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ENERGY

Market Assessment Services to Characterize the Opportunities for Renewable Energy – *Final Report*

For: Rutgers, The State University of New Jersey and the New Jersey Board of Public Utilities

RUTGERS
THE STATE UNIVERSITY
OF NEW JERSEY

August 6, 2012

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DISPUTES & INVESTIGATIONS • ECONOMICS • FINANCIAL ADVISORY • MANAGEMENT CONSULTING

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August 6, 2012

Key Objectives

Navigant Project Objectives

- **Key objective: Identify opportunities to accelerate deployment of renewable and clean technologies in New Jersey for the years 2013-2016.**
- Provide timely and insightful results to assist BPU in making programmatic decisions for the years 2013-2016.
- Provide a foundation for developing next generation policies and regulations.
- Evaluate New Jersey's potential for the following renewable and clean energy technologies:
  - On-shore wind energy
  - Marine hydrokinetic
  - Small hydropower
  - Energy storage technologies
  - Fuel cells.

Given the short time-frame of the project, most of the research leveraged the work performed under BPU's three previous Comprehensive Resource Analysis (CRA) proceedings, as well as other relevant renewable energy potential studies conducted in New Jersey and throughout the United States. In cases where additional information was needed, Navigant performed primary research to supplement existing sources.

Agenda

Onshore wind resources in New Jersey are good (Class 3 and 4 winds) in locations near the coast, but generally limited elsewhere. NJ has about 132 MW of technical potential for onshore wind power.

Key Points – Onshore Wind Power

- The majority of Class 3 or higher wind resources are located near the coastline. There are some Class 4 sites along the barrier islands north of Atlantic City and at the southern tip of the state.
- Inland, there are limited sites that reach or exceed Class 3.
- There is about 132 MW of technical potential for onshore wind power in NJ.
- The majority of onshore wind development in NJ is likely to be small sites ranging from 1-10 MW. These smaller plants will not be able to take full advantage of economies of scale.
- Power output and reliability issues have also been a challenge for NJ on-shore wind sites as many sites are producing power below stated performance claims. This is largely a result of the turbulent nature of the wind resource most common in NJ.
- While project costs continue to decline and performance improves expiring federal incentives will influence project attractiveness.
- If both the PTC and ITC expire or are significantly reduced this will negatively impact the wind industry in the US and NJ.

Notes: PTC: Production Tax Credit; ITC: Investment Tax Credit; See appendix for potential definitions; details on the findings are in the wind section of the report.

The technical potential for NJ inland hydropower is low compared to other US states - there is about 126 MW of technical potential for inland hydropower and about 975 MW of ocean wave hydropower potential.

Key Points – Marine and Inland Hydro

- There is about 126 MW of technical potential for inland hydropower in NJ and about 975 MW of ocean wave hydropower potential.
- The available wave resource for the East Coast (ME to FL) is about 260 TWh/year of which 5-8% are in NJ.
- Ocean hydro technologies are in various stages of development: tidal barrage is a mature ocean hydropower technology. However, most other technologies are still in the research or demonstration stage.
- Due to lower technology maturity of ocean hydropower systems there is currently limited commercial-scale project cost and performance data.
- Inland hydropower plant costs can range broadly depending on the size and type of the project. However, conventional inland hydro technologies are mature technologies, and installed costs are expected to change moderately in the future as commodity costs change.

