can continue from one session to the next. From the Home Page, clicking on *Login* or the Launch Tool icon ( ) will bring you to a banner containing the Department of Energy terms and conditions notice. After you have read and agreed to the terms and conditions, click on the *I Agree* button.

(2) Clicking the *I Agree* button will lead you to the Sign in page. To register for the tool, click on the Register link in the bottom left-hand corner of the screen.

(3) On the Registration page, fill out the information pertaining to your name, organization, and state. Your e-mail address and password will be used as your login information. There are two options at the bottom of the page. By leaving the box next to the User Community page option unchecked, you agree to have your first name, last name, organization, and state listed on the User Community page. If your organization is not already in the Organization list, choose "Other (Enter below)" from the bottom of the drop-down list, and enter your organization in the Other organization box. By leaving the box checked next to the e-mail notification option, you agree that you would like to be e-mailed occasionally when significant changes are made to the site. After you have completed the registration information, click on ***Register*** at the bottom of the page. You will receive an e-mail confirmation message. Use the link in that message to confirm your e-mail address, and you will receive a second e-mail when your registration is complete.

(4) When your registration is complete, return to the sign in page, enter your e-mail and password, and click *Sign in*. This will lead you to the "Terms and Conditions" page of the EZ mapping tool.
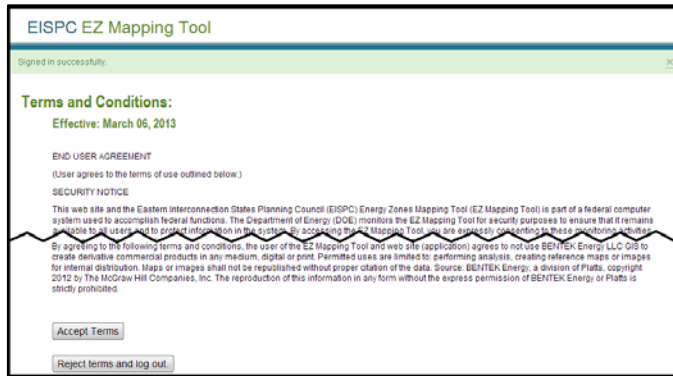
(5) Either accept the terms by clicking *Accept Terms* or reject the terms by clicking *Reject terms and log out*. Clicking on *Accept Terms* will either launch the EZ Mapping Tool (if you originally clicked the Launch Tool icon) or will take you back to the home page (if you originally clicked *Login*) where you can now click the Launch Tool icon ().

(6) When the tool launches, a splash screen appears with links to training videos and a version of this document. The check box in the lower left corner controls whether the splash screen will be displayed in later sessions, and it can be displayed at any time by clicking Help at the top right of the page.

6.3 Understanding the Default Layout
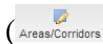
Launching the tool will open a new tab or browser window with the default layout of the mapping tool.

- The panel on the left side of the screen contains the *Main Menu* and *Map Contents.*

- The *Main Menu* contains the Library, Areas/Corridors, Analyze, and Results icons.
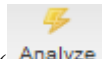
  - The Library icon (Library) is used to add new map layers or model layers to the map Contents dialog (see Adding Map Layers and Adding Model Layers).
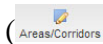
  - The Areas/Corridors icon (Areas/Corridors) is used to create analysis areas (see Creating an Analysis Area) and corridors (see Creating a Corridor).
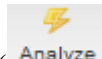
  - The Analyze icon (Analyze) is used to run models or reports (see Running a Model or Running a Report).

  - The Results icon (Results) is used to view model and report results (see Running a Model or Running a Report).

- The *Map contents* panel controls the layers displayed on the map.
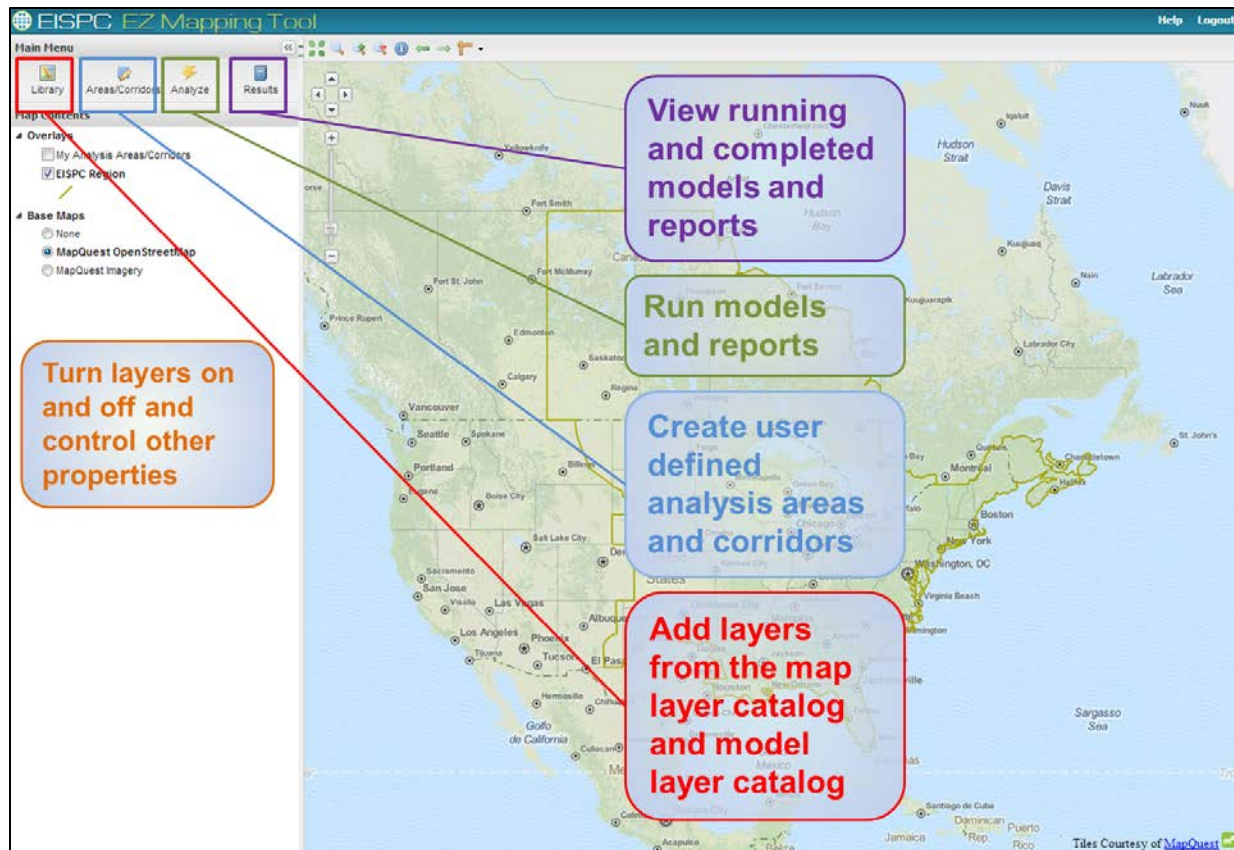
6.4 Layers

The default map shows a few base map options and the EISPC region, but more than 250 mapping layers are available in the tool.

All other layers are added by using the icons in the *Main Menu* panel.

6.4.1 Adding Map Layers

(1) Click the Library icon (Library) in the upper left corner of the *Main Menu*.

(2) A dialog opens, displaying all of the layers contained in the *Map Layer Catalog*. Click on the plus (+) next to a layer name to display the abstract, publication date, and last date the layer was updated.
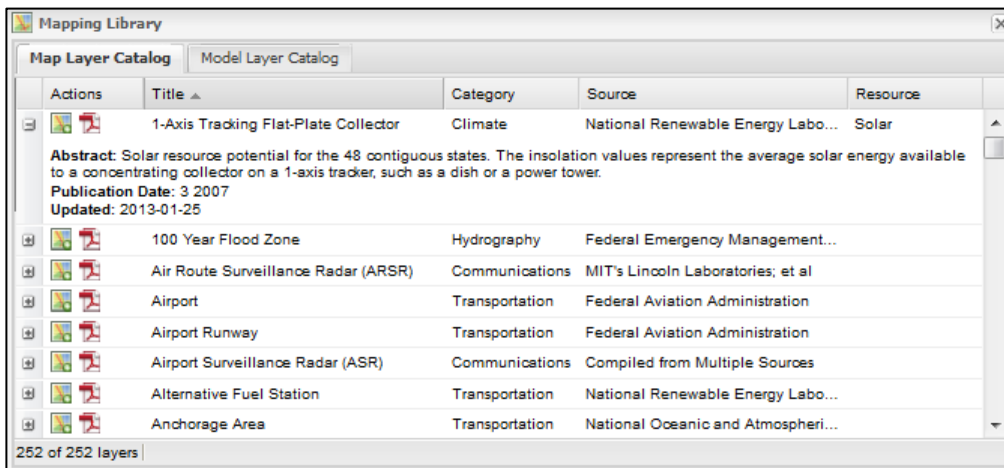
(3) Place the cursor over a heading (*Title*, *Category*, *Source*, or *Resource*) and a down arrow appears to the right of the heading name. Click the down arrow to sort or filter the list. The *Category* and *Resource* columns list all possible options to sort by. Click the filters that you wish to use. The *Title* and *Source* columns allow you to choose a filter term. Place the cursor over *Filters* and type a word in the box that appears. You can remove the filters by unchecking the boxes at the bottom of the dialog.
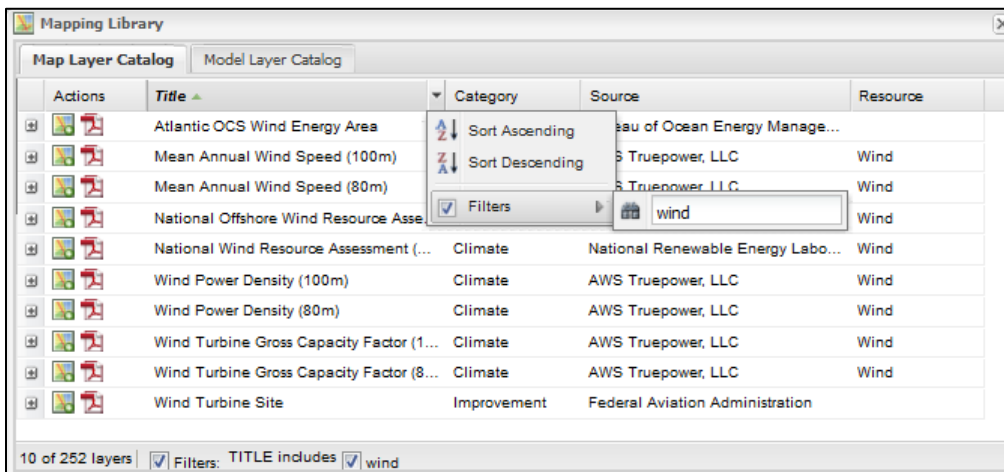
(4) Click the Map icon ( ) to add the layer to the map. It will also be listed in the *Overlays* section of the *Map Contents* dialog.

(5) If you would like to see the metadata for a particular layer, click on the PDF icon ( ) next to the layer name. A PDF will open containing the metadata for that layer.

6.4.2 Adding Model Layers

(1) If you are interested in viewing the screening layers for a particular model, click the

Library icon (Library) in the upper left corner of the *Main Menu*.

(2) In the Mapping Library dialog, click the *Model Layer Catalog* tab. Click on the plus (+)
next to a layer name to display the abstract, publication date, and last date the layer was
updated.
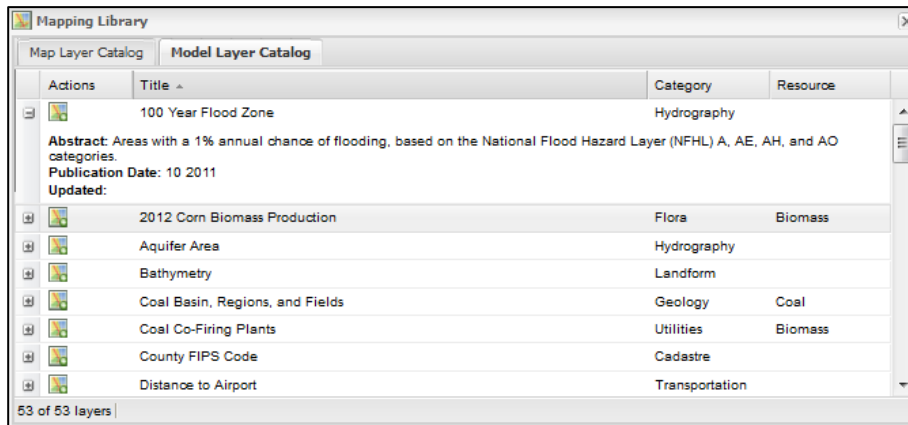
(3) Place the cursor over a heading (*Title*, *Category*, or *Resource*) and a down arrow appears
to the right of the heading name. Click the down arrow to sort or filter the list. The
Category and *Resource* columns list all possible options to sort by. Click the filters that
you wish to use. The *Title* column allows you to choose a filter term. Place the cursor
over *Filters* and type a word in the box that appears. You can remove the filters by
unchecking the boxes at the bottom of the dialog.
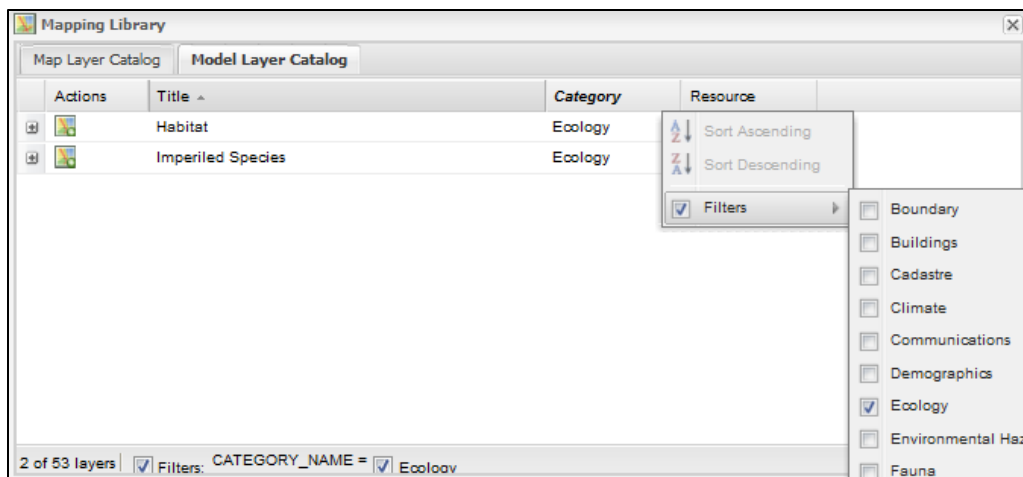
(4) Click the Map icon ( ) to add the layer to the map.

(5) The selected layer is added to the *Map Contents* panel.
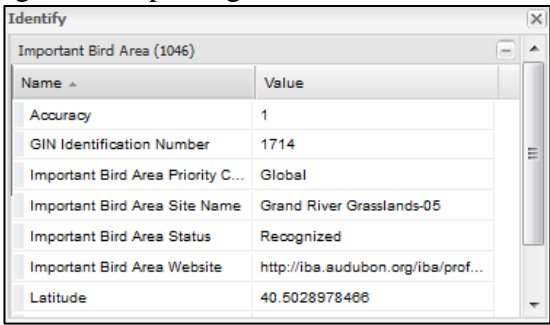
6.4.3 Removing Layers

- To remove a layer from the map but keep it in the *Map Contents* panel, uncheck its box.

- To remove a layer from the map and the *Map Contents* panel, right-click the layer name and then click Remove layer (⊖ red circle with white minus sign). This does not permanently remove the layer from the application, but only from your *Map Contents* panel. To add the layer again at a later time, repeat the steps under Layers.

6.5 Using the Map Tools

The map tools are located at the top of the map and allow you to navigate the map.

	Zoom to Max Extent	Click to display the map at its maximum extent (i.e., zoom out as far as possible).
	Zoom by Dragging	When active, click or click-and-drag on the map to zoom to the selected area. Click the icon again to stop zooming.
	Zoom In	Click to zoom in one level on the map.
	Zoom Out	Click to zoom out one level on the map.
	Identify	When active, click a feature on the map to retrieve more information about that specific feature. If there is more than one layer or feature at the click point, the information for each one will be listed in the results. Click the *Identify* tool icon again to stop using it.
	Zoom to Previous Extent	Return to the previous zoom level/view.

⇒	*Zoom to Next Extent*	Go to the next zoom level/view (after going to Previous Extent).
╆ ▾	*Measure*	Click the black down arrow, choose Length or Area, then click the map to draw a polygon to measure. Click once to draw each point on the line (Length) or polygon (Area). To complete the polygon, double click. Click the Measure tool again to stop measuring.

6.5.1 Map Navigation

▲◄ ►▼	*Pan Controls*	Use the pan controls to pan the map up and down, left and right.
⊞	*Zoom In*	Click to zoom in one level.
⊟	*Zoom Out*	Click to zoom out one level.
(slider)	*Zoom Slider*	Click and drag the slider to zoom in (up) and out (down).

6.6 Creating an Analysis Area

(1) Click the Areas/Corridors icon (Areas) in the *Main Menu* panel. The *Analysis Areas and Corridors* dialog opens.
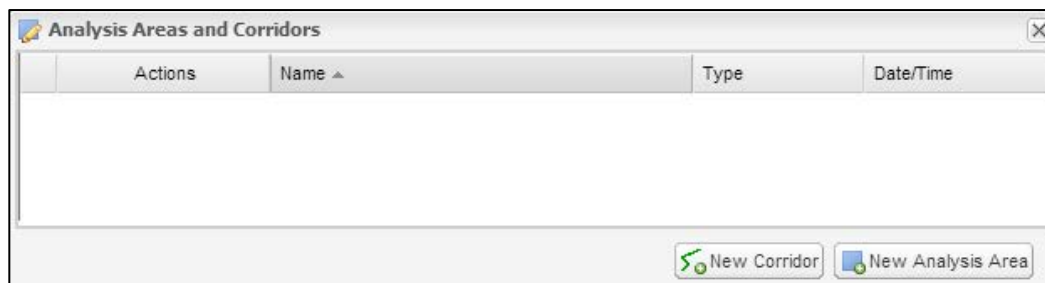
(2) Click the New Analysis Area icon (New Analysis Area).

(3) Add an analysis area to the map by clicking the mouse once for each point and double-clicking to complete the analysis area. Then the *Analysis Area* dialog will open to assign a name and notes for the analysis area.
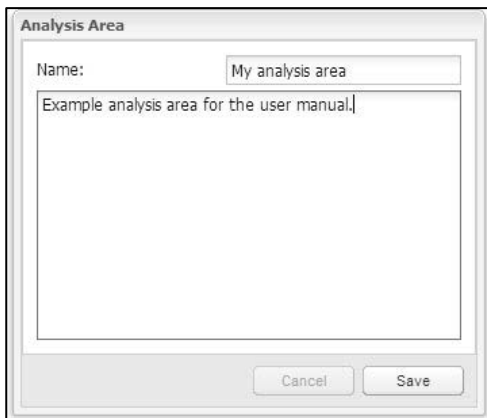
(4) Click *Save*. The analysis area will be listed in the *Analysis Areas and Corridors* dialog. To display the analysis area on the map, click the box next to *My Analysis Areas/Corridors* in the *Overlays* section of the *Map Contents* panel. A shaded region will then appear on your map. The analysis area can now be chosen in the *Choose Region* drop down when you run a report (See Running a Report for instructions).

(5) There are several actions to choose in the *Actions* column of the *Analysis Areas* and *Corridors* dialog.
- The Show/Hide Area icon ( ) controls whether individual analysis areas or corridors are shown on the map.
- The Magnifying Glass icon ( ) zooms the map to the analysis area or corridor.
- The Run Report icon ( ) runs a report on that analysis area or corridor (see Running a Report).
- The Edit icon ( ) allows the name and notes for analysis areas and corridors to be edited and also allows the user to copy and revise the analysis areas and corridors on the map.
- The Delete icon ( ) permanently deletes the analysis area or corridor.

6.7 Creating a Corridor

(1) Click the Areas/Corridors icon (Areas) in the *Main Menu* panel. The *Analysis Areas and Corridors* dialog opens.

(2) Click the New Corridor icon ( ).

(3) Add a corridor centerline to the map by clicking the mouse once for each point and double-clicking the last point to complete the centerline. Then the *Corridor* dialog will open to assign a name and notes for the corridor.

(4) Click *Save*. The corridor will be listed in the *Analysis Areas and Corridors* dialog. To display the corridor on the map, click the box next to *My Analysis Areas/Corridors* in the *Overlays* section of the *Map Contents* panel. The corridor will then appear on the map with the width shown as a shaded area around the centerline. The corridor can now be chosen in the *Choose Region* drop down when you run a corridor report (See Running a Report for instructions).

(5) There are several actions to choose in the *Actions* column of the *Analysis Areas* and *Corridors* dialog.

- The Show/Hide Area icon ( ) controls whether individual analysis areas or corridors are shows on the map.
- The Magnifying Glass icon ( ) zooms the map to the analysis area or corridor.
- The Run Report icon ( ) runs a report on that analysis area or corridor (see Running a Report).
- The Edit icon ( ) allows the name and notes for analysis areas and corridors to be edited, and also allows the user to copy and revise the analysis areas and corridors on the map.
- The Delete icon ( ) permanently deletes the analysis area or corridor.

6.8 Copying and Revising Analysis Areas and Corridors

In some cases, it is useful to copy and revise an analysis area or corridor to investigate alternate extents. For example, if a potential issue is found along a corridor route, an adjustment to the centerline or width might avoid the issue.

(1) Click the Areas/Corridors icon ( ) in the *Main Menu* panel. The *Analysis Areas and Corridors* dialog opens.

(2) Click the Edit icon ( ) for the analysis area or corridor to be copied and revised.

(3) Depending on whether an analysis area or corridor is chosen, the *Analysis Area* or *Corridor* dialog will open, with **Copy** button added.
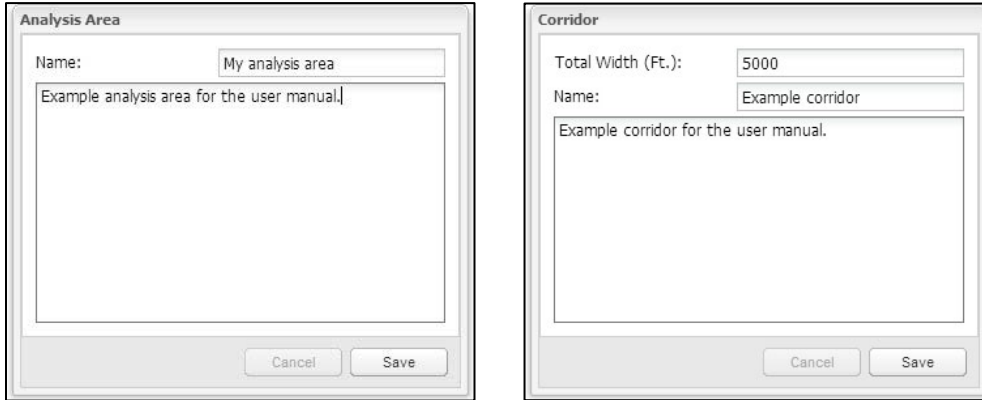
(4) Clicking **Copy** displays one of the instructional dialogs shown below. Click **OK**.
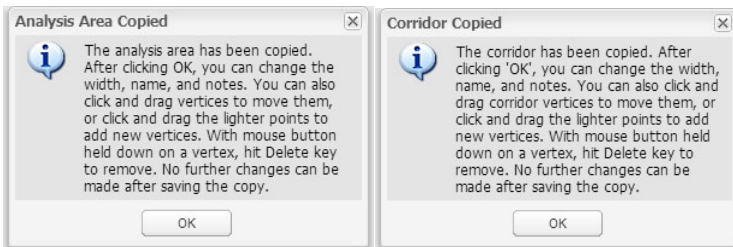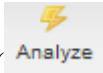
(5) Until you click **Save** in the main dialog, you can change the name and notes, change the width for corridors, and edit the analysis area boundary or corridor centerline on the map. On the map, edit handles are shown at each point making up the analysis area or corridor centerline. Click and drag these handles to move them. Midway between each point are lighter handles. Clicking and dragging these handles adds a new point to the shape. To delete a point, hold down the mouse button over a handle and hit the Delete key. Click **Save** when you are finished making changes.

The image below shows an example of a corridor being revised.
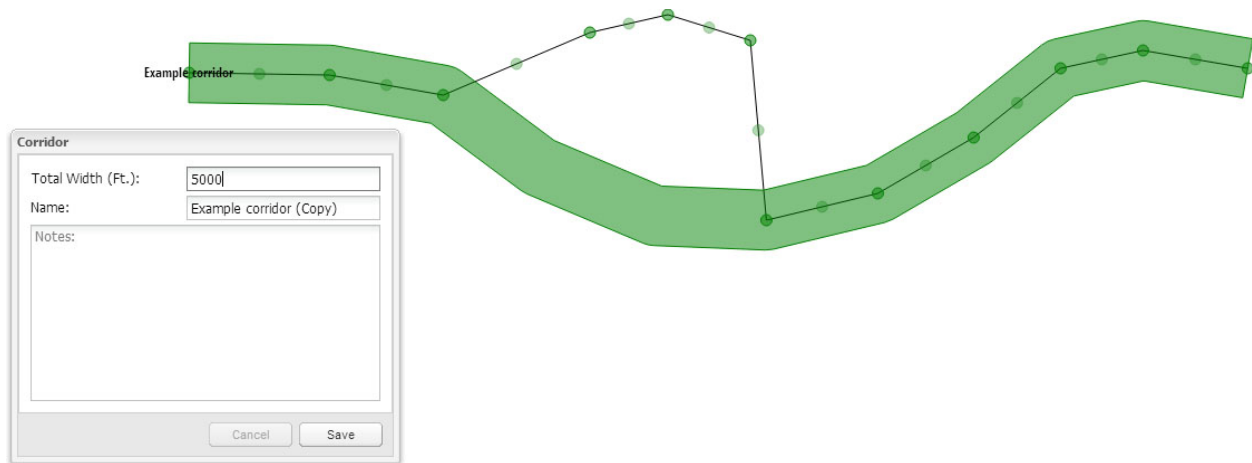
6.9 Running a Model

(1) Click the Analyze icon ( ) in the *Main Menu* panel to open the *Analyze – Run Models and Reports* dialog. All of the available models are listed in the *Models* section of the dialog. Click on the plus (+) next to a model name to display a description of that model.
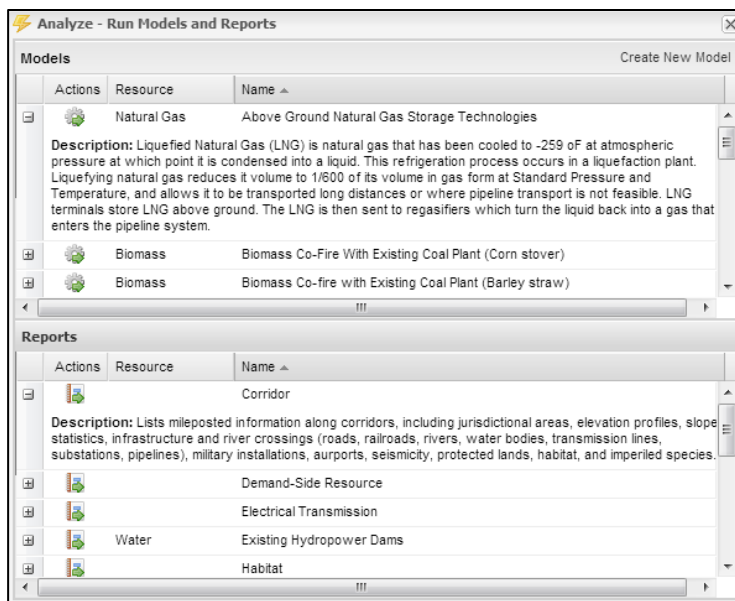
(2) Click on the Run Model icon ( ) to the left of the model name to open the *Model Launcher*.
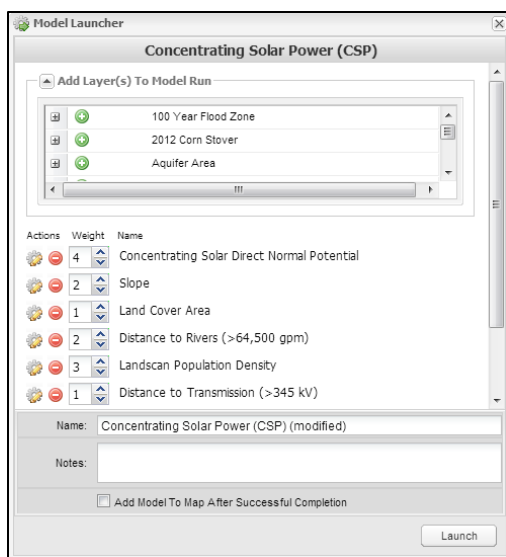
(3) The default screening layers and weights are displayed in the *Model Launcher* dialog. These settings are based on the recommendations of subject matter experts familiar with the technology being modeled, but should be reviewed and revised by individual users to meet their analysis goals and assumptions. Clicking the down arrow next to *Add Layer(s) To Model Run* displays a list of additional screening layers that can be added to your model run by clicking the Add Layer icon (⊕) next to the layer name. If desired, adjust the relative weights given to each screening layer by increasing or decreasing the numbers to the left of the layer names from 1 to 10, with 1 meaning that the layer should be given the smallest possible influence on the model and 10 meaning that the layer should be given the highest possible influence on the model. You can also remove a screening layer from the model run by clicking the Remove Layer icon (⊖).

(4) To inspect or adjust the suitability values within a screening layer, click on the Edit Suitability Settings icon (⚙) to the left of the layer name. The *Suitability Adjustment* dialog opens. To adjust suitability values for one of the ranges in a screening layer, type a value or use the arrows. Suitability values range from 0 (unsuitable) to 100 (most suitable). Click **Save** if you have made changes you want to keep, or **Cancel**, to return to the *Model Launcher* dialog.

(5) If you would like to view a screening layer listed in the *Model Launcher* dialog on the map, you can add it using the *Model Layer Catalog* (see Adding Model Layers).

(6) Change the default name of the model and add any notes about the model run by typing in the boxes at the bottom of the *Model Launcher* dialog.

(7) When you have finished customizing your model run, click ***Launch***. You can view the status of your model run by clicking on the Results icon (Results). The *Analysis Results* dialog will open. The status will be displayed as an hourglass while the model is running and a check mark when the model is complete.

The A*nalysis Results* dialog also lists default versions of each model as System runs. You can add these model results to the map and view them without having to run the model.

(8) There are several actions to choose from in the *Actions* column of the *Analysis Results* window.

- The Add Results icon ( ) allows you to add model results to the *Map Contents* panel and the map.

- The Run Report icon ( ) allows you to run a Model Results Report on that model.

- The Report Results icon ( ) allows you to display the generated report.

- The Modify Model icon ( ) opens up the *Model Launcher* dialog with the model settings saved. The settings can be revised and run as a new model.

- The Edit icon ( ) allows you to edit the name and notes for a personal model run.

- The Delete icon ( ) allows you to permanently delete personal model runs.

6.10 Running a Report

(1) Click the Analyze icon (Analyze) in the *Main Menu* panel. The *Analyze – Run Models and Reports* dialog opens. All of the available reports are listed in the *Reports* section of the dialog. Click on the plus (+) next to a report name to display a description of that report.
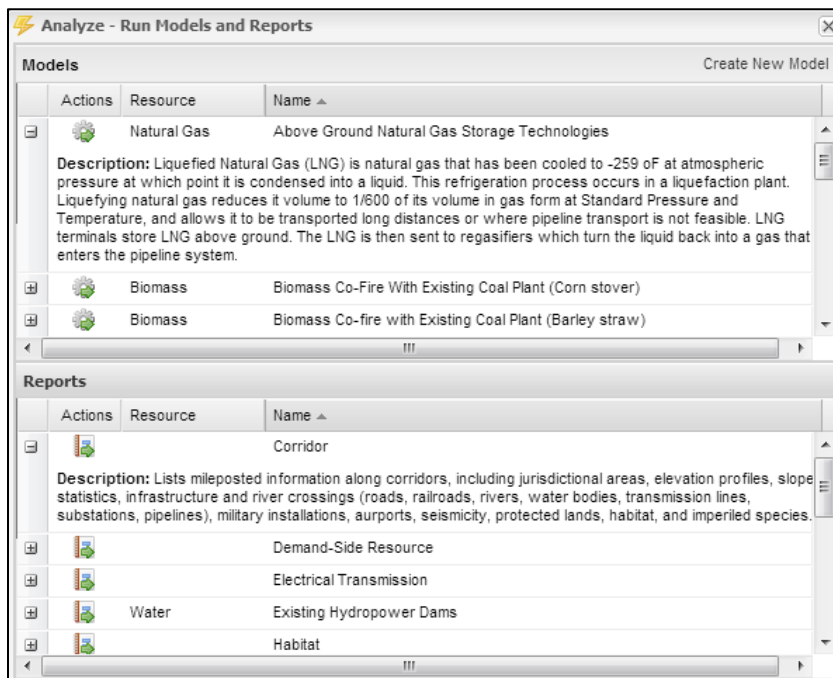
(2) Select a report by clicking on the Run Report icon ( ) to the left of the report name. The *Report Run Launcher* dialog opens.

Note: The Corridor report can only be run for corridors.

(3) In the *Region* section of the *Report Run Launcher* dialog, use the *Type* drop-down menu to choose whether to run a report on an analysis area, corridor, state, or county. Then use the subsequent drop-down menu to select the specific choice within that group that you would like to run your report on.

(4) Contents of the *Parameters* section vary, depending on the report. For the report shown, two buffer distances can be specified around the analysis area.

(5) You can change the default name of the report and add any notes about the report by typing in the boxes at the bottom of the *Report Run Launcher* dialog.

(6) When you have finished customizing your report run, click **Launch Report**. You can view the status of your report run by clicking on the Results icon (Results). The *Analysis Results* dialog will open. The status will be displayed as an hourglass while the report is running, and a check mark when the report is complete.

(7) There are several actions to choose from in the *Actions* column of the *Analysis Results* dialog.
- The Display Report icon ( ) allows you to view your report in a new browser tab.
- The Edit icon ( ) allows you to edit the name and notes for your report.

- The Delete icon ( ) allows you to permanently delete your report.
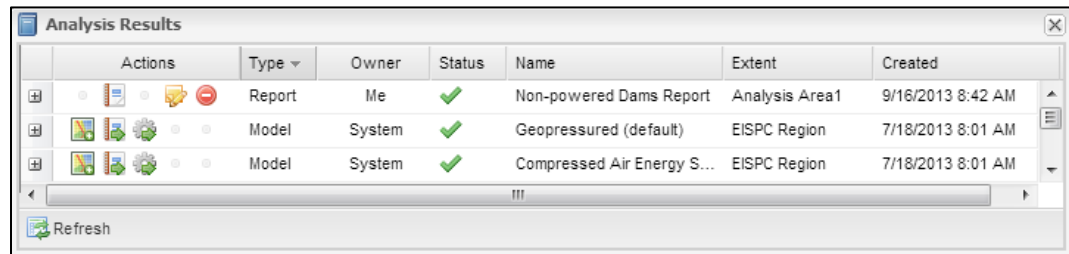
6.11 Exiting the Mapping Tool

To exit the mapping tool, simply close the browser window or tab, or click ***Logout*** in the upper right-hand corner of the screen. Your layers in your *Map Contents* panel as well as your model runs and reports are saved as you work and can be accessed the next time you log in to the EISPC EZ Mapping Tool.

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7 Case Studies and Interpreting Results

This section discusses several case examples that demonstrate the numerous ways the EZ Mapping Tool can be used. Section 7.1 includes an example of running models for both CSP and new clean coal technologies, and it explains how to find a synergy between them. Section 7.2 investigates using the environmental data in the tool to quickly determine whether a possible EZ has protected land or habitat nearby. Practical use of geothermal geopressured technology is discussed in Section 7.3, and Section 7.4 describes a corridor report use case example.

7.1 Concentrating Solar Power Co-sited with New Pulverized Coal Synergy Case

A hypothetical, synergistic example of using the EZ Mapping Tool can be seen when investigating the possibility of co-locating two technologies, such as CSP and a clean coal technology. The plant uses the CSP portion to preheat or create steam, which is then used in the coal plant to generate electricity.

The EZ Mapping Tool can be used to help identify regions where this technology may be feasible to implement. In this example, a new PC plant with CCS technology is considered coupled with a CSP plant located on site. The PC model uses a layer that represents the proximity to geologic formations that are considered suitable to store CO_2. This unique coupling of technologies creates a low-carbon-emission power plant.

To begin, a model representing the PC technology is run. The user has a choice between accepting the default configuration of the model, which has been determined by technology experts for this energy resource, or modifying the weighting and suitability scheme in the tool. In this example, the default configuration will suffice. Regionally, the results of the suitability display show that the highest valued areas are near Indiana, eastern Kansas, eastern Arkansas, and eastern Ohio, primarily due to the saline aquifer layer that allows for the CO_2 to be stored.