Notes: See appendix for potential definitions;

The technical potential[1] for Renewable Energy (RE) - related storage is 750 MW for shifting and 52.5 MW for frequency regulation.[2]

Key Points – Energy Storage

- **Renewable Energy Related Storage Applications in NJ**: Based on the amount of intermittent RE installed in NJ, Navigant identified two potential opportunities for storage in the near term (2012 through 2016):
  - Shifting renewable generation to more optimal times of the day
  - Providing some of the additional frequency regulation that may be required with higher levels of intermittent renewable energy
- **Shifting:** For renewable energy shifting in New Jersey, Navigant estimated that the current technical potential for storage is 750 MW, where 250 MW is dependent on offshore wind development and 500 MW is associated with solar PV. Navigant ran a low and high scenario resulting in 375 MW and 1250 MW of current technical potential respectively.
- **Frequency Regulation (FR)**: For the additional FR required due to the growth of intermittent renewables, Navigant estimated that the current technical potential for storage is 52.5 MW, when both offshore wind and solar PV are considered. If only offshore wind is considered the current technical potential for storage falls to 7.5 MW.

NYPA 1.2-MW/7.2-MWh Sodium-Sulfur Battery Facility

1-MW/15-min Beacon Power flywheel in an ISO ancillary service application

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1. The current technical potential for storage is defined as the amount of storage that is technically feasible to install based on the opportunities generated by the total installed amount of intermittent renewable in NJ through 2016.
2. These numbers reflect results from the base case, results from a high and low scenario are shown later.

Current technical potential in NJ for renewable fuel cells at wastewater and landfill is 22 MW; potential could be higher if other markets are included.

Key Points – Renewable Fuel Cells

- **Standard vs. Renewable Fuel Cell Potential**: The majority of potential for fuel cells in New Jersey is for fuel cells operating on standard fuel (i.e., natural gas). For example, based on the NJ FC Report there is a current market potential of 223 MW for standard fuel cells and 1 MW[1] for those fueled by renewable fuel.
- **Current Technical Potential for Renewable Fuel Cells**: The current technical potential for fuel cells operating directly at sites with renewable fuel, including wastewater treatment plants and landfills, is 22 MW[1].
- **Additional Market Segments to Consider**: Additional potential for renewable-fuel fuel cells may be found at facilities with food and animal waste using anaerobic digesters to produce the renewable fuel.

Photo from FuelCell Energy, Spotlight on the City of Tulare, CA fuel cell at a wastewater treatment plant.

Note: Three terms referring to potential are used throughout the fuel cell section (current theoretical potential, current technical potential, and current market potential). These terms are defined on the following slide.

1. See page 61 for more details.

Resource availability, technical potential, levelized cost of energy, and installed costs are summarized, along with technology analysis level:

● Good ◒ Fair ○ Poor

		Technology Summary					
		NJ Resource Availability	NJ Current Technical Potential		LCOE ($/kWh)[3]	Installed Costs ($/W)	Analysis Level
Onshore Wind	**Utility Scale**	◒	◒	132 MW	0.06-0.07	1.60-1.70	1
	Customer Sited	◒	◒	▨	▨	▨	2
Inland Hydro	**Small Hydro (≤30 MW)**	○/◒	○/◒	126 MW	0.05-0.25	1.50-6.00	1
	Large Hydro (>30 MW)	○	○	▨	0.04-0.13	1.00-5.00	2
	Pumped Hydro	○	○	▨	▨	▨	3
Ocean Hydro	**Wave[2]**	◒	◒	975 MW	0.08-0.10	~2.50 (in 2020)	1
	Tidal	◒	◒		0.10-0.14	1.00-4.00	1
Energy Storage[5]	**Fly Wheels**	◒	◒	800 MW[4]	▨	1.95-2.20	1
	Batteries	◒	◒		▨	1.70-4.90	1
	Flow Batteries	◒	◒		▨	1.45-3.70	1
	Compressed Air	○	○	▨	▨	▨	3
	Thermal Energy	○	○	▨	▨	▨	3
Fuel Cells	**Renewable Fuels**	○/◒	○/◒	22 MW	0.15-0.21	Adder: 0.50-0.90	1
	Standard Fuels	◒	◒	223 MW[1]	0.09-0.14	4.00-5.50	2

Analysis Level: 1 – Detailed Market Assessment; 2 – Brief Description; 3 – Not Included

1. Market Potential (see Fuel Cell section for detailed explanation). Description of technical potential is in Appendix
2. Ocean Hydro Wave Power LCOE price is estimated price for 2020.
3. LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt; Assumed 2012$
4. NJ Current Technology Potential rates to applications associated with renewable energy applications only.
5. Installed costs are only presented as the final LCOE depends on the varying nature of the charging costs

Agenda

Onshore wind resources in New Jersey are good (Class 3 and 4 winds) in locations near the coast, but generally limited elsewhere. NJ has about 132 MW of technical potential for onshore wind power.