Running the CSP model indicates that the southwestern part of the Eastern Interconnection is most highly suited. The solar insolation values are the highest there, which is the driving force of the CSP model. Other factors aid in screening out areas where other resources, such as water, are not available in sufficient quantities, or physical characteristics, such as geographical slope, do not allow for the development of this technology.

The results of the two models can be run through a function of the tool that allows for areas of best overlap to be shown together (Figure 7-1). This allows two or more technologies to be co-located together. Weights can be assigned to the suitability inputs that can prioritize a given technology. In this example, the CSP model is given a two-to-one preference over the coal technology. The area with greatest synergy is seen in eastern Kansas.

In the synergy presented here, areas outside of the preferred region are incompatible, or listed as marginally suitable due to the physical constraints of the technology requirements. Both CSP and clean coal technologies require a supply of water for their operation. In this case, the PC coal technology is assumed to require 12,500 gallons per minute (gpm) of water and the CSP

Concentrating Solar Power / New Pulverized Coal Synergy

EISPC Region

■	0 (Unsuitable)
■	10
■	20
■	30
■	40
■	50 (Marginally Suitable)
■	60
■	70
■	80
■	90
■	100 (Fully Suitable)

May 16, 2013 : EZ71
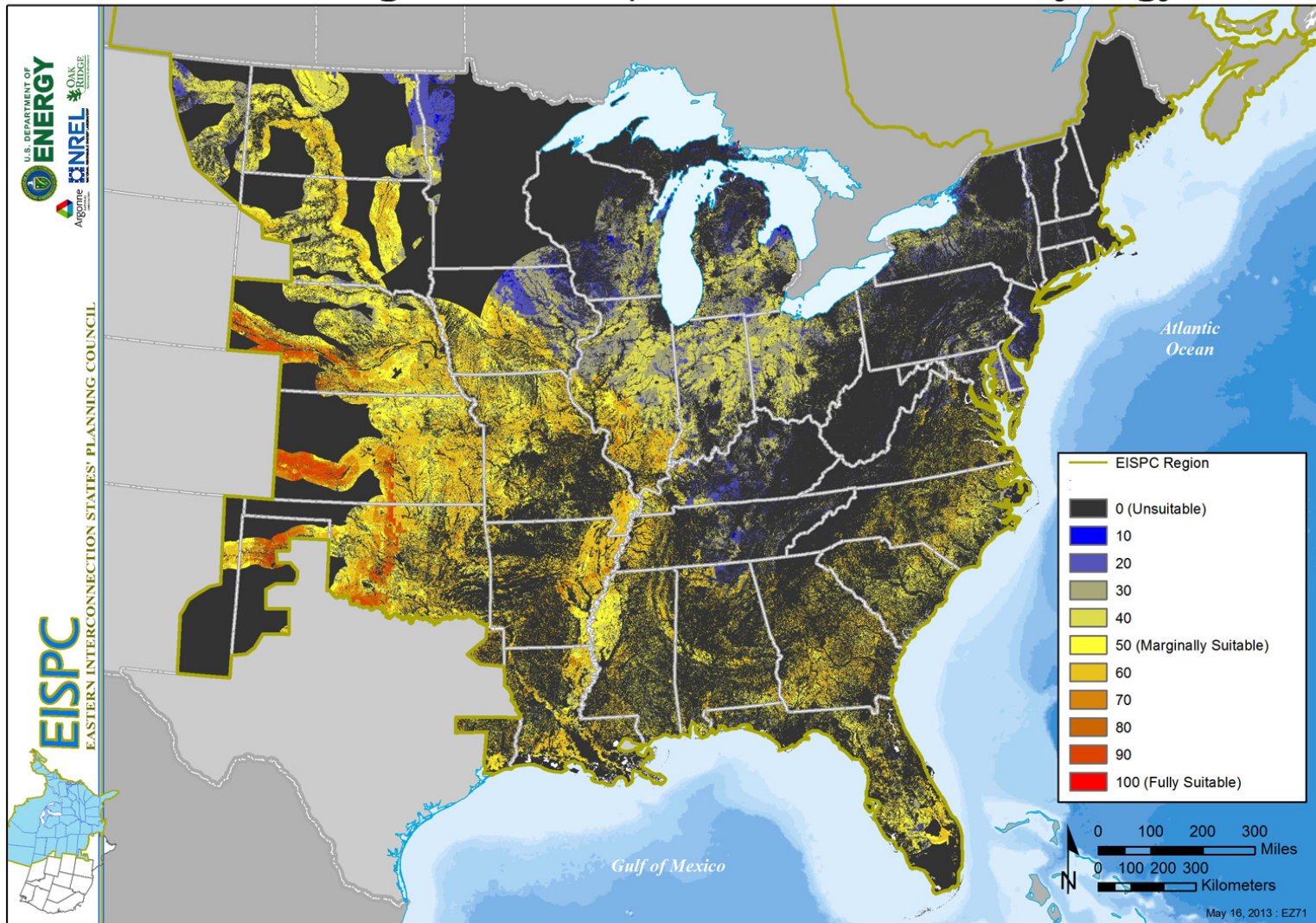
Figure 7-1 Example Synergy between Concentrating Solar Power and Clean Coal Power Technologies

technology would require 6,400 gpm. These are sourced from 125,000- and 64,000-gpm rivers respectively, assuming a 10% output withdraw. Because the coal plant requires a larger amount of water and the CSP plant would be utilizing this same water and not requiring additional water, the water layer was removed from the CSP model.

Further analysis of the synergistic areas could be investigated by using the various reporting options available in the EZ Mapping Tool. Some reports that may be of interest in this application are the transmission, protected lands, habitat, and imperiled species reports. The policies and regulations database search on the website is also valuable for further analysis.

7.2 Environmental Investigation Case

Using several built-in functions of the EZ Mapping Tool, a user can incorporate environmental factors into the process of identifying a suitable EZ. The environmental components of the EZ Mapping Tool include a large library of environmental layers, three composite environmental screening layers that the user can incorporate into any suitability model, and three environmental reporting tools.

There are two ways to view environmental data layers in the EZ Mapping Tool: the original data as they arrived from the various sources, or a composite overlay that combines the original datasets and ranks them based on their sensitivity to energy development. When viewing the original layers on the map, additional attribute information can be viewed about specific areas by using the "Identify" tool. This is not accessible with the composite graphic; only the sensitivity categorization is shown in the composites. Section 4.2 details the process of making these composite layers.

Running a resource model will make use of the three environmental composite layers by default. The weights that are assigned to these three layers were suggested by technology experts and provide a reasonable reflection of their importance in respect to the other layers in the model. In this example, an 80-m land-based wind model is run with a low importance assigned to the environmental layers. It is then contrasted with a suitability run (Figure 7-2) using a high environmental importance. Table 7-1 shows the different model run parameters for each composite environmental layer.

When searching for an EZ, it is important to run a model multiple times to favor different aspects of the model in order to see how each layer influences the outcome. For example, Figure 7-2 shows that some environmentally protected areas are harder to see with the default weight. The yellow linear feature that is visible in the highly weighted (right) version is most clearly defined as the environmental weights are increased; while it is evident the yellow parameter of the airport in the low-weighted model run disappears as the environmental layers are weighted more.

Low Environmental Suitability Default Environmental Suitability High Environmental Suitability
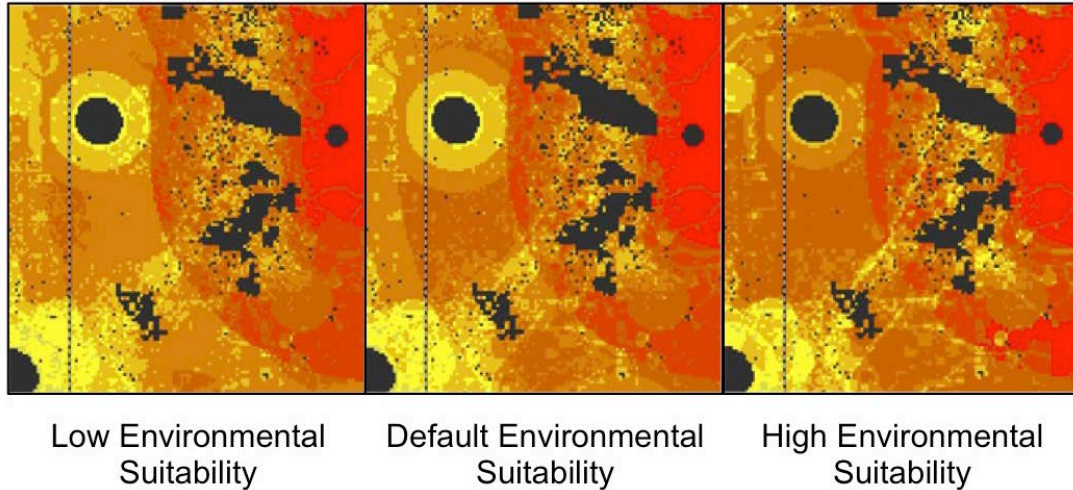
Figure 7-2 Suitability Map Showing Different Suitability Weights for the Three Environmental Layers (Red indicates highly suitable areas, orange is minimally suitable, and yellow areas are not suitable.)

Table 7-1 Adjusted Weights for Environmental Layers

Low Environmental Importance		Default Environmental Importance		High Environmental Importance	
Layer	Weight	Layer	Weight	Layer	Weight
Protected Lands	2	Protected Lands	3	Protected Lands	5
Habitat	1	Habitat	2	Habitat	4
Imperiled Species	2	Imperiled Species	3	Imperiled Species	5

After viewing the model results and understanding the significance of the environmental layers, the user may want to run the habitat, protected lands, or imperiled species reports on an area to learn more about why the area is environmentally sensitive. Each of these reports summarizes the occurrence of imperiled species or lists the datasets of the protected areas, or habitat, that was found in the analysis area. These provide a quick summary, which saves the user time by eliminating the need to manually go through and check each layer for conflicting areas. If an area needs to be investigated further, the original layers can be overlaid on the map. These layers will provide additional attribute details about the protected land or habitat area.

7.3 Geothermal Geopressured Case

The geothermal geopressured resource technology is one of the unique cases in the EZ Mapping Tool where the resource is concentrated in a specific region. The nature of geopressured energy relies on heat and fluid availability in the Earth's crust to generate hot water, or steam, which is then used to turn a turbine. In the Eastern Interconnection, the only area favorable for this unique geologic situation is along the Texas and Louisiana Gulf Coast.

The default configuration for this model shows areas suitable for utility-scale land-based geothermal plants. However, a significant portion of the resource is available offshore. The geopressured model allows the user to choose between showing land-based or offshore areas using a "Land-based/Offshore" layer. The visibility of these areas can be adjusted to either show the region assigned a suitability above zero, or it will mask out a region assigned a suitability of zero. In this situation, the suitability of the layer is being used as a 100%/0% toggle, and so the layer weight is assigned a 1. The layer's overall impact is not significant because it is a Boolean yes/no layer, and, as such, it is given the lowest possible model layer weight of one. Figure 7-3 illustrates land-based (left) or offshore (right) areas of the geopressured model.

7.4 Corridor Report Use Case

Investigating a region in the western part of Nebraska provides an interesting hypothetical example of how to use the corridor reporting tool. Figure 7-4 shows suitability model results for land-based wind turbines with a 100-m hub height for Nebraska, with and without the proximity to transmission lines being included in the model (top and bottom, respectively). When proximity to transmission is removed from the model, new areas in northwest Nebraska (circled) are shown as suitable. This indicates that a primary limiting factor for wind turbine development in that area is electrical transmission. Extending transmission lines to that area may be appropriate.

A utility company in Omaha might want to investigate buying power from a hypothetical wind farm in northwest Nebraska. Figure 7-5 shows existing electrical transmission lines of 345 kV or greater in Nebraska, and the analysis area of interest. Few high-voltage transmission lines exist in that part of the state.

To investigate the characteristics of a potential corridor from Energy Zone 1 to Omaha, a corridor was added (Figure 7-6). A width of 1,000 ft was used for the corridor.

Land-based Geopressured Resource Area

Offshore Geopressured Resource Area
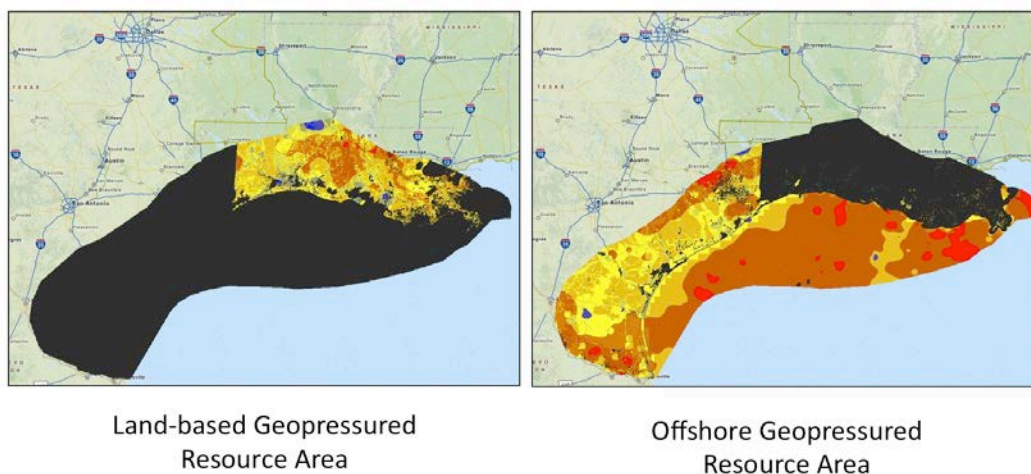
Figure 7-3 Suitability Map Showing Land-Based (right) and Offshore Geopressured Resource Areas (Note: Red indicates highly suitable areas, orange is minimally suitable, and yellow areas are not suitable.)
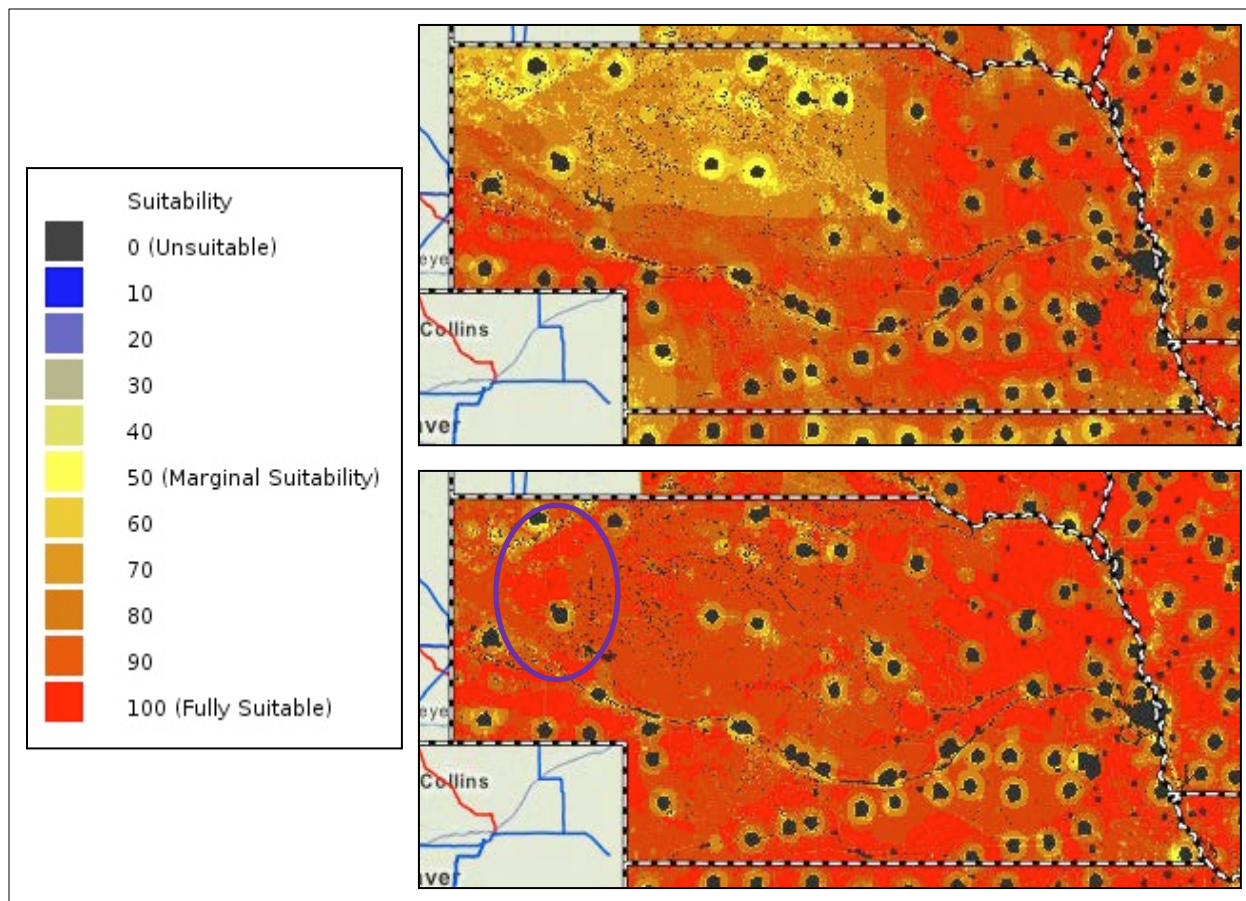
Figure 7-4 Comparison of Default Wind Turbine Model Results (top), and with the Proximity to Electrical Transmission Siting Factor Removed (bottom)
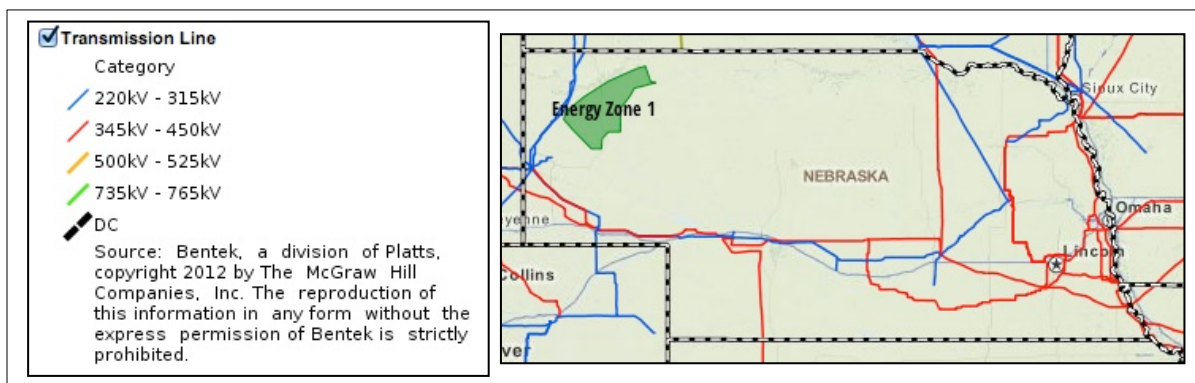
Figure 7-5 Existing Electrical Transmission Lines in Nebraska and a Hypothetical Energy Zone

Figure 7-6 Map Displaying a Hypothetical Transmission Corridor (green line) from Energy Zone 1 to Omaha, Nebraska

A corridor report generated from the corridor in Figure 7-6 provides a quick summary of potential issues that may be encountered within its extent. It shows that the corridor is 354 mi long and crosses 16 counties. The elevation difference is 923 ft from the highest (west) to lowest (east) point. Features crossing the corridor include roads, railroads, rivers, water bodies, existing electrical transmission lines, substations, pipelines, airports, military areas, and earthquake peak ground acceleration factors are listed. Environmental factors, including protected lands, habitat, and imperiled species are summarized at the end of the report. The report indicates numerous places where the analyzed corridor crosses areas marked as "develop with extreme caution" for protected lands. This layer can be added to the map and investigated for opportunities to revise the corridor route to reduce the potential impacts in this category. In the interface, a corridor can be duplicated and the route revised to avoid an issue identified by the initial corridor report. Figure 7-7 shows an example of revising a corridor to avoid an identified issue.

Running the report on the revised corridor route will show the effect of routing around this particular issue, and whether new issues occur in the changed area. The corridor report is also intended for screening level assessment of oil and natural gas pipeline corridors.
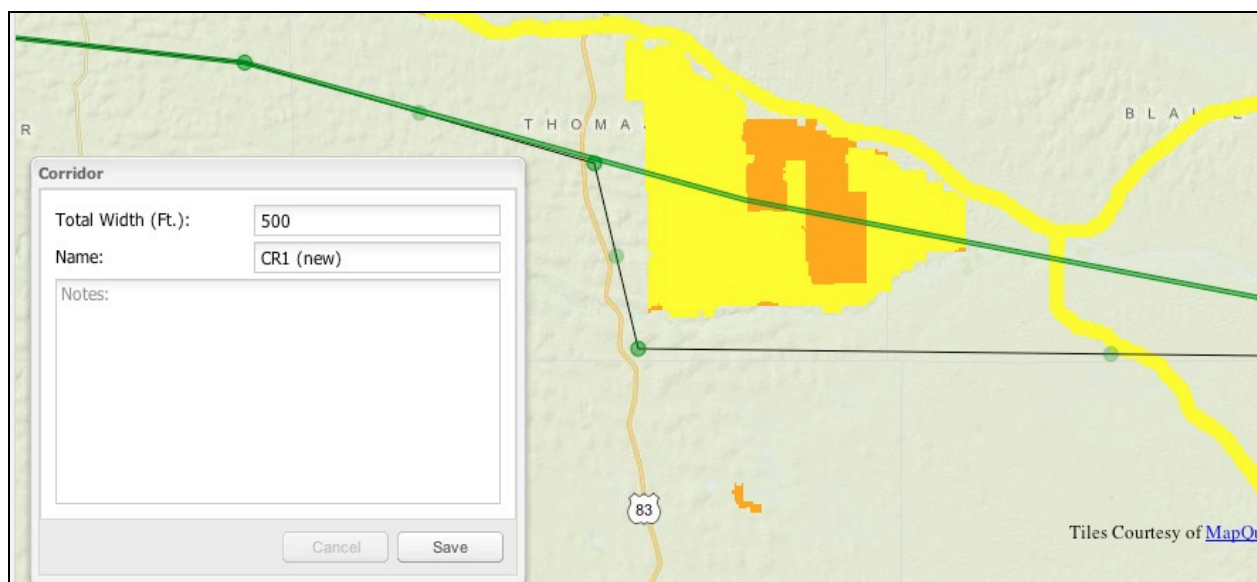
Figure 7-7 Map Showing a Revised Corridor Path (black) to Avoid Crossing a Sensitive Wildlife Area (yellow and orange).

8 Recommendations for Future Work

The following recommendations for future work cover two broad areas: (1) enhancements to the EZ Mapping Tool itself, and (2) planning applications where the tool's capabilities could provide additional insight and transparency. Both these areas provide opportunities to link the work of EISPC with companion work conducted by the EIPC.

A key element of any future work using the EZ Mapping Tool is to continue the planning work of EISPC itself. The purpose guiding the development of the tool is to aid "the development of coordinated State electricity policies, programs, laws, and regulations," as stated in the American Recovery and Reinvestment Act. The National Association of Regulatory Utility Commissioners (NARUC) is the awardee for Recovery Act funding focusing on policy coordination in the Eastern Interconnection, working through EISPC. Keeping the EZ Mapping Tool consistent with its original purpose and expanding its use and applications by EISPC members and other stakeholders will greatly depend on the continued engagement of NARUC and EISPC.

8.1 Enhancements

Specific tool enhancements could include the following:

- Regular updates of resource data, the policy inventory, and the addition of new data layers identified by EISPC and other users as available and relevant.

- More detailed screening analysis of potential energy corridors, including developing models that use screening factors to create a suitability surface map and optimization techniques to compute the best path connecting two locations specified by the user. The optimization routine would avoid sensitive ecological areas and other protected lands and attempt to minimize the overall path distance and other factors such as close proximity to densely populated areas and large river crossings.

- Development of a model for identifying areas suitable for smaller natural gas combined-cycle plants (250–500 MW) in populated areas at industrial or brownfield locations, including existing power plants that might be repowered.

- Development of models for estimating electricity generation potential of certain clean energy technologies within an analysis area.

- Development of models to analyze an optimal mix of generating resources and the number of power plants that can be located within a selected analysis area.

- Addition of wind resource layers showing the temporal characteristics of wind power in a given location (i.e., seasonal profiles and diurnal profiles).

- Enhancement of models to account for zone contiguity (i.e., eliminate areas computed as otherwise suitable but too small and too isolated from other suitable areas to accommodate a project).

- Ability to upload new GIS layers for individual users, groups of users, or all users.

- Enhancements to facilitate virtual collaboration, such as sharing models and analysis areas among different users.

- Integration of policy data as a map layer to allow users to include relevant policy information in reports.

More complex enhancements could include layers showing current load, load growth, the potential for distributed resources in addition to rooftop solar, current and future water consumption needs for electricity generation, potential load changes due to energy efficiency, and potential load changes resulting from increased use of electric vehicles.

8.2 Planning Applications

EIPC's final report suggests a number of planning applications using the mapping tool. For example, EIPC projected that about 728 TWh of new generation would come from wind power under its scenario that assumes nationally implemented federal carbon constraints, increased energy efficiency, and increased demand response. The EZ Mapping Tool could complement this projection by identifying where 728 TWh could be generated with the least amount of capital investment and the least environmental impact. In addition, the tool could be used to perform a screening analysis of potential pathways for new transmission lines. Case studies could be conducted for all three EIPC scenarios for wind, other renewables, combined-cycle gas generators, and peakers.

Other potential planning applications could include:

- Mapping the location of flexible generating resources, such as pumped hydro and compressed-air energy storage, in relation to variable renewable resources (wind and solar).

- Identifying environmental and land use impacts that could limit capacity expansion at sites with existing natural gas plants.

- Mapping and characterizing offshore wind resources in the Great Lakes region, their likely injection points, and their hourly coincidence with load.

- Identifying areas in the Great Plains region where wind potential has the highest capacity factors, the least environmental impact, and exists in the greatest geographic concentration.

- Identifying biomass zones in the Southeast and New England.

- Constructing renewable energy supply curves by state or other user-selected region, taking into account resource energy potential, environmental and other land use constraints, capacity factor gradients, and other factors likely to affect cost.

- Measuring and mapping the reduction in wind potential when assuming stringent rather than moderate habitat avoidance criteria.

- Validating modeled results against existing project locations.

These examples of EZ Mapping Tool applications can support a broader goal: to facilitate strategic planning throughout the Eastern Interconnection. Many of the issues and risks confronting long-term electric delivery in the Eastern Interconnection extend beyond traditional short-term operational planning. They require examining risk and uncertainty over a 20-year time frame or longer, and many of the solutions are regional and inter-regional rather than local. The tool can help states collaboratively examine common risks and opportunities, providing utilities with an impetus to engage in their own long-term strategic planning.

In some applications, the EZ Mapping Tool could supplement other analytical tools such as production cost models and capacity expansion models. Examples include consolidated planning (i.e., combining smaller transmission projects into one higher-voltage project to take advantage of economies of scale), energy corridor analysis, the temporal mismatch between the development of new generation and new transmission, and other issues.

Expanding the tool to include the Western Interconnection, Texas Interconnection, and the Canadian portions of the Eastern Interconnection would be a logical next step and desirable extension of this work. While technically feasible, expanding the tool's geographic coverage would require scoping decisions that are beyond the original purpose of Recovery Act funding used for this project. Such issues are more appropriately explored by NARUC and its peer organizations, in collaboration with DOE.

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Appendix A: Screening Factors

The specific default suitability criteria and ranges for each screening parameter for the models contained in the EZ Mapping Tool are listed below. The suitability scale ranges from zero to 100 with zero being unsuitable and 100 being most-suitable. The weights listed for each screening parameter range from 1 to 10, with 1 representing the lowest importance and 10 representing the highest importance.

Biomass Co-Firing with Coal

2012 Corn Stover Production

Weight: 8		(Dry tons per sq. mile)
Minimum	Maximum	Suitability
0	100	0
101	250	1
251	500	20
501	1000	40
1001	1500	50
1501	2000	75
2001	2500	100
2501	3000	100
3001	3500	100
3501	100000	100

Distance to Coal Plants with Biomass Cofiring

Weight: 3		(Miles)
Minimum	Maximum	Suitability
0	5	100
6	10	90
11	20	80
21	30	70
31	40	60
41	50	50
51	60	1
61	100000	0

Slope

Weight: 2		(Percent)
Minimum	Maximum	Suitability
0	2	100
3	4	100
5	6	100
7	8	90
9	10	80
11	12	50
13	14	25
15	16	1
17	18	0
19	20	0
21	30	0
31	10000	0

Surface Water Flow (>2,000 GPM)

Weight: 3		(Miles)
Minimum	Maximum	Suitability
0	1	100
2	2	85
3	5	70
6	10	50
11	20	20
21	50	1
51	100000	0

Landscan Population Density

Weight: 2		(People per sq. km)
Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Distance to Railroad

Weight: 5		(Miles)
Minimum	Maximum	Suitability
0	25	100
26	50	100
51	75	100
76	100	75
101	125	50
126	100000	0

Distance to Major Roads

Weight: 1		(Miles)
Minimum	Maximum	Suitability
0	5	100
6	10	80
11	15	50
16	20	1
21	30	1
31	100000	1

100 Year Flood Zone
Weight: 1

Category	Suitability
A	0
AE	0
AH	0
AO	0

Protected Land
Weight: 3

Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Distance to Port
Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	1	100
2	3	75
4	5	50
6	10	5
11	20	5
21	100000	1

Habitat
Weight: 3

Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Imperiled Species
Weight: 3

Category	Suitability
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Distance to Transmission (>220 kV)
Weight: 3 (Miles)

Minimum	Maximum	Suitability
0	1	100
2	2	85
3	5	70
6	10	50
11	20	20
21	50	1
51	100000	0

Biomass

2012 Wheat Straw Production		
Weight: 8		(Dry tons per sq. mile)
Minimum	Maximum	Suitability
0	50	0
0	100	0
101	200	10
201	300	30
301	400	50
401	500	60
501	600	70
601	700	80
701	800	90
801	900	100
901	1000	100
1001	100000	100

Slope		
Weight: 2		(Percent)
Minimum	Maximum	Suitability
0	2	100
3	4	100
5	6	100
7	8	90
9	10	80
11	12	50
13	14	25
15	16	1
17	18	0
19	20	0
21	30	0
31	10000	0

Surface Water Flow (>2000 GPM)		
Weight: 3		(Miles)
Minimum	Maximum	Suitability
0	1	100
2	2	85
3	5	70
6	10	50
11	20	20
21	50	1
51	100000	0

Landscan Population Density		
Weight: 2		(People per sq. km)
Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Distance to Railroad		
Weight: 5		(Miles)
Minimum	Maximum	Suitability
0	25	100
26	50	100
51	75	100
76	100	75
101	125	50
126	100000	0

100 Year Flood Zone
Weight: 1

Category		Suitability
A		0
AE		0
AH		0
AO		0

Distance to Port
Weight: 1   (Miles)

Minimum	Maximum	Suitability
0	1	100
2	3	75
4	5	50
6	10	5
11	20	5
21	100000	1

Distance to Transmission (>220 kV)
Weight: 3   (Miles)

Minimum	Maximum	Suitability
0	1	100
2	2	85
3	5	70
6	10	50
11	20	20
21	50	1
51	100000	0

Distance to Major Roads
Weight: 1   (Miles)

Minimum	Maximum	Suitability
0	5	100
6	10	80
11	15	50
16	20	1
21	30	1
31	100000	1

Habitat
Weight: 3

Category		Suitability
Likely low conflict area		95
Develop with caution		40
Develop with extreme caution		20

Imperiled Species
Weight: 3

Category		Suitability
Low conflict area		95
Develop with caution		40
Develop with extreme caution		20

Protected Land
Weight: 3

Category		Suitability
Likely low conflict area		95
Develop with caution		40
Develop with extreme caution		20
Exclude from development		0

Coal Fluidized Bed

Coal Basin Regions and Fields Weight: 5		
Category		Suitability
Inter-resource Area		50
Coal Resource		100

Distance to Saline Formation for CO2 Storage Weight: 5 (Miles)		
Minimum	Maximum	Suitability
0	25	100
26	50	90
51	75	80
76	100	70
101	125	60
126	150	50
151	175	40
176	200	30
201	225	20
226	250	10
251	100000	0

Slope Weight: 1 (Percent)		
Minimum	Maximum	Suitability
0	2	100
3	4	100
5	6	100
7	8	100
9	10	100
11	12	100
13	14	85
15	16	75
17	18	65
19	20	50
21	30	10
31	10000	0

Land Cover Area Weight: 2	
Category	Suitability
Unclassified	50
Open Water	0
Perennial Snow/Ice	0
Open Space	50
Developed Low Intensity	50
Developed Medium Intensity	10
Developed High Intensity	1
Barren Land	100
Deciduous Forest	70
Evergreen Forest	70
Mixed Forest	70
Shrub/Scrub	100
Herbaceuous	100
Hay/Pasture	100
Cultivated Crops	100
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

Distance to Rivers (>30000 GPM) Weight: 3 (Miles)		
Minimum	Maximum	Suitability
0	10	100
11	20	50
21	30	20
31	40	1
41	100000	0

Landscan Population Density Weight: 3 (People per sq. km)		
Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Distance to Railroad

Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	2	100
3	4	75
5	7	45
8	10	10
11	20	1
21	100000	1

Distance to Transmission (>345kV)

Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	5	100
6	10	75
11	15	50
16	20	25
21	50	5
51	100000	1

100 Year Flood Zone

Weight: 1

Category	Suitability
A	0
AE	0
AH	0
AO	0

Protected Land

Weight: 4

Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Distance to Port

Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	1	100
2	3	100
4	5	50
6	10	1
11	20	1
21	100000	1

Habitat

Weight: 4

Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Imperiled Species

Weight: 4

Category	Suitability
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Coal Integrated Gasification Combined Cycle

Coal Basin Regions and Fields	
Weight: 5	
Category	**Suitability**
Inter-resource Area	50
Coal Resource	100

Distance to Saline Formation for CO2 Storage		
Weight: 5		**(Miles)**
Minimum	**Maximum**	**Suitability**
0	25	100
26	50	90
51	75	80
76	100	70
101	125	60
126	150	50
151	175	40
176	200	30
201	225	20
226	250	10
251	100000	0

Land Cover Area	
Weight: 2	
Category	**Suitability**
Unclassified	50
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	50
Developed Low Intensity	50
Developed Medium Intensity	10
Developed High Intensity	1
Barren Land	100
Deciduous Forest	70
Evergreen Forest	70
Mixed Forest	70
Shrub/Scrub	100
Herbaceuous	100
Hay/Pasture	100
Cultivated Crops	100
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

Slope		
Weight: 1		**(Percent)**
Minimum	**Maximum**	**Suitability**
0	2	100
3	4	100
5	6	100
7	8	100
9	10	100
11	12	100
13	14	85
15	16	75
17	18	65
19	20	50
21	30	10
31	10000	0

Distance to Rivers (>45,000 GPM)		
Weight: 3		**(Miles)**
Minimum	**Maximum**	**Suitability**
0	10	100
11	20	50
21	30	20
31	40	1
41	100000	0

Landscan Population Density		
Weight: 3		**(People per sq. km)**
Minimum	**Maximum**	**Suitability**
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

100 Year Flood Zone
Weight: 1

Category	Suitability
A	0
AE	0
AH	0
AO	0

Distance to Railroad
Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	2	100
3	4	75
5	7	45
8	10	10
11	20	1
21	100000	1

Distance to Port
Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	1	100
2	3	100
4	5	50
6	10	1
11	20	1
21	100000	1

Distance to Transmission (>345kV)
Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	5	100
6	10	75
11	15	50
16	20	25
21	50	5
51	100000	1

Protected Land
Weight: 4

Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Habitat
Weight: 4

Category	Suitability
Likely low conflict low conflict area	95
Develop with caulop with caution	40
Develop with ext extreme caution	20

Imperiled Species
Weight: 4

Category	Suitability
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Pulverized Coal

Coal Basin Regions and Fields Weight: 5		
Category		Suitability
Inter-resource Area		50
Coal Resource		100

Slope Weight: 1 (Percent)		
Minimum	Maximum	Suitability
0	2	100
3	4	100
5	6	100
7	8	100
9	10	100
11	12	100
13	14	85
15	16	75
17	18	65
19	20	50
21	30	10
31	10000	0

Distance to Saline Formation for CO2 Storage Weight: 5 (Miles)		
Minimum	Maximum	Suitability
0	25	100
26	50	90
51	75	80
76	100	70
101	125	60
126	150	50
151	175	40
176	200	30
201	225	20
226	250	10
251	100000	0

Land Cover Area Weight: 2	
Category	Suitability
Unclassified	50
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	50
Developed Low Intensity	50
Developed Medium Intensity	10
Developed High Intensity	1
Barren Land	100
Deciduous Forest	70
Evergreen Forest	70
Mixed Forest	70
Shrub/Scrub	100
Herbaceuous	100
Hay/Pasture	100
Cultivated Crops	100
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