Key Points – Onshore Wind Power

- The majority of Class 3 or higher wind resources are located near the coastline. There are some Class 4 sites along the barrier islands north of Atlantic City and at the southern tip of the state.
- Inland there are limited sites that reach or exceed Class 3.
- There is about 132 MW of technical potential for onshore wind power in NJ.
- The majority of onshore wind development in NJ is likely to be small sites ranging from 1-10 MW. These smaller plants will not be able to take full advantage of economies of scale.
- Power output and reliability issues have also been a challenge for NJ on-shore wind sites as many sites are producing power below stated performance claims. This is largely as result of the turbulent nature of the wind resource most common in NJ.
- While project costs continue to decline and performance improves expiring federal incentives will influence project attractiveness.
- If both the PTC and ITC expire or are significantly reduced this will likely negatively impact the wind industry in the US and NJ.

Notes: PTC: Production Tax Credit; ITC: Investment Tax Credit; See appendix for potential definitions;

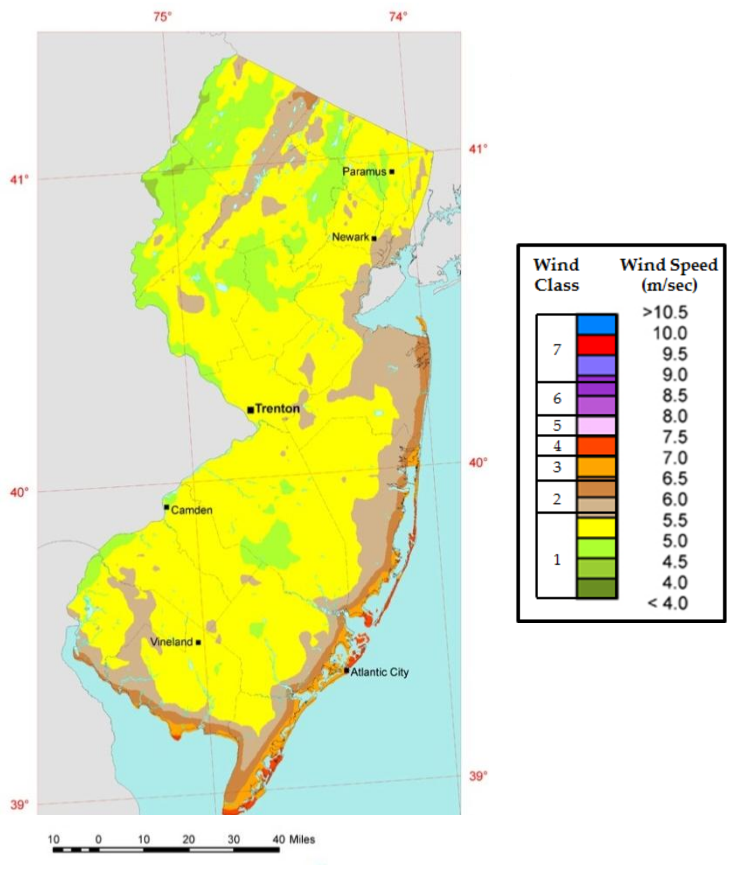
The wind potential in New Jersey has been estimated using the following approach.