Surface Water Flow (>125,000 GPM) Weight: 3 (Miles)		
Minimum	Maximum	Suitability
0	10	100
11	20	50
21	30	20
31	40	1
41	100000	0

Landscan Population Density Weight: 3 (People per sq. km)		
Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Distance to Railroad

Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	2	100
3	4	75
5	7	45
8	10	10
11	20	1
21	100000	1

100 Year Flood Zone

Weight: 1

Category	Suitability
A	0
AE	0
AH	0
AO	0

Distance to Port

Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	1	100
2	3	100
4	5	50
6	10	1
11	20	1
21	100000	1

Distance to Transmission (>345kV)

Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	5	100
6	10	75
11	15	50
16	20	25
21	50	5
51	100000	1

Protected Land

Weight: 4

Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Habitat

Weight: 4

Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Imperiled Species

Weight: 4

Category	Suitability
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Enhanced Geothermal Systems

Enhanced Geothermal System Potential
Weight: 8

Category		Suitability
Most favorable		100
highly favorable		80
Moderately favorable		50
Less avorable		10
Least favorable		1
Unknown		0

Landscan Population Density
Weight: 2 — (People per sq. km)

Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Slope
Weight: 2

Minimum	Maximum	Suitability
0	30	100
31	10000	0

Distance to Transmission (>220kV)
Weight: 1 — (Miles)

Minimum	Maximum	Suitability
0	5	100
6	10	75
11	15	50
16	20	25
21	50	10
51	100000	1

Land Cover Area
Weight: 1

Category		Suitability
Unclassified		100
Open Water		0
Perennial Snow/Ice		0
Developed Open Space		100
Developed Low Intensity		100
Developed Medium Intensity		0
Developed High Intensity		0
Barren Land		100
Deciduous Forest		100
Evergreen Forest		100
Mixed Forest		100
Shrub/Scrub		100
Herbaceuous		100
Hay/Pasture		100
Cultivated Crops		100
Woody Wetlands		0
Emergent Herbaceuous Wetlands		0

Distance to Rivers (>130,000 GPM)
Weight: 2 — (Miles)

Minimum	Maximum	Suitability
0	10	100
11	20	75
21	30	50
31	40	25
41	50	1
51	100000	0

Protected Lands
Weight: 2

Category		Suitability
Likely low conflict area		95
Develop with caution		40
Develop with extreme caution		20
Exclude from development		0

Habitat Weight: 2	
Category ▼	**Suitability** ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Imperiled Species Weight: 2	
Category ▼	**Suitability** ▼
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Geopressured Geothermal

GeoPressure Energy Potential - Plan 2		
Weight: 10		(kWe/km²)
Minimum	Maximum	Suitability
0	250	1
251	500	15
501	750	45
751	1000	50
1001	1500	80
1501	1800	100
1801	2000	100

Onshore/Offshore		
Weight: 1		
Category		Suitability
Onshore		100
Offshore		0

Land Cover Area		
Weight: 1		
Category		Suitability
Unclassified		100
Open Water		0
Perennial Snow/Ice		0
Developed Open Space		100
Developed Low Intensity		100
Developed Medium Intensity		0
Developed High Intensity		0
Barren Land		100
Deciduous Forest		100
Evergreen Forest		100
Mixed Forest		100
Shrub/Scrub		100
Herbaceuous		100
Hay/Pasture		100
Cultivated Crops		100
Woody Wetlands		100
Emergent Herbaceuous Wetlands		100

Slope		
Weight: 1		(Percent)
Minimum	Maximum	Suitability
0	30	100
31	10000	0

Protected Lands		
Weight: 5		
Category		Suitability
Likely low conflict area		95
Develop with caution		40
Develop with extreme caution		20
Exclude from development		0

Habitat		
Weight: 5		
Category		Suitability
Likely low conflict area		95
Develop with caution		40
Develop with extreme caution		20

Imperiled Species		
Weight: 5		
Category		Suitability
Low conflict area		95
Develop with caution		40
Develop with extreme caution		20

Nuclear High-Temperature Gas-cooled Reactor

Slope Weight: 1 (Percent)		
Minimum	Maximum	Suitability
0	2	100
3	4	100
5	6	100
7	8	100
9	10	100
11	12	100
13	14	85
15	16	75
17	18	65
19	20	50
21	30	10
31	10000	0

Land Cover Area Weight: 2	
Category	Suitability
Unclassified	50
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	50
Developed Low Intensity	40
Developed Medium Intensity	5
Developed High Intensity	1
Barren Land	100
Deciduous Forest	70
Evergreen Forest	70
Mixed Forest	70
Shrub/Scrub	100
Herbaceuous	100
Hay/Pasture	100
Cultivated Crops	100
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

Seismic Hazard Weight: 7	
Category	Suitability
No Damage: 0-3.9 %g	100
Light Damage: 9.2-18 %g	50
Moderate Damage: 18-34 %g	25
Mod./Heavy Damage: 34-65 %g	10

Landscan Population Density Weight: 3		
Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Quaternary Fault Exclusion Weight: 1	
Category	Suitability
Background	100
Fault Exclusion Area	0

Distance to Airport Weight: 1 (Miles)		
Minimum	Maximum	Suitability
0	5	0
6	10	0
11	15	50
16	20	100
21	100000	100

100 Year Flood Zone Weight: 1	
Category	Suitability
A	0
AE	0
AH	0
AO	0

Distance to Military Installation		
Weight: 1		**(Miles)**
Minimum ▼	**Maximum** ▼	**Suitability** ▼
0	1	0
2	3	25
4	5	50
6	1000000	100

Habitat	
Weight: 4	
Category ▼	**Suitability** ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Protected Land	
Weight: 4	
Category ▼	**Suitabil** ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Imperiled Species	
Weight: 4	
Category ▼	**Suitability** ▼
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Nuclear Light-Water Reactor

Slope
Weight: 1 (Percent)

Minimum	Maximum	Suitability
0	2	100
3	4	100
5	6	100
7	8	100
9	10	100
11	12	100
13	14	85
15	16	75
17	18	65
19	20	50
21	30	10
31	10000	0

Seismic Hazard
Weight: 7

Category	Suitability
No Damage: 0-3.9 %g	100
Light Damage: 9.2-18 %g	50
Moderate Damage: 18-34 %g	25
Mod./Heavy Damage: 34-65 %g	10

Quaternary Fault Exclusion
Weight: 1

Category		Suitability
-1	-1	100
1	1	0

100 Year Flood Zone
Weight: 1

Category	Suitability
A	0
AE	0
AH	0
AO	0

Land Cover Area
Weight: 2

Category	Suitability
Unclassified	50
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	50
Developed Low Intensity	20
Developed Medium Intensity	1
Developed High Intensity	0
Barren Land	100
Deciduous Forest	70
Evergreen Forest	70
Mixed Forest	70
Shrub/Scrub	100
Herbaceuous	100
Hay/Pasture	100
Cultivated Crops	100
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

Distance to Rivers (>200,000 GPM)
weight: 3 (Miles)

Minimum	Maximum	Suitability
0	10	100
11	20	50
21	30	20
31	40	1
41	100000	0

Landscan Population Density
Weight: 3 (People per sq. km)

Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Distance to Airport		
Weight: 1		**(Miles)**
Minimum	**Maximum**	**Suitability**
0	5	0
6	10	0
11	15	50
16	20	100
21	100000	100

Distance to Military Installation		
Weight: 1		**(Miles)**
Minimum	**Maximum**	**Suitability**
0	1	0
2	3	25
4	5	50
6	1000000	100

Protected Land	
Weight: 4	
Category	**Suitability**
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Habitat	
Weight: 4	
Category	**Suitability**
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Imperiled Species	
Weight: 4	
Category	**Suitability**
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Nuclear Small Modular Reactor

Slope Weight: 1		(Percent)
Minimum ▼	Maximum ▼	Suitability ▼
0	2	100
3	4	100
5	6	100
7	8	100
9	10	100
11	12	100
13	14	85
15	16	75
17	18	65
19	20	50
21	30	10
31	10000	0

Seismic Hazard Weight: 7	
Category ▼	Suitability ▼
No Damage: 0-3.9 %g	100
Light Damage: 9.2-18 %g	50
Moderate Damage: 18-34 %g	25
Mod./Heavy Damage: 34-65 %g	5

Quaternary Fault Exclusion Weight: 1	
Category ▼	Suitability ▼
Background	100
Fault Exclusion Area	0

100 Year Flood Zone Weight: 1	
Category ▼	Suitability ▼
A	0
AE	0
AH	0
AO	0

Land Cover Area Weight: 2	
Category ▼	Suitability ▼
Unclassified	50
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	50
Developed Low Intensity	50
Developed Medium Intensity	10
Developed High Intensity	1
Barren Land	100
Deciduous Forest	70
Evergreen Forest	70
Mixed Forest	70
Shrub/Scrub	100
Herbaceuous	100
Hay/Pasture	100
Cultivated Crops	100
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

Distance to Rivers (>50,000 GPM) Weight: 3		(Miles)
Minimum ▼	Maximum ▼	Suitability ▼
0	10	100
11	20	50
21	30	20
31	40	1
41	100000	0

Landscan Population Density Weight: 3		(People per sq. km)
Minimum ▼	Maximum ▼	Suitability ▼
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Distance to Airport		
Weight: 1		**(Miles)**
Minimum	**Maximum**	**Suitability**
0	5	0
6	10	0
11	15	50
16	20	100
21	100000	100

Distance to Military Installation		
Weight: 1		**(Miles)**
Minimum	**Maximum**	**Suitability**
0	1	0
2	3	25
4	5	50
6	1000000	100

Protected Land	
Weight: 4	
Category	**Suitability**
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Habitat	
Weight: 4	
Category	**Suitability**
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Imperiled Species	
Weight: 4	
Category	**Suitability**
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Natural Gas Combined-Cycle Gas Turbine

Distance to Natural Gas Pipeline (>=12 inch)		
Weight: 5		(Miles)
Minimum	Maximum	Suitability
0	5	100
6	10	90
11	15	80
16	20	70
21	25	50
26	30	40
31	35	30
36	40	20
41	45	10
46	50	1
51	500	0

Slope		
Weight: 5		(Percent)
Minimum	Maximum	Suitability
0	2	100
3	4	75
5	6	50
7	8	40
9	10	30
11	12	20
13	14	10
15	16	1
17	18	0
19	20	0
21	30	0
31	10000	0

Distance to Railroad		
Weight: 3		(Miles)
Minimum	Maximum	Suitability
0	2	100
3	4	75
5	7	45
8	10	10
11	20	1
21	100000	1

Land Cover Area	
Weight: 5	
Category	Suitability
Unclassified	50
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	30
Developed Low Intensity	30
Developed Medium Intensity	65
Developed High Intensity	10
Barren Land	100
Deciduous Forest	60
Evergreen Forest	60
Mixed Forest	60
Shrub/Scrub	100
Herbaceuous	100
Hay/Pasture	100
Cultivated Crops	100
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

Surface Water Flow (>100,000 GPM)		
Weight: 5		(Miles)
Minimum	Maximum	Suitability
0	10	100
11	20	70
21	30	25
31	40	1
41	100000	0

Landscan Population Density		
Weight: 1		(People per sq. km)
Minimum	Maximum	Suitability
0	100	100
101	150	100
151	200	100
201	300	100
301	400	100
401	500	0
501	100000	0

100 Year Flood Zone Weight: 1		
Category		Suitability
A		0
AE		0
AH		0
AO		0

Protected Land Weight: 4		
Category		Suitability
Likely low conflict area		95
Develop with caution		40
Develop with extreme caution		20
Exclude from development		0

Distance to Port Weight: 2 (Miles)		
Minimum	Maximum	Suitability
0	2	100
3	4	75
5	7	45
8	10	10
11	20	1
21	100000	1

Habitat Weight: 4		
Category		Suitability
Likely low conflict area		95
Develop with caution		40
Develop with extreme caution		20

Imperiled Species Weight: 4		
Category		Suitability
Low conflict area		95
Develop with caution		40
Develop with extreme caution		20

Distance to Transmission (>=100 kV) Weight: 5 (Miles)		
Minimum	Maximum	Suitability
0	5	100
6	10	80
11	15	65
16	20	50
21	50	5
51	100000	1

Photovoltaic Solar

Tilted Photovoltaic Potential		
Weight: 4		(Wh/m²/Day)
Minimum	Maximum	Suitability
0	3000	1
3001	4000	5
4001	4500	15
4501	5000	20
5001	5250	55
5251	5500	85
5501	6000	90
6001	7000	92
7001	8000	95
8001	9000	100
9001	10000	100

Slope		
Weight: 2		(Percent)
Minimum	Maximum	Suitability
0	1	100
2	2	90
3	3	90
4	4	30
5	5	10
6	10	1
11	10000	0

Distance to Transmission (>345 kV)		
Weight: 1		(Miles)
Minimum	Maximum	Suitability
0	5	100
6	10	90
11	15	80
16	20	70
21	50	45
51	100000	5

Land Cover Area	
Weight: 1	
Category	Suitability
Unclassified	100
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	0
Developed Low Intensity	50
Developed Medium Intensity	15
Developed High Intensity	10
Barren Land	100
Deciduous Forest	20
Evergreen Forest	10
Mixed Forest	10
Shrub/Scrub	25
Herbaceuous	10
Hay/Pasture	80
Cultivated Crops	70
Woody Wetlands	5
Emergent Herbaceuous Wetlands	5

Landscan Population Density		
Weight: 2		(People per sq. km)
Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Protected Lands	
Weight: 2	
Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Habitat Weight: 2	
Category	**Suitability**
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Imperiled Species Weight: 2	
Category	**Suitability**
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Concentrating Solar Power

Concentrating Solar Direct Normal Potential		
Weight: 4		(Wh/m²/Day)
Minimum	Maximum	Suitability
0	3000	0
3001	4000	1
4001	5000	15
5001	5500	50
5501	6000	75
6001	6500	85
6501	7000	100
7001	7500	100
7501	8000	100
8001	9000	100

Slope		
Weight: 2		(Percent)
Minimum	Maximum	Suitability
0	1	100
2	2	90
3	3	80
4	4	50
5	5	10
6	10	0
11	10000	0

Distance to Transmission (>345 kV)		
Weight: 1		(Miles)
Minimum	Maximum	Suitability
0	5	100
6	10	75
11	15	50
16	20	25
21	50	5
51	100000	1

Land Cover Area	
Weight: 1	
Category	Suitability
Unclassified	100
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	0
Developed Low Intensity	50
Developed Medium Intensity	15
Developed High Intensity	0
Barren Land	100
Deciduous Forest	0
Evergreen Forest	0
Mixed Forest	0
Shrub/Scrub	50
Herbaceuous	100
Hay/Pasture	80
Cultivated Crops	75
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

Distance to Rivers (>64,500 gpm)		
Weight: 2		(Miles)
Minimum	Maximum	Suitability
0	10	100
11	20	75
21	30	50
31	100000	0

Landscan Population Density		
Weight: 3		(People per sq. km)
Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Protected Lands Weight: 2	
Category ▼	▼ Suitability ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Imperiled Species Weight: 2		
Category ▼	▼ Suitability ▼	
Low conflict area	10	95
Develop with cau	100	40
Develop with ext	1000	20

Habitat Weight: 2	
Category ▼	▼ Suitability ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Compressed Air Energy Storage

Aquifer Area
Weight:3

Category	Suitability
Unknown Lithology	75
Carbonate-rock aquifers	100
Igneous and metamorphic-rock aq	10
Sandstone and carbonate-rock aqu	100
Sandstone aquifers	100
Semiconsolidated sand aquifers	10
Unconsolidated sand and gravel a	10

Distance to Domal Salt Formation
Weight: 4 (Miles)

Minimum	Maximum	Suitability
0	1	100
2	20	1
21	30	1
31	40	1
41	100000	1

Distance to Bedded Salt Formation
Weight: 3 (Miles)

Minimum	Maximum	Suitability
0	1	100
2	20	1
21	30	1
31	40	1
41	100000	1

Population Density
Weight: 2 (People per sq. km)

Minimum	Maximum	Suitability
0	100	100
101	150	75
151	200	50
201	300	25
301	400	0
401	500	0
501	100000	0

Slope
Weight: 2 (Miles)

Minimum	Maximum	Suitability
0	2	100
3	4	90
5	6	80
7	8	70
9	10	60
11	12	50
13	14	0
15	16	0
17	18	0
19	20	0
21	30	0
31	10000	0

Land Cover Area
Weight: 2

Category	Suitability
Unclassified	50
Open Water	0
Perennial Snow/Ice	0
Developed Open Space	50
Developed Low Intensity	50
Developed Medium Intensity	0
Developed High Intensity	0
Barren Land	100
Deciduous Forest	80
Evergreen Forest	80
Mixed Forest	70
Shrub/Scrub	100
Herbaceuous	100
Hay/Pasture	100
Cultivated Crops	100
Woody Wetlands	0
Emergent Herbaceuous Wetlands	0

100 Year Flood Zone
Weight: 1

Category		Suitability	
A		0	
AE		0	
AH		0	
AO		0	

Distance to Transmission (All lines)
Weight: 1 (Miles)

Minimum		Maximum		Suitability	
0		5		100	
6		10		80	
11		15		70	
16		20		60	
21		24		50	
25		100000		0	

Distance to Natural Gas Pipelines
Weight: 3 (Miles)

Minimum		Maximum		Suitability	
0		1		100	
2		3		75	
4		5		50	
6		10		10	
11		20		1	
21		100000		0	

Landslide
Weight: 1 (Incidence and Susceptibility)

Category		Suitability	
Low		100	
Moderate		0	
High		0	
Suspected moderate		100	
Suspected high		100	
Combo-high		0	
No-data		100	

Protected Land
Weight: 2

Category		Suitability	
Likely low conflict area		95	
Develop with caution		40	
Develop with extreme caution		20	
Exclude from development		0	

Habitat
Weight: 2

Category		Suitability	
Likely low conflict area		95	
Develop with caution		40	
Develop with extreme caution		20	

Imperiled Species
Weight: 2

Category		Suitability	
Low conflict area		95	
Develop with caution		40	
Develop with extreme caution		20	

Marine Tidal Hydrokinetic

Tidal Current Speed
Weight: 5 (cm/sec)

Minimum	Maximum	Suitability
0	20	1
21	40	1
41	60	50
61	80	70
81	100	80
101	120	90
121	140	100
141	160	100
161	180	100
181	200	100

Distance to Tranmission (all lines)
Weight: 3 (Miles)

Minimum	Maximum	Suitability
0	0	100
1	1	100
2	2	90
3	3	80
4	4	70
5	5	50
6	10	15
11	15	10
16	20	1
21	100000	0