Key Data Sources	Maps and wind potential estimates resulted from a collaborative project between : • National Renewable Energy Laboratory (NREL). • U.S. Department of Energy – Wind Powering America. http://www.windpoweringamerica.gov/ • AWS Truepower. http://www.awstruepower.com/ • Navigant – New Jersey Renewable Energy Market Assessment http://www.njcleanenergy.com/files/file/Final_Report.pdf Costs: • Energy Information Administration • Department of Energy – 2010 Wind Technologies Market Report • BTM World Market Update.
Approach	• Approach was assumed to be same as the one used by the Department of Energy - Wind Powering America. • Wind resource potential was assigned a gross capacity factor at 80m and 100m hub heights. • Wind resource was used in combinations with a minimum capacity factor of 30%. • Further reductions were made to the wind potential area estimates by excluding areas not likely to be developed, such as wilderness areas, parks, urban areas, and water features (see Technical and Theoretical Potential » Onshore Wind Power › Exclusions and Other Considerations Table for more detail) • The estimated available area was derived after applying the criteria described above. • The wind energy potential capacity was calculated using the available windy area and assuming 5 MW/km^2.

The majority of Class 3 or higher wind resources are located near the coastline.

- The majority of Class 3 or higher wind resources are located near the coastline.
- There are some Class 4 sites along the barrier islands north of Atlantic City and at the southern tip of the state.
- Inland there are limited sites that reach or exceed Class 3.
- There are a couple of distinct "ridgelines" at the north end of the state which are the only significant non-shoreline wind resources. Much of this land is labeled as forest according to the land use classification.
- Virtually the entire coastline, with the exception of areas that are particularly sheltered, could be considered potential for small, community-based turbine clusters.

New Jersey Annual Average Wind Map at 80 Meters



Source: Department of Energy; National Renewable Energy Laboratory
http://www.windpoweringamerica.gov/wind_resource_maps.asp?stateab=nj

There is about 132 MW of technical potential for onshore wind power in NJ.

- The established exclusion for wetlands is 100%. However, wetlands are by far the single largest land class with suitable wind regimes in New Jersey, suggesting a closer examination is warranted.
- The majority of onshore wind development in NJ is likely to be small sites ranging from 1-10 MW. The highest cost-benefits ratios for wind plants start around 50 MW and above; smaller plants will not be able to take full advantage of economies of scale.
- However, smaller plants may have advantages with regard to permitting and interconnection. Smaller plants will also be able to connect directly to the distribution system and not require a connection through the transmission system.

NJ Windy Land Area >= 30% Gross Capacity Factor at 80m						NJ Wind Energy Potential	
Total (km²)	Total[3] (MW)	Excluded[2] (km²)	Available (km²)	Available % of State[5]	% of Total Windy Land Excluded	Installed Capacity[3] (MW)	Annual Generation (GWh)
281	1,404	255	26	0.14%	90.6%	132	373

Notes:

1. Wind potential estimates were based on maps produced by AWS Truewind using their MesoMap® system.
2. http://www.windpoweringamerica.gov/wind_resource_maps.asp?stateab=nj
3. Excluded lands include protected lands (national parks, wilderness, etc.), incompatible land use (urban, airports, wetland, and water features), and other considerations.
4. Assumes 5 MW/km² of installed nameplate capacity
5. Total area of the state of NJ is roughly 7,350 miles² or 19,000 km². http://quickfacts.census.gov/qfd/states/34000.html

Wind resource exclusions include environmental and land use criteria among other considerations.

Wind Resource Exclusions

Criteria for Defining Available Windy Land (listed in the order they are applied)	
Environmental Criteria	100% exclusion of National Park Service and Fish and Wildlife Service managed lands
	100% exclusion of federal lands designated as park, wilderness, wilderness study area, national monument, national battlefield, recreation area, national conservation area, wildlife refuge, wildlife area, wild and scenic river or inventoried roadless area.
	100% exclusion of state and private lands equivalent to criteria 2 and 3, where GIS data is available.
	50% exclusion of remaining USDA Forest Service (FS) lands (incl. National Grasslands) except ridgecrests
	50% exclusion of remaining Dept. of Defense lands except ridgecrests
	50% exclusion of state forest land, where GIS data is available
Land Use Criteria	100% exclusion of airfields, urban, wetland and water areas.
	50% exclusion of non-ridgecrest forest
Other Criteria	Exclude areas of slope > 20%
	100% exclude 3 km surrounding criteria 2-5 (except water)
	Note - 50% exclusions are not cumulative. If an area is non-ridgecrest forest on FS land, it is just excluded at the 50% level one time.

Source: National Renewable Energy Laboratory, AWS Truewind
Note: 50% exclusions are not cumulative. If an area is non-ridgecrest forest on FS land, it is just excluded at the 50% level one time.
http://www.windpoweringamerica.gov/wind_resource_maps.asp?stateab=nj

Most on-shore wind development in New Jersey is likely to be 1-10 MW. Smaller plant sizes lead to higher prices due to economies of scale.

Other Wind Power Considerations	
Economies of Scale	• To achieve most favorable economies of scale cost estimates assume large scale wind farms that are tens of MW in size.
Plant Size and Cost	• In NJ large wind farms are less likely due to land constraints in the areas with the best wind resource. Smaller sites and clusters of up to 10 MW are more likely to be developed. Such sites will have less opportunity to take advantage of economies of scale resulting in higher installation costs, up to 30% higher than large scale wind farms.
Grid Interconnection	• Smaller wind farms are more likely to be connected directly to the distribution system generally resulting in lower interconnection costs. However, the power in this case will have to be sold in the same feeder and require an off-take agreement. Connecting directly to the transmission line allows trading of the power on the PJM system. • Net metering rules in NJ allow systems up to 10 MW to be net metered and collect higher rates as long as the system does not exceed the power consumption of the customer.
Performance Issues	• System performance issues have also been a challenge for NJ on-shore wind sites as according to customers many sites are producing power below stated performance claims. This is largely a result of the turbulent wind most common in NJ. Wind turbines are designed for optimal performance in laminar wind conditions.

Source: Navigant, 2012.

While project costs continue to decline and performance improves, expiring federal incentives will influence project attractiveness.

- The average installed cost of wind power projects held steady in 2010, but is expected to decline in the near term.
- Wind power project performance has generally improved over time, but has leveled off in recent years to around 30% capacity factor.
- Operations and Maintenance (O&M) costs are affected by the age and commercial operation date of the project. It appears that projects installed more recently have, on average, incurred lower O&M costs than older projects in their first several years of operation, and that O&M costs increase as projects age
- Under present law, the Federal Production Tax Credit (PTC) provides an income tax credit of 2.2 cents/kWh for the production of electricity from utility-scale wind turbines. There is also a 30% Investment Tax Credit (ITC). Both of which are set to expire on December 31, 2012.

	Onshore Wind – Utility Scale (>50 MW)				
	2012	2013	2014	2015	2016
Installed Cost ($/kW)	1,700	1,700	1,650	1,600	1,600
O&M ($/MWh)	13.50	13.00	13.00	12.50	12.50
Capacity Factor	30%	30%	30%	30%	30%
Project Life	25	25	25	25	25
Federal Incentives	ITC: 30% or PTC: ₵2.2/kWh	None	None	None	None
State Incentives	NA	NA	NA	NA	NA
LCOE ($/kWh)	0.058	0.072	0.070	0.068	0.067

Sources: Navigant; 2010 Wind Technologies Market Report, US DOE 6/11; BTM World Market Update 2010, 3/11; Bloomberg, 6/10
Notes: smaller scale wind farm in the 1-10 MW range will have a 25-35% higher installed cost;
LCOE Assumptions: 2012 $, debt rate 8%; equity rate 10%; debt/equity 70:30; 20 years debt.

If both the PTC and ITC expire or are significantly reduced, this will negatively impact the wind industry in the US and NJ.