Tidal Power Density
Weight: 5 (W/m²)

Minimum	Maximum	Suitability
0	100	1
101	200	1
201	300	50
301	400	70
401	500	80
501	600	90
601	700	100
701	800	100
801	900	100
901	1000	100
1001	100000	100

Bathymetry
Weight: 4 (Meters)

Minimum	Maximum	Suitability
-10000	-31	100
-30	-16	100
-15	-6	100
-5	0	0
1	5000	0

Unexploded Ordnance
Weight: 1

Category	Suitability
Area between features	100
Unexploded ordnance area	1

Distance to Port
Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	0	100
1	1	100
2	10	100
11	20	75
21	30	50
31	10000	25

Navigable Waterways
Weight: 2

Category	Suitability
Background	100
Waterway	1

Protected Lands	
Weight: 3	
Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Imperiled Species	
Weight: 3	
Category	Suitability
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Habitat	
Weight: 3	
Category	Suitability
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Offshore Wind Turbine

Wind Turbine Gross Capacity Factor (80m)
Weight: 5 (Percent)

Minimum	Maximum	Suitability
0	5	0
6	10	0
11	15	0
16	20	0
21	25	0
26	30	1
31	35	30
36	40	50
41	45	70
46	50	80
51	55	90
56	60	100
61	65	100
66	70	100
71	75	100
76	80	100
81	85	100

Landscan Population Density
Weight: 1

Category	Suitability
Background	100
500 People/sq. mile with two mile buffer	0

Bathymetry
Weight: 2 (Meters)

Minimum	Maximum	Suitability
-5000	-91	0
-90	-61	0
-60	-31	20
-30	0	100
1	5000	0

Distance to Substation
Weight: 1 (Miles)

Minimum	Maximum	Suitability
0	5	100
6	10	100
11	15	100
16	20	85
21	50	75
51	75	50
76	100	25
101	100000	25

Unexploded Ordnance
Weight: 1

Category	Suitability
Area between features	100
Unexploded ordnance area	1

Distance to Shore
Weight: 1

Minimum	Maximum	Suitability
0	1	80
2	3	87
4	5	93
6	7	95
8	9	100
10	15	90
16	20	70
21	25	50
26	30	20
31	40	10
41	50	1
51	1000	0

Navigable Waterways
Weight: 2

Category	Suitability
Background	100
Waterway	1

Protected Lands	
Weight: 3	
Category ▼ ▼	**Suitability** ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Imperiled Species	
Weight: 2	
Category ▼ ▼	**Suitability** ▼
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Habitat	
Weight: 2	
Category ▼ ▼	**Suitability** ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Land-Based Wind Turbine

Wind Turbine Gross Capacity Factor (80m)		
Weight: 5		(Percent)
Minimum ▼	Maximum ▼	Suitability ▼
0	5	0
6	10	0
11	15	0
16	20	1
21	25	10
26	30	30
31	35	50
36	40	60
41	45	70
46	50	80
51	55	90
56	60	100
61	65	100
66	70	100
71	75	100
76	80	100
81	85	100

Land Cover Area		
Weight: 2		
Category ▼	▼	Suitability ▼
Unclassified		100
Open Water		0
Perennial Snow/Ice		0
Developed Open Space		100
Developed Low Intensity		50
Developed Medium Intensity		0
Developed High Intensity		0
Barren Land		100
Deciduous Forest		50
Evergreen Forest		50
Mixed Forest		50
Shrub/Scrub		100
Herbaceuous		100
Hay/Pasture		100
Cultivated Crops		100
Woody Wetlands		0
Emergent Herbaceuous Wetlands		0

Slope		
Weight: 2		(Percent)
Minimum ▼	Maximum ▼	Suitability ▼
0	3	100
4	5	70
6	8	60
9	12	50
13	20	10
21	50	0
51	10000	0

Distance to Transmission (>345 kV)		
Weight: 3		(Miles)
Minimum ▼	Maximum ▼	Suitability ▼
0	5	100
6	10	85
11	15	75
16	20	60
21	50	40
51	75	10
76	100000	5

Population Density (with 2 mile buffer)		
Weight: 1		
Category ▼	▼	Suitability ▼
Background		100
500 People/sq. mile with two mile buffer		0

Distance to Major Road		
Weight: 1		(Miles)
Minimum ▼	Maximum ▼	Suitability ▼
0	5	100
6	10	85
11	15	75
16	20	60
21	50	40
51	75	10
76	100000	5

Distance to Airport Runway
Weight: 2 (Miles)

Minimum ▼	Maximum ▼	Suitability ▼
0	1	0
2	5	1
6	10	5
11	15	50
16	20	100
21	100000	100

Imperiled Species
Weight: 3

Category ▼	▼ Suitability ▼
Low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Habitat
Weight: 2

Category ▼	▼ Suitability ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20

Protected Lands
Weight: 3

Category ▼	▼ Suitability ▼
Likely low conflict area	95
Develop with caution	40
Develop with extreme caution	20
Exclude from development	0

Appendix B: EZ Mapping Tool Informational Layers

Layer Title	Category	Source	Layer Type	Publication Year
100-Year Flood Zone	Hydrography	Federal Emergency Management Agency	Screening	2011
113th Congressional District		U.S. Census Bureau	Information	2013
1-Axis Tracking Flat-Plate Collector	Climate	National Renewable Energy Laboratory (NREL), et al.	Resource	2007
Air Route Surveillance Radar (ARSR)	Communications	Massachusetts Institute of Technology's (MIT's) Lincoln Laboratories, et al.	Information	2012
Airport	Transportation	Federal Aviation Administration (FAA)	Information	2012
Airport Runway	Transportation	FAA	Information	2012
Airport Surveillance Radar (ASR)	Communications	Compiled from multiple sources	Resource	2012
Alternative Fuel Station	Transportation	NREL	Information	2012
Anchorage Area	Transportation	National Oceanic and Atmospheric Administration (NOAA)	Screening	2010
Appalachian Foothills Focus Area (OH)	Ecology	OH Department of Natural Resources - Division of Wildlife	Screening	
Aquatic Conservation Focus Area (MT)	Ecology	MT Department of Fish, Wildlife, and Parks	Screening	2006
Aquatic Priority Area (TN)	Ecology	TN Wildlife Resources Agency	Screening	2005
Aquatic Priority Conservation Area (AL)	Ecology	AL Department of Conservation and Natural Resources	Screening	2008
Aquifer Area	Hydrography	U.S. Geological Survey (USGS)	Screening	2003
Artificial Reef		NOAA	Screening	2012
Atlantic Outer Continental Shelf (OCS) Wind Energy Area	Climate	Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE)	Information	2012
Bathymetry Digital Elevation Model (DEM) with Great Lakes	Landform	NOAA	Information	
Bedded Salt Formation	Geology	Oak Ridge National Laboratory (ORNL)	Resource	2005
Biodiversity (Indiana)	Ecology	IN Department of Natural Resources	Screening	
Biodiversity and Wildlife Habitat Assessment (NC)	Ecology	NC Office of Conservation, Planning, and Community Affairs	Screening	2010
Biological Hotspot (VT)	Ecology	University of VT - Spatial Analysis Lab	Screening	2000
Biologically Unique Landscape (NE)	Land Status	NE Game and Parks Commission	Screening	2011
Candidate Landfill Methane Project	Environmental Hazards	U.S. Environmental Protection Agency (EPA)	Resource	2012
Census Tract	Demographics	U.S. Census Bureau	Screening	2010
County Natural Heritage Inventory (CNHI): Core Habitat (PA)	Ecology	PA Natural Heritage Program - Western PA Conservancy	Screening	2010
CNHI: Landscape Conservation Area (PA)	Land Status	PA Natural Heritage Program - Western PA Conservancy	Screening	2010
CNHI: Supporting Landscapes (PA)	Ecology	PA Natural Heritage Program - Western PA Conservancy	Screening	2010
Coal Basin, Region and Field	Geology	U.S. Energy Information Administration (EIA)	Information	2007
Coal Bed Carbon Dioxide Storage Suitability	Geology	NREL	Information	2011
Coal Mine/Facility	Geology	USGS	Resource	

Layer Title	Category	Source	Layer Type	Publication Year
Coal Plants Suitable for Co-Firing Biomass	Utilities	EPA	Resource	2011
Coal Power Plant	Utilities	NREL	Resource	2007
Coalbed Methane Field	Geology	EIA	Information	2007
Coastal Barrier Resources System	Improvement	U.S. Fish and Wildlife Service (USFWS)	Information	2010
Cold-Water Coral Habitat	Ecology	USGS	Screening	2010
College/University	Buildings	Argonne National Laboratory (Argonne)	Screening	
Commercial Nuclear Power Plant	Utilities	UN Environment Programme/GRID	Information	1999
Concentrating Solar Direct Normal Potential	Climate	NREL, et al.	Resource	2005
Conservation Focus Area (NH)	Land Status	The Nature Conservancy	Screening	2006
Conservation Opportunity Area (MO)	Ecology	MO Department of Conservation	Screening	
Conservation Opportunity Area (PA)	Land Status	PA Natural Heritage Program	Screening	
Conserved Land (ME)	Land Status	ME Department of Conservation Bureau of Parks and Land, et al.	Screening	2010
Conserved Land (NH)	Land Status	Complex Systems Research Center - University of NH	Screening	1995
Conventional Crops 2012	Flora	Bioenergy Knowledge Discovery Framework	Resource	2011
Conventional Crops 2022	Flora	Bioenergy Knowledge Discovery Framework	Resource	2011
County Boundary	Boundary	U.S. Census Bureau, et al.	Information	2012
Critical Habitat Area		USFWS	Screening	2010
Cross Ranch State Nature Preserve (ND)	Cadastre	ND Parks and Recreation Department	Screening	
Crude Oil Pipeline	Utilities	Platts/Bentek Energy	Information	2011
Current State House Legislative District		U.S. Census Bureau	Information	2013
Current State Senate Legislative District		U.S. Census Bureau	Information	2013
Dam/Lock	Hydrography	U.S. Army Corps of Engineers (USACE)	Information	2006
Domal Salt Formation	Geology	ORNL	Resource	
Earthquake Intensity	Geology	USGS	Screening	2010
Eastern Brook Trout Status	Fauna	U.S. Forest Service (USFS)	Screening	2006
Ecological Conservation Site (TN)	Land Status	TN Department of Environment and Conservation - Division of Natural Areas - Natural Heritage Inventory Program	Screening	2010
Ecological Cores/Restoration Priorities	Ecology	The Wilderness Society	Screening	
Ecoregional Portfolio	Ecology	The Nature Conservancy	Screening	2011
EISPC Region	Boundary	Argonne	Information	2010
Electrical Power Plant Capacity	Utilities	EPA	Screening	2011
Energy Potential Non-Powered Dam	Improvement	ORNL	Resource	2012
Enhanced Geothermal System (EGS) Potential	Geology	NREL	Resource	2009

Layer Title	Category	Source	Layer Type	Publication Year
Enhanced Geothermal System (EGS) Technology Potential	Geology	NREL	Resource	
Environmental Hazard Site	Environmental Hazards	EPA	Screening	2012
Environmental Sensitive Area (NJ)	Land Status	NJ Department of Environmental Protection (NJDEP) - Planning and Sustainable Communities	Screening	2008
EPA Class I Area	Visual	EPA	Screening	2007
EPA Renewable Energy Sites	Environmental Hazard	EPA, et al.	Screening	2009
Essential Fish Habitat	Ecology	NOAA	Screening	2009
Existing Hydropower Dam (At least 50 MW)	Utilities	Platts/Bentek Energy	Information	2011
Ferry Route	Transportation	USGS	Screening	2012
USFWS Boundary	Cadastre	USFWS	Screening	2012
Florida Conservation Land (FL)	Land Status	FL Natural Areas Inventory - FL State University	Screening	2010
Florida Forever Board of Trustees Project Area (FL)	Land Status	FL Natural Areas Inventory - FL State University	Screening	2010
Focal Areas of Conservation Significance	Ecology	The Nature Conservancy	Screening	2012
Focus Area (ND)	Land Status	ND Parks and Recreation Department	Screening	2007
Focus Area of Ecological Significance (ME)	Ecology	ME Department of Conservation	Screening	2011
Forest Focal Areas - Atlantic Flyway	Ecology	National Audubon Society	Screening	2012
Formerly Used Defense Site	Environmental Hazards	USACE	Information	2010
USFWS Specially Designated Area	Land Status	USFWS	Screening	2012
Gauging Station	Improvement	USGS	Information	2001
Geologic Fault	Geology	USGS	Screening	2003
Geologic Survey Map	Geology	USGS	Information	2005
Geopressure Energy Potential - Plan 2	Geology	NREL	Resource	1978
Geopressure Energy Potential - Plan 3	Geology	NREL	Resource	1978
Grand River/Mosquito Focus Area (OH)	Ecology	OH Department of Natural Resources - Division of Wildlife	Screening	
Great Lake Opportunity Area (WI)	Ecology	WI Department of Natural Resources - Bureau of Endangered Resources	Screening	2008
Green Infrastructure Network Characterization	Ecology	The Conservation Fund	Screening	2010
Greenway Corridor (RI)	Cadastre	RI Department of Administration - Statewide Planning	Screening	1995
Gunlogson State Nature Preserve (ND)	Cadastre	ND Parks and Recreation Department	Screening	
H.R. Morgan State Nature Preserve (ND)	Cadastre	ND Parks and Recreation Department	Screening	
Habitat	Ecology	Argonne, et al.	Screening	2013
Habitat Block/Wildlife Corridor (VT)	Ecology	VT Agency of Natural Resources	Screening	2011
Habitats of Particular Concern	Ecology	NOAA	Screening	2010
Head of the Mountain State Nature Preserve (ND)	Cadastre	ND Parks and Recreation Department	Screening	

Layer Title	Category	Source	Layer Type	Publication Year
High Irreplaceability Area	Ecology	Two Countries, One Forest	Screening	2007
Highest Ranked Wildlife Habitat (NH)	Ecology	NH Fish and Game Department - Wildlife Division	Screening	2010
Hospital	Buildings	USGS	Screening	2012
Human Footprint (Northern Appalachian/Acadian Ecoregion)	Ecology	Wildlife Conservation Society Canada	Screening	2007
HydroKinetic Project Issued Preliminary Permit	Hydrography	Federal Energy Regulatory Commission (FERC)	Resource	2012
HydroKinetic Project Pending Preliminary Permit	Hydrography	FERC	Resource	2012
Imperiled Species	Ecology	NatureServe	Screening	2013
Important Bird Area	Land Status	National Audubon Society	Screening	2012
Indian Reservation	Cadastre	U.S. Census Bureau, et al.	Information	2012
Karst Area	Geology	USGS	Information	2005
Key Area for Conservation Action (NM)	Land Status	NM Department of Game and Fish	Screening	
Killbuck Focus Area (OH)	Ecology	OH Department of Natural Resources - Division of Wildlife	Screening	
Killdeer Focus Area (OH)	Ecology	OH Department of Natural Resources - Division of Wildlife	Screening	
Lake Erie Marsh Focus Area (OH)	Ecology	OH Department of Natural Resources - Division of Wildlife	Screening	
Landscape Permeability Flow Model	Ecology	Colorado State University	Screening	2012
Landscape v3.1 - Atlantic Coastal Region (NJ)	Ecology	NJDEP - Division of Fish & Wildlife	Screening	2012
Landscape v3.1 - Delaware Bay Region (NJ)	Ecology	NJDEP - Division of Fish & Wildlife	Screening	2012
Landscape v3.1 - Freshwater Mussel Habitat (NJ)	Ecology	NJDEP - Division of Fish & Wildlife	Screening	2012
Landscape v3.1 - Marine Region (NJ)	Ecology	NJDEP - Division of Fish & Wildlife	Screening	2012
Landscape v3.1 - Piedmont Plains Region (NJ)	Ecology	NJDEP - Division of Fish & Wildlife	Screening	2012
Landscape v3.1 - Pinelands Region (NJ)	Ecology	NJDEP - Division of Fish & Wildlife	Screening	2012
Landscape v3.1 - Skylands Region (NJ)	Ecology	NJDEP - Division of Fish & Wildlife	Screening	2012
Landscape v3.1 - Vernal Habitat (NJ)	Ecology	NJ DEP - Division of Fish & Wildlife	Screening	2012
Landslide Incidence and Susceptibility	Environmental Hazards	USGS	Screening	2001
Lasuan Focus Area (OH)	Ecology	OH Department of Natural Resources - Division of Wildlife	Screening	
Major Road	Transportation	Federal Highway Administration, et al.	Information	2012
Marine Port	Transportation	USACE	Information	2012
Marine Protected Areas Database	Land Status	USGS	Screening	2011
Marine Sanctuary	Land Status	NOAA	Screening	2004
Marine Wreck/Obstruction	Transportation	NOAA	Screening	2002
Mean Annual Wind Speed (100 m)	Climate	AWS Truepower, LLC (AWST)	Resource	2012
Mean Annual Wind Speed (80 m)	Climate	AWST	Resource	2012

Layer Title	Category	Source	Layer Type	Publication Year
Military Installation	Cadastre	Office of the Deputy Under Secretary of Defense for Installations and Environment	Screening	2011
Military Training Route Centerline	Military Operations	National Geospatial-Intelligence Agency (NGA)	Information	2010
Military Training Route Corridor	Military Operations	NGA	Information	2010
Mineral Resource	Land Status	USGS	Resource	2005
Mountain Treasures Area	Land Status	The Wilderness Society	Screening	
National Ambient Air Quality Standard Area - Lead	Environmental Hazards	EPA	Information	2007
National Ambient Air Quality Standard Area - Ozone - 1-hour	Environmental Hazards	EPA	Information	2007
National Ambient Air Quality Standard Area - Ozone - 8-hour	Environmental Hazards	EPA	Information	2006
National Ambient Air Quality Standard Area - Carbon Monoxide	Environmental Hazards	EPA	Screening	2007
National Ambient Air Quality Standard Area - PM10	Environmental Hazards	EPA	Screening	2007
National Ambient Air Quality Standard Area - PM2.5	Environmental Hazards	EPA	Information	2006
National Ambient Air Quality Standard Area - Sulfur Dioxide	Environmental Hazards	EPA	Screening	2007
National Conservation Easement Database	Cadastre	The Conservation Registry	Screening	2012
National Interest Electric Transmission Corridor	Land Status	Argonne, et al.	Information	2010
National Land Cover Database	Flora	USGS	Screening	2006
National Monument	Land Status	Argonne, et al.	Screening	2009
National Offshore Wind Resource Assessment (90 m)	Climate	NREL, et al.	Resource	2009
National Park Service Boundary	Cadastre	U.S. National Park Service	Screening	2010
National Trail	Improvement	Argonne, et al.	Screening	2011
National Wind Resource Assessment (50 m)	Climate	NREL, et al.	Resource	2003
Natural Area (DE)	Ecology	DE Department of Natural Resources and Environmental Control - Division of Parks and Recreation	Screening	2006
Natural Diversity Database (CT)	Ecology	CT Department of Environmental Protection	Screening	2010
Natural Gas Pipeline	Utilities	Platts/Bentek Energy	Information	2011
Natural Heritage Area (NC)	Ecology	NC Department of Environment and Natural Resources	Screening	2012
Natural Heritage Area (RI)	Ecology	RI Department of Environmental Management - The Nature Conservancy Natural Heritage Program	Screening	1990
Natural Heritage Inventory Managed Area (OK)	Land Status	University of OK - Natural Heritage Inventory	Screening	2010