Future Trends

- Under present law, the Federal Production Tax Credit (PTC) provides an income tax credit of 2.2 cents/kWh for the production of electricity from utility-scale wind turbines. The PTC is set to expire on December 31, 2012. Through Section 1603 of the American Recovery and Reinvestment Act of 2009, wind project developers can choose to receive a 30% Investment Tax Credit (ITC) in place of the PTC. For projects placed in service before 2013, at which construction begins before the end of 2011, developers can elect to receive an equivalent cash payment from the Department of Treasury for the value of the 30% ITC.
- The Federal ITC allowing projects placed in service before 2013 to receive an ITC of 30% is also set to expire on December 31, 2012.
- If both the PTC and ITC expire or are significantly reduced this will negatively impact the wind industry in the US and NJ. Project costs will likely increase making it more difficult to obtain financing for wind projects in the US.
- Forecasts for 2013 and beyond remain volatile depending in part on assumptions about the possible extension of federal incentives beyond 2012. As of June 2012, industry representatives interviewed by Navigant estimate a market of 1 – 4 GW, down from 9 – 12 GW expected in 2012 for the U.S. In general forecasts are weighed down by policy uncertainty and the expected limited need for new electric capacity additions.

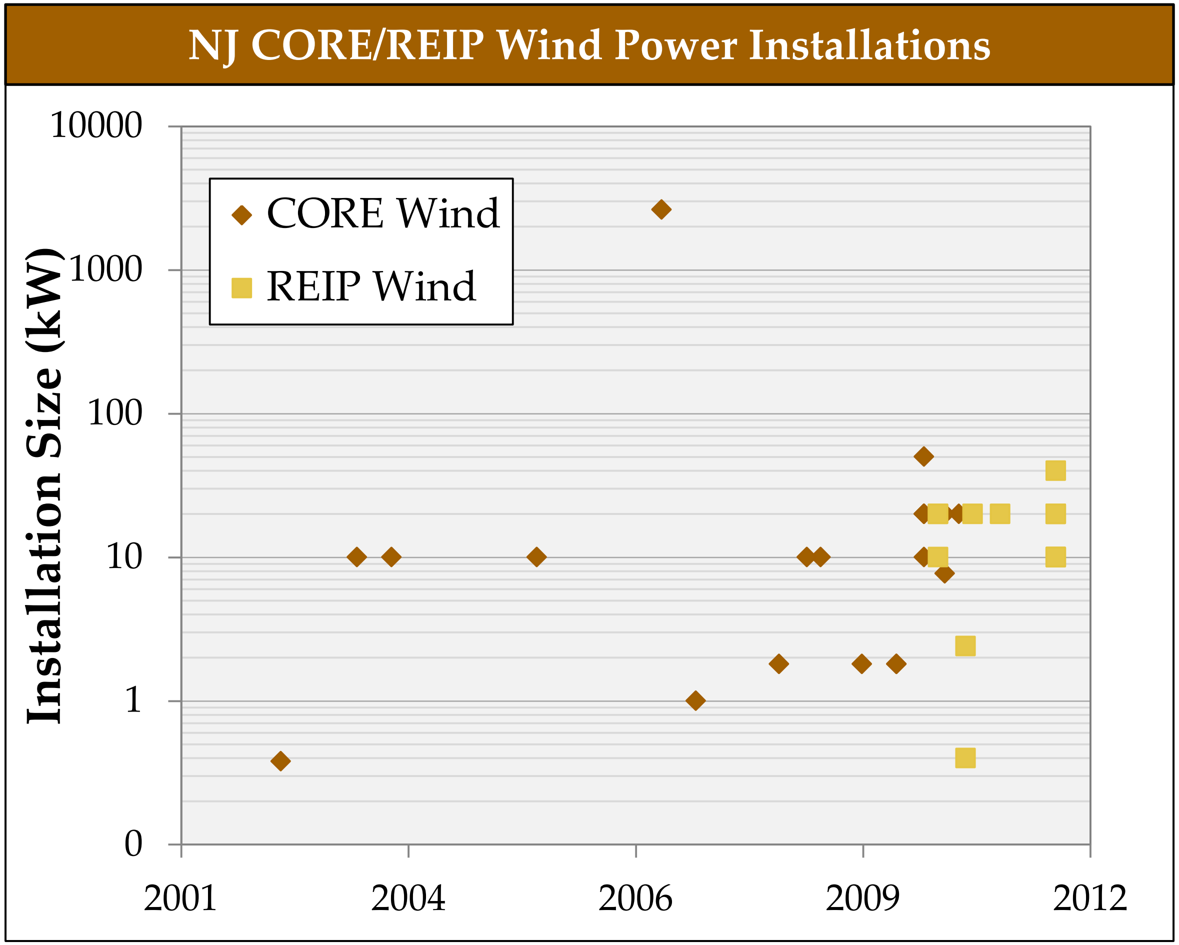
While customer sited plants are more likely in NJ, project economics and underperforming plants present a challenge for future growth.