Layer Title	Category	Source	Layer Type	Publication Year
Natural Heritage Priority Site (NJ)	Land Status	NJDEP - Office of Natural Lands Management	Screening	2007
Natural Land Network (VA)	Land Status	VA Department of Conservation & Recreation - Natural Heritage Program	Screening	2007
Natural Landscape Assessment: Ecological Core (VA)	Ecology	VA Department of Conservation & Recreation - Natural Heritage Program	Screening	2007
Natural Landscape Block (VA)	Ecology	VA Department of Conservation & Recreation - Natural Heritage Program	Screening	2007
Natural Services Network (NH)	Land Status	NH Department of Transportation	Screening	2007
Natural Vegetation (IA)	Flora	IA Department of Natural Resources - Wildlife Bureau	Screening	
Navigable Waterway Network	Transportation	Research and Innovative Technology Administration, et al.	Information	2012
Navigational Aid	Transportation	NOAA	Screening	2010
Next-Generation Weather Radar (NEXRAD)	Communications	NOAA, et al.	Information	2012
NHESP BioMap2 Core Habitat	Ecology	MA Division of Fisheries and Wildlife, et al.	Screening	2010
NHESP BioMap2 Critical Natural Landscape	Ecology	MA Division of Fisheries and Wildlife, et al.	Screening	2010
North American Carbon Dioxide Source	Environmental Hazards	NREL	Information	
North American Oil & Gas Field	Geology	NREL	Information	
North American Saline Basin	Geology	NREL	Screening	
Operational Anaerobic Digester	Environmental Hazards	EPA	Resource	2012
Operational Landfill Methane Project	Environmental Hazards	EPA	Resource	2012
Paint Creek Focus Area (OH)	Ecology	OH Department of Natural Resources - Division of Wildlife	Screening	
Petrochemical Facility	Utilities	ORNL	Screening	2011
Photovoltaic Potential	Climate	NREL, et al.	Resource	2007
Population Density (LandScan)	Demographics	ORNL	Screening	2009
Potential Bicknell Thrush Habitat	Ecology	Vermont Center for Ecostudies	Information	2009
Potential Conservation Opportunity Area (GA)	Flora	GA Department of Natural Resources	Screening	
Potential Retrofitted Pulverized Coal Plant	Utilities	Platts/Bentek Energy	Information	2011
Power Plant - Existing	Utilities	Platts/Bentek Energy	Information	2011
Power Plant - Not Operational/Unknown	Utilities	Platts/Bentek Energy	Information	2011
Power Plant - Planned	Utilities	Platts/Bentek Energy	Information	2011
Prison	Buildings	Argonne	Screening	2004
Protected Areas Database	Land Status	USGS, et al.	Screening	2011
Protected Lands	Land Status	Argonne, et al.	Screening	2013
Pumped Storage Issued Preliminary Permit	Hydrography	FERC	Resource	2011
Pumped Storage Pending Preliminary Permit	Hydrography	FERC	Resource	2011
Pumped Storage Site	Hydrography	Argonne	Resource	2011

Layer Title	Category	Source	Layer Type	Publication Year
Quaternary Fault	Geology	USGS	Screening	2004
Railroad	Transportation	Federal Railroad Administration	Information	2012
Rare Species (MA)	Ecology	MA Division of Fisheries and Wildlife; et al.	Screening	2008
Rare Species Concentration Area (MN)	Ecology	MN Department of Natural Resources - Division of Ecological Resources	Screening	2008
Rare, Threatened, and Endangered Species and Significant Community (VT)	Ecology	VT Fish and Wildlife Department - Nongame and Natural Heritage Program	Screening	2006
Refined Product Pipeline	Utilities	Platts/Bentek Energy	Information	2011
River Opportunity Area (WI)	Ecology	WI Department of Natural Resources - Bureau of Endangered Resources	Screening	2008
Saline Formation Suitability	Geology	NREL, et al.	Resource	
Scenic Byway	Visual	U.S. Department of Transportation	Screening	2010
School	Buildings	USGS	Screening	2012
Seafloor Geology	Geology	USGS	Information	2005
Secondary Agriculture Residue 2012	Flora	Bioenergy Knowledge Discovery Framework	Resource	2011
Section 368 Centerline	Land Status	Argonne, et al.	Information	2008
Section 368 Centerline (Developable Area)	Land Status	Argonne, et al.	Information	2008
Section 368 Zone	Land Status	Argonne, et al.	Information	2008
Section 368 Zone (Developable Area)	Land Status	Argonne, et al.	Information	2008
Seismic Hazard	Geology	USGS	Screening	2012
Sensitive Species Project Review Area (MD)	Ecology	MD Department of Natural Resources - Wildlife and Heritage Service	Screening	2010
Sentinel Butte State Nature Preserve (ND)	Cadastre	ND Parks and Recreation Department	Screening	
Shale Gas Basin	Geology	EIA	Information	2008
Shipping Fairways, Lanes, and Zones	Transportation	NOAA	Screening	2013
Shutdown Anaerobic Digester	Environmental Hazards	EPA	Resource	2012
Slope	Landform	USGS, et al.	Information	2011
Southeastern Ecological Framework Model	Ecology	University of Florida - GeoPlan Center	Screening	2001
Special Use Airspace	Military Operations	NGA	Screening	2010
Stacked Plays	Geology	EIA	Information	2008
State Boundary	Boundary	U.S. Census Bureau, et al.	Information	2012
State Claimed Water Body (LA)	Land Status	LA Division of Administration - State Land Office	Screening	2011
State Owned/Leased Land (LA)	Land Status	LA Division of Administration - State Land Office	Screening	2011
Stream/River	Hydrography	USGS	Information	2010
Submarine Cable	Utilities	NOAA	Screening	2011
Substation	Utilities	Platts/Bentek Energy	Information	2011
Subterranean Priority Area (TN)	Ecology	TN Wildlife Resources Agency	Screening	2005
Surface Water Flow - NHDPlus Version 2	Hydrography	Horizon Systems Corporation, et al.	Screening	2012
Tecumseh Focus Area (OH)	Ecology	OH Department of Natural Resources - Division of Wildlife	Screening	
Terminal Doppler Weather Radar (TDWR)	Communications	NOAA, et al.	Screening	2012
Terrestrial Conservation Focus Area (MT)	Ecology	MT Department of Fish, Wildlife, and Parks	Screening	2006

Layer Title	Category	Source	Layer Type	Publication Year
Terrestrial Opportunity Area (WI)	Ecology	WI Department of Natural Resources - Bureau of Endangered Resources	Screening	2008
Terrestrial Priority Area (TN)	Ecology	TN Wildlife Resources Agency	Screening	2005
Terrestrial Priority Conservation Area (AL)	Ecology	AL Department of Conservation and Natural Resources	Screening	2011
Tethered Aerostat Radar System (TARS)	Communications	NOAA, et al.	Screening	2012
Tidal - Mean Current Speed	Hydrography	Georgia Institute of Technology – Savannah	Resource	2011
Tidal - Mean Kinetic Power Density	Hydrography	Georgia Institute of Technology – Savannah	Resource	2011
Tier 1 Conservation Area (KY)	Ecology	KY Department of Fish & Wildlife Resources - Information Systems Office	Screening	2005
Tilted Photovoltaic Potential	Climate	NREL, et al.	Resource	2005
Transmission Line	Utilities	Platts/Bentek Energy	Information	2011
U.S. Populated Place		U.S. Census Bureau	Information	2010
Under Construction Landfill Methane Project	Environmental Hazards	EPA	Resource	2012
Under Construction/Unknown Anaerobic Digester	Environmental Hazards	EPA	Resource	2012
Unexploded Ordnance	Environmental Hazards	NOAA	Screening	2012
Urban Area	Demographics	U.S. Census Bureau	Information	2010
U.S. Forest Service (USFS) Roadless Area	Land Status	USFS	Screening	2003
USFS Specially Designated Area	Land Status	USFS	Screening	2000
Wastewater Treatment Facility	Utilities	EPA	Resource	2006
Water Body	Hydrography	USGS	Information	2010
Watershed	Hydrography	USGS, et al.	Information	2005
Wave Energy - Energy Period	Hydrography	NREL, et al.	Resource	2011
Wave Energy - Power Density	Hydrography	NREL, et al.	Resource	2011
Wave Energy - Significant Wave Height	Hydrography	NREL, et al.	Resource	2011
Wave Energy - Water Depth	Hydrography	NREL, et al.	Resource	2011
Well Locations (Bottom Hole Temperature [BHT] degrees Celsius)	Geology	Southern Methodist University	Information	2008
Wilderness Area	Land Status	Wilderness Institute, et al.	Screening	2010
Wind Power Density (100 m)	Climate	AWST	Resource	2012
Wind Power Density (80 m)	Climate	AWST	Resource	2012
Wind Turbine Gross Capacity Factor (100 m)	Climate	AWST	Resource	2012
Wind Turbine Gross Capacity Factor (80 m)	Climate	AWST	Resource	2012
Wind Turbine Site	Improvement	FAA	Information	2012

Appendix C: Estimating Rooftop PV Potential

C.1 Introduction

As discussed in Sections 2 and 3, rooftop photovoltaic (PV) differs significantly from the utility-scale solar resources. For completeness, this Appendix repeats some of the earlier discussion in Section 3.6.

As a local, distribution-level resource, rooftop PV needs no transmission to connect it to customer load. What matters most for transmission system planning are the degree of rooftop PV penetration in that locale and the extent of peak load reduction, potentially reducing the need for transmission. The precise location of individual solar installations within the load center has little bearing on transmission-level system planning and distribution-level issues; while important, the latter are not addressed here.

The way in which decisions regarding deployment of rooftop PV are made is also fundamentally different from that for deployment of utility-scale resources. The construction of a 200-megawatt (MW) utility-scale solar plant involves a set of decisions toward one single capital investment. In contrast, deploying an equivalent amount of rooftop PV involves many independent and fragmented decisions spread among thousands of individual customers. Residential customer decisions involve a few kilowatts (kW), whereas large industrial or commercial customers installing systems may involve as much as a megawatt (MW). In other words, the deployment of 200 MW of rooftop PV is not based on a single decision. Rather, it is the result of the aggregation of many individual decisions influenced by local, state, and federal incentives; utility practices and rate structures; as well as the quality of the local solar resource, among other variables. Estimating rooftop solar PV potential combines information about population and buildings stock (residential, commercial, and industrial) and the amount of sunshine the locality has during a typical year. The operational questions are as follows:

- How much useful rooftop space is there in a given locale?

- How much sunlight is likely to fall on rooftops during the course of a typical year?

- How much electricity can the rooftop PV provide, and how will it change peak demand?

Consequently, while utility-scale solar is a generation resource from the perspective of transmission planning, rooftop PV is a load-reducing technology.[1] Location is not the unknown variable. What affects system planning is how much load reduction might occur in a given locale due to greater rooftop PV deployment.

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[1] For a particular rooftop installation, generation may exceed the building load and be fed back onto the grid. At very high penetration levels, rooftop PV might exceed the aggregate load in the local distribution system and then impact transmission.

This analysis deals with the *aggregate* amount of rooftop PV that might be available in a given locale. It does not address specifically where rooftop PV might be located. The Eastern Interconnection States' Planning Council (EISPC) Mapping Tool is not designed for analyzing the viability of specific sites or buildings.[2]

Panel and installation costs are also outside the scope of this analysis. Such costs are better addressed as follow-on analyses, as they would not materially affect the system-wide planning questions that this analysis aims to examine. The focus here is on how net load would change in a given locale with various penetration levels of rooftop PV.

This analysis makes no assumption about the effectiveness of state and local policies affecting financial incentives for rooftop PV. Instead, users of the tool are asked to define the level of effectiveness they assume for whatever incentives may be in place (or for programs that might be under consideration). The tool can test the system-wide results of achieving a certain level of rooftop PV deployment. It does not answer the question of what incentives might be required to achieve that level of deployment.

C.2 Rooftop Estimation

Mapping rooftop solar PV potential involves two analytical components: population and buildings stock (residential, commercial, and industrial) and the amount of sunshine the area has during a typical year.

The amount of rooftop space depends on urban density and the geographic expanse of the metropolitan area. Not all rooftops are the same, however, and many of these differences can affect the efficiency of a PV installation. In the northern hemisphere, a roof pitched facing the south generally allows a solar panel to produce more electricity than one facing another direction. Even if the roof faces south, the angle of the pitch will also affect production. If there is no shade obstructing solar exposure, a south-facing panel tilted at an angle equal to the site's geographic latitude will capture the most sunshine and produce the most electricity.

Trees and other vegetation can obstruct sunlight and affect the amount of electricity produced throughout the day. The height of neighboring buildings to the south can also limit PV output. The amount of rooftop space containing heating, ventilation and air-conditioning (HVAC) equipment will also reduce the space available for solar panels. Buildings in warmer climates tend to have more tree shading and more HVAC, resulting in less area available for rooftop PV panels. Another factor that has to be taken into account is rooftop loading (weight) limitation. This level of detail needs to be addressed in the actual permitting process.

This analysis relies on a 2008 study by Denholm and Margolis that estimates the building stock rooftop area that is potentially available for solar PV (Denholm and Margolis 2008). The methodology applies general adjustments to account for differences in roof slope, roof orientation, shading from adjacent buildings, and shading from overhanging vegetation. As of

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[2] For a suite of publicly available site assessment tools, see
http://www.nrel.gov/analysis/analysis_tools_tech_sol.html.

this writing, more precise validation for key metropolitan areas is being conducted using light detection and ranging (LIDAR) remote sensing, but results have not yet been published.

All of the adjustments listed above applied to the stock of buildings result in an estimate describing the total rooftop area in a load center capable of accommodating rooftop PV. This is an upper limit estimate based on physical rooftop configuration and yields the technical potential. The actual penetration rate will be less than 100% of the technical potential. Installations by individual homeowners and commercial property owners will be influenced by policy, expected payback, and other factors.

The total available rooftop area is estimated for commercial and residential buildings in each grid (Census Block or Block Group or a higher level aggregation such as City, County, or State). Total floor space data for each aggregated grid are obtained from McGraw-Hill (FW Dodge Building Stock Database) and then scaled to estimate the total building "footprint" area based on the number of floors in each building class (i.e., a three-story building with 3,000 ft^2 of floor space would be assumed to have a roof footprint of 1,000 ft^2).

The average number of floors per building type was based on estimates from the Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS) (DOE 2001) and the 2003 Commercial Building Energy Consumption Survey (CBECS) (DOE 2003).

The roof footprint was assumed to equal the roof area for flat-roofed buildings and was adjusted by using a typical pitch angle to estimate the roof area for sloped roofs. Because the building footprint is based on usable floor space, this eliminates roof overhang, which is not considered usable for PV. The actual distribution between flat and tilted roofs, as well as roof orientation, was based on several factors.

For residential rooftops, Denholm and Margolis (2008) assumed that 8% of all roofs are flat, based on estimates from Navigant Consulting (Paidipati et al. 2008). For commercial buildings, Denholm and Margolis used the CBECS database to estimate the distribution between flat and pitched roofs (DOE 2003). The CBECS data indicate that about 37% of commercial buildings (corresponding to about 31% of commercial roof area) use shingles, wood, or slate; and the data assumed that these roof materials are used on pitched roofs, with the remainder of the roofs flat.

For the orientations of pitched roofs, Denholm and Margolis assumed a uniform distribution. Total roof area was then translated into usable area by using an availability factor, which accounts for shading, rooftop obstructions, and other constraints. This number is highly uncertain and will vary regionally due to several factors, including local climate and vegetation; HVAC equipment requirements; and building density (Paidipati et al. 2008). Denholm and Margolis's base estimate was derived from Navigant Consulting data, which assumes 22% availability of roof area for residential buildings in cool climates, and 27% in warm/arid climates (due to reduced tree shading). For commercial buildings, the availability is estimated at 60% for warm climates and 65% for cooler climates.

C.3 Solar Data and Energy Conversion

Estimations of the amount of sunlight falling on rooftops in a given area draw on the same detailed satellite and ground observation data used to estimate utility-scale solar potential in Section 3.6. Most rooftop PV installations are small scale and use fixed mounting. Therefore, the raw solar potential for rooftop PV in a given area is calculated on the basis of a fixed-mounted panel tilted at an angle equal to the latitude of where the panel is installed. This is the angle that generally captures the most sunshine over the course of a year.

How much electricity comes from a square meter of rooftop PV will depend on the technology. Tracking of the best efficiencies of various PV technologies over time is shown in a chart available at http://www.nrel.gov/ncpv/images/efficiency_chart.jpg. The efficiency of panels currently in use range widely, with silicon technologies—most commonly used in rooftop arrays—ranging between 14% and 21%.[3]

Research for future panel technologies generally follows two tracks: new technologies with improved conversion efficiency, and production improvements that will reduce the cost of existing technologies. Achieving lower costs to end-use customers involves advancements in both areas.

Another component of the PV energy conversion system is the inverter. A PV panel generates direct current (DC) which must be converted to alternating current (AC) before it can connect to the distribution system. Inverters typically lose between 4% and 6% of the DC power generated; that is, a 100-kW DC system will be equivalent to 94 to 96 kW AC.[4] The U.S. Department of Energy (DOE) projects that invert efficiency will improve over the next 20 years to between 97% and 98%.

C.4 Peak Load Reduction

Rooftop PV will begin to influence peak demand as its penetration increases in a given metropolitan area, county, or state. This is especially true in hot climates where sunny days and high temperatures correlate with greater use of air-conditioning, leading to higher demand for electricity.

Summer peaks tend to occur in the mid- to late-afternoon hours. PV output peaks around noon and declines in the afternoon as the sun moves lower in the sky. PV's effect on peak demand is therefore less than its full rated capacity. It tends to shift the peak to later in the day, which also complicates the task of estimating PV's value in reducing peak demand.

This analysis uses a new metric to estimate the degree to which rooftop PV reduces an area's annual peak load. It relies on the building estimation methods and solar exposure discussed previously, along with user-defined assumptions about the level of rooftop PV deployment. The index calculation is as follows.

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[3] Monocrystalline silicon modules range from 14% to 16%; multicrystalline silicon modules range from 17% to 21% (DOE 2012, p. 7)1.

[4] Ibid., p 78.

1. Obtain hourly load data for the region or zone of interest, either for the most recent year or averaged across several years.

2. Obtain hourly production levels for rooftop PV during a typical year in the region or zone of interest, with production calculated as a percentage of a PV system's rated capacity for each hour.

3. Select an assumed penetration level for rooftop PV (in MW) in the region or zone of interest.

4. Calculate the net load for each hour by subtracting from load the amount of electricity generated by the assumed penetration of rooftop PV.

5. Calculate diurnal load profiles for each month of the year, based on average hourly load. Identify the month and hour with the highest average load.

6. Similarly, calculate diurnal net load profiles for each month of the year and identify the month and hour with the highest average net load.

The difference between the highest average load and the highest average net load (step 5 minus step 6) is the amount of peak reduction associated with the penetration level assumed in step 3.

Figure C-1 shows the annual load contour for the Entergy planning region, by month and by hour averaged over each day of the month. The shading for each cell indicates average load for that hour (darker cells indicate higher average load). In this example, the highest average is 26,127 MW, which occurs for the hour beginning at 3 p.m. during the month of August. This is the block during which the annual peak is most likely to occur.

Figure C-2 shows average PV production for the year, mapped in the same manner as the data for load. PV output is expressed as a percentage of installed capacity (in megawatt electric [MWe]). In this example, PV production is 41% of capacity during the period when the system peak is most likely to occur (before accounting for PV). In other words, 100 MW of installed PV will most likely reduce demand by 41 MW during the typical 3 p.m. hour in August.

After adding the effect of PV, however, the hour beginning at 3 p.m. during the month of August will no longer be the peak. August demand declines by a very small amount over the period of an hour at that time of day; however, over that same time, PV's average output drops from 41% of its rated capacity to only 24%. The effect is that the system peak tends to fall at a later hour when accounting for the effect of PV.

If total rated capacity of rooftop PV throughout the Entergy region were 6% of peak demand, or 1,747 MWe, the annual system peak net of rooftop PV would still occur in August but would shift to an hour later. The new peak with rooftop PV would occur at 4 p.m. and would be 1.8% lower than it would have been at 3 p.m. without rooftop PV. This means that rooftop PV reduces peak load by less than 1 MW for every 3 MWe of installed rooftop PV capacity, when the system-wide penetration of rooftop PV is equal to 6% of peak load.
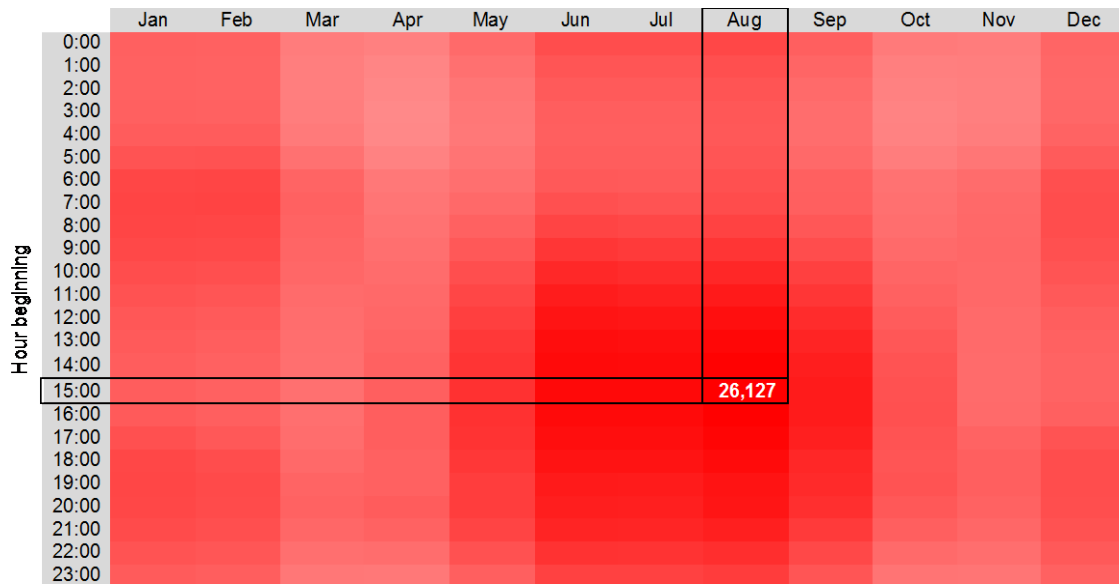
Figure C-1 Daily Demand Profiles by Month for the Entergy Planning Area (Darker shading indicates higher load. In this example, the annual peak is most likely to occur between 3 p.m. and 4 pm. on a day in August.)
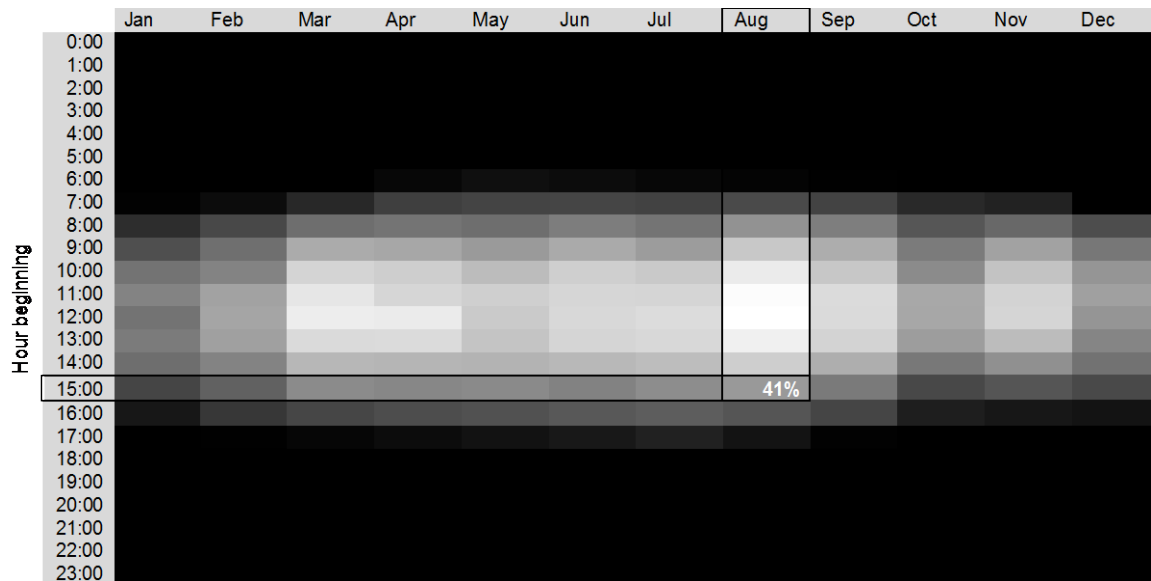

Figure C-2 Daily Production Profiles by Month for a PV Array Located in the Entergy Planning Area (Expressed as a percentage of installed capacity [assuming fixed mounting at an angle equal to latitude, with no shading obstacles]. Light shading indicates peak production; dark shading indicates no production. During the time that the annual peak is most likely to occur, the output of a PV system will most likely be 41% of its rated capacity.) (Source: NREL 2008)

Rooftop PV's peak-reducing effect is not linear, and at some point the effect tends to diminish as penetration increases (Mills and Wiser 2012). For simplicity, the above methodology was applied to three indicative penetration levels: 2%, 6%, and 10% of regional system peak. The EISPC Mapping Tool applies these values in estimating the peak reduction associated with a user-selected rooftop PV penetration level in a zone selected by the user.

C.5 Data and Sources

Modeled, satellite-based data available for annual insolation potential are the same as described in Section 3.6. Data were provided by the National Renewable Energy Laboratory (NREL) and are available at http://www.nrel.gov/gis/data_solar.html. The data include monthly average and annual average daily total solar resource for areas of 0.1 degrees in both latitude and longitude (~10 square kilometers [km^2] in size). Additional data are described in Table C-1.

Table C-1 Rooftop PV Data and Sources[a]

Information	Data and Source
The average number of floors per building type	EIA, 2005 Residential Energy Consumption Survey (RECS) and the 2003 Commercial Building Energy Consumption Survey (CBECS)
Total floor space	McGraw-Hill, FW Dodge Building Stock Database
Solar resource	http://www.nrel.gov/gis/data_solar.html
[a] All metadata can be accessed via the EISPC EZ Mapping Tool.	

C.6 Bibliography

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Appendix D: Habitat Table

Dataset Name	Sensitivity Level
Appalachian Foothills Focus Area (OH)	Yellow
Aquatic Conservation Focus Area (MT)	Yellow
Aquatic Priority Area (TN)	Aquatic habitat prioritization = Very high: Orange Aquatic habitat prioritization = Medium, high: Yellow Aquatic habitat prioritization = Blank, low: Low conflict area
Aquatic Priority Conservation Area (AL)	Yellow
Artificial Reef	Yellow
Biodiversity and Wildlife Habitat Assessment (NC)	Conservation value = 5–10: Orange Conservation value = 1–4: Yellow Conservation value = -1: Low conflict area
Biodiversity (IN)	Yellow
Biological Hotspots (VT)	Yellow
Biologically Unique Landscape (NE)	Yellow
County Natural Heritage Inventory (CNHI): Core Habitat (PA)	Orange
CNHI: Landscape Conservation Area (PA)	Yellow
CNHI: Supporting Landscapes (PA)	Yellow
Cold-Water Coral Habitat	Yellow
Conservation Focus Area (NH)	Type of area = Core area: Orange Type of area = Supporting natural landscape: Yellow
Conservation Opportunity Area (MO)	Yellow
Conservation Opportunity Area (PA)	Yellow
Critical Habitat Area	Orange
Ecological Conservation Site (TN)	Biodiversity rank = B1, B2: Orange Biodiversity rank = B3, B4, B5, B?-Unknown, No Data: Yellow
Ecoregional Portfolio	Yellow
Environmental Sensitive Area (NJ)	Yellow
Focal Areas of Conservation Significance	Priority climate and current biodiversity area = Orange Priority climate area = Yellow
Focus Area (ND)	Yellow
Focus Area of Ecological Significance (ME)	Yellow
Forest Focal Areas – Atlantic Flyway	Yellow
Grand River/Mosquito Focus Area (OH)	Yellow
Great Lake Opportunity Area (WI)	Yellow
Green Infrastructure Network Characterization	Quality score = 4, 5: Orange Quality score = 1, 2, 3: Yellow
Greenway Corridor (RI)	Yellow

Dataset Name	Sensitivity Level
Habitats of Particular Concern	Yellow
Habitat Block/Wildlife Corridor (VT)	Final weighted score = 10, 9: Orange Final weighted score = 8, 7: Yellow Final weighted score = 1–6: Low conflict area
Highest Ranked Wildlife Habitat (NH)	Habitat condition rank = 1: Orange Habitat condition rank = 2, 3: Yellow
High Irreplaceability Area	Irreplaceable: Orange Not Irreplaceable: Low conflict area
Human Footprint (Northern Appalachian/Acadian Ecoregion)	Ranking of human influence = 0–20: Orange Ranking of human influence = 21–30: Yellow Ranking of human influence = 31–100: Low conflict area
Important Bird Area	Priority = Global, continental: Orange Priority = State: Yellow
Key Area for Conservation Action (NM)	Priority ranking for conservation planning = 13, 14, 15, 16: Orange Priority ranking for conservation planning = 9, 10, 11, 12: Yellow Priority ranking for conservation planning = 4, 5, 6, 7, 8: Low conflict area
Killbuck Focus Area (OH)	Yellow
Killdeer Focus Area (OH)	Yellow
Lake Erie Marsh Focus Area (OH)	Yellow
Landscape Permeability Flow Model	Flow rank = 9, 10 ,11, 12: Orange Flow rank = 6, 7, 8: Yellow
Landscape v3.1 - Atlantic Coastal Region (NJ)	Conservation status of species present = State threatened, state endangered, federally listed: Orange Conservation status of species present = Suitable habitat, priority concern: Yellow
Landscape v3.1 - Delaware Bay Region (NJ)	Conservation status of species present = State threatened, state endangered, federally listed: Orange Conservation status of species present = Suitable habitat, priority concern: Yellow
Landscape v3.1 - Freshwater Mussel Habitat (NJ)	Conservation status of species present = State threatened, state endangered, federally listed: Orange Conservation status of species present = Priority concern: Yellow
Landscape v3.1 - Marine Region (NJ)	Orange
Landscape v3.1 - Piedmont Plains Region (NJ)	Conservation status of species present = State threatened, state endangered, federally listed: Orange Conservation status of species present = Suitable habitat, priority concern: Yellow
Landscape v3.1 - Pinelands Region (NJ)	Conservation status of species present = State threatened, state endangered, federally listed: Orange Conservation status of species present = Suitable habitat, priority concern: Yellow
Landscape v3.1 - Skylands Region (NJ)	Conservation status of species present = State threatened, state endangered, federally listed: Orange Conservation status of species present = Suitable habitat, priority concern: Yellow
Landscape v3.1 - Vernal Habitat (NJ)	Vernal pool habitat type = Vernal habitat area: Orange Vernal pool habitat type = Potential vernal habitat area: Yellow
Lasuan Focus Area (OH)	Yellow
Mountain Treasures Area	Priority = 1: Orange Priority = 0: Yellow
Natural Diversity Database (CT)	Yellow
Natural Heritage Area (NC)	Significance = National, state, region: Orange Significance = County: Yellow
Natural Heritage Area (RI)	Yellow
Natural Heritage Priority Site (NJ)	Biodiversity rank = B1, B1V1, B2, B2V1, B2V2: Orange Biodiversity rank = B3, B3V1, B3V2, B4, B4V1, B4V2, B4V3, B4V5, B5, B5V1, B5V2, B5V3, B5V4, B5V5: Yellow

Dataset Name	Sensitivity Level
Natural Landscape Assessment: Ecological Core (VA)	Ecological integrity score = 1, 2: Orange Ecological integrity score = 3, 4, 5: Yellow
Natural Services Network (NH)	Yellow
Natural Vegetation (IA)	Number of priorities for conservation = 10, 11: Orange Number of priorities for conservation = 2–9: Yellow Number of priorities for conservation = 1: Low conflict area
NHESP BioMap2 Core Habitat	Orange
NHESP BioMap2 Critical Natural Landscape	Yellow
National Wetlands Inventory (NWI) Dataset	Wetland type = Palustrine (emergent and forested): Orange Wetland type = Marine, estuarine, riverine, lacustrine, and palustrine (rock bottom, unconsolidated bottom, aquatic bed, unconsolidated shore, moss-lichen, and scrub-shrub): Yellow
Paint Creek Focus Area (OH)	Yellow
Potential Conservation Opportunity Area (GA)	Conservation opportunity ranking = 5, 6, 7: Orange Conservation opportunity ranking = 2, 3, 4: Yellow
Rare Species Concentration Area (MN)	Statewide biodiversity significance rank = Outstanding, high: Orange Statewide biodiversity significance rank = Moderate: Yellow Statewide biodiversity significance rank = Below: Low conflict area
Rare Species (MA)	Yellow
Rare, Threatened, and Endangered Species and Significant Community (VT)	G-rank = G1G2: Orange G-rank = G2, G2?, G2G3, G2G3Q, G3, G3?, G3G4: Yellow G-rank = G3G5, G4, G4?, G4G5, G4Q, G4T4, G5, G5?, G5?Q, G5?T3, G5?T5?, G5T1, G5T2Q, G5T3?, G5T3T4Q, G5T4, G5T4?, G5T4Q, G5T4T5, G5T5, G5T5?, G5TNR, GNA, GNR: Low conflict area
River Opportunity Area (WI)	Ecological significance = Continental: Orange Ecological significance = Upper Midwest, state: Yellow
Sensitive Species Project Review Area (MD)	Species status = Federally listed, state listed: Orange Species status = Species of concern to the Maryland Department of Natural Resources, bald eagle nest site: Yellow
Southeastern Ecological Framework Model	Identified area of Southeastern Ecological Framework = Yellow Unidentified area = Low impact
Subterranean Priority Area (TN)	Subterranean habitat prioritization = 4: Orange Subterranean habitat prioritization = 2, 3: Yellow Subterranean habitat prioritization = 0, 1: Low conflict area
Tecumseh Focus Area (OH)	Yellow
Terrestrial Conservation Focus Area (MT)	Yellow
Terrestrial Opportunity Area (WI)	Ecological significance = Global, continental: Orange Ecological significance = Upper Midwest, state: Yellow
Terrestrial Priority Area (TN)	Priority = Very high: Orange Priority = Medium, high: Yellow Priority = Low: Low conflict area
Terrestrial Priority Conservation Area (AL)	Yellow
Tier 1 Conservation Area (KY)	Yellow
VA Natural Landscape Assessment: Ecological Core	Ecological integrity score = 1, 2: Orange Ecological integrity score = 3, 4, 5: Yellow

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Appendix E: Protected Lands Table

Dataset Name	Sensitivity Level
Conserved Land (ME)	Conservation type = Fee: Red Conservation type = Easement, easement enforcer, lease, project agreement, restricted, third-party easement: Orange Conservation type = Public Access Easement, blank: Yellow
Conserved Land (NH)	Gap status = 1: Red GAP status = 2: Orange GAP status = 3: Yellow GAP status = 3A, 4, 9: Low conflict area
Cross Ranch State Nature Preserve (ND)	Red
Florida Conservation Land (FL)	Protection status = 1: Red Protection status = 2: Orange Protection status = 3: Yellow
Florida Forever Board of Trustees Project Area (FL)	Work plan priority = High, high/med, medium: Orange Work plan priority = Medium/low, low: Yellow
Marine Protected Areas Database	GAP status = 1: Red GAP status = 2: Orange GAP status = 3: Yellow GAP status = 4: Low conflict area
Marine Sanctuary	Red
National Conservation Easement Database	Orange
National Trail	Yellow
Natural Area (DE)	Yellow
Natural Heritage Inventory Managed Area (OK)	Yellow
Protected Areas Database	GAP status = 1: Red GAP status = 2: Orange GAP status = 3: Yellow GAP status = 4: Low conflict area
Scenic Byway	Yellow
Sentinel Butte State Nature Preserve (ND)	Red
State Claimed Water Body (LA)	Yellow
State Owned/Leased Land (LA)	Yellow
U.S. Forest Service Roadless Area	Red

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