Key Points – Customer Sited Onshore Wind Power

- The majority of onshore wind development in NJ is likely to be small sites ranging from 1-10 MW. These smaller, customer sited, plants will not be able to take full advantage of economies of scale. Historically wind plants in NJ have ranged from 10-50kW.
- Power output and reliability issues have been reported by customer sited wind plant owners in NJ. Many plants are underperforming and not achieving stated energy generation targets. This is largely attributed to the turbulent nature of the wind resource in NJ. For customer sited wind plants that can be found in/near areas with higher concentration of buildings and other obstacles this issue can be magnified.
- Several companies are developing products to more effectively address the customer sited market. Most promising products include smaller sized systems. These product offerings are expected to enter the market over the next 2-3 years. However, building integrated and horizontal wind solutions are also under development but are likely to take longer to reach commercial cost and performance targets.
- If both federal incentives (PTC and ITC) expire or are significantly reduced this will negatively impact the wind industry including the customer sited wind market in NJ.
- Customer sited wind is more likely to be adopted in higher populated areas which tend to be inland and have a reduced wind resource potential.

Sources: NJ BPU; Navigant
Note: System cost declines may partially offset the loss of federal incentives.

Historically, wind plants in NJ have ranged from 10-50 kW.



Program	Customer Type	Average System Size (kW)
Core Wind	Commercial	30
	Farm	20
	Government Facility	2,625
	Municipality	51
	Residential	165
	TOTAL	**2,891**
REIP Wind	Commercial	20
	Farm	70
	Residential	143
	TOTAL	**233**
Grand Total		**3,124**

Definitions: CORE: Customer Onsite Renewable Energy; REIP: Renewable Energy Incentive Program
Sources: NJ BPU 2012
http://www.njcleanenergy.com/renewable-energy/project-activity-reports/installation-summary-by-technology/wind-biopower-and-fuel-cell-installation-reports

The technical potential for inland hydropower in NJ is low compared to other US states - about 126 MW of technical potential for inland hydropower and about 975 MW of ocean wave hydropower potential.

- There is about 126 MW of technical potential for inland hydropower in NJ and about 975 MW of ocean wave hydropower potential.
- The available wave resource for the East Coast (ME to FL) is about 260 TWh/year of which 5-8% are in NJ.
- Ocean hydro technologies are in various stages of development: tidal barrage is a mature ocean hydropower technology. However, most other technologies are still in the research or demonstration stage.
- Due to lower technology maturity of ocean hydropower systems there is currently limited commercial-scale project cost and performance data.
- Inland hydropower plant costs can range broadly depending on the size and type of the project. However, conventional inland hydro technologies are mature technologies, so installed costs are expected to change moderately in the future as commodity costs change.

Notes: See appendix for potential definitions;

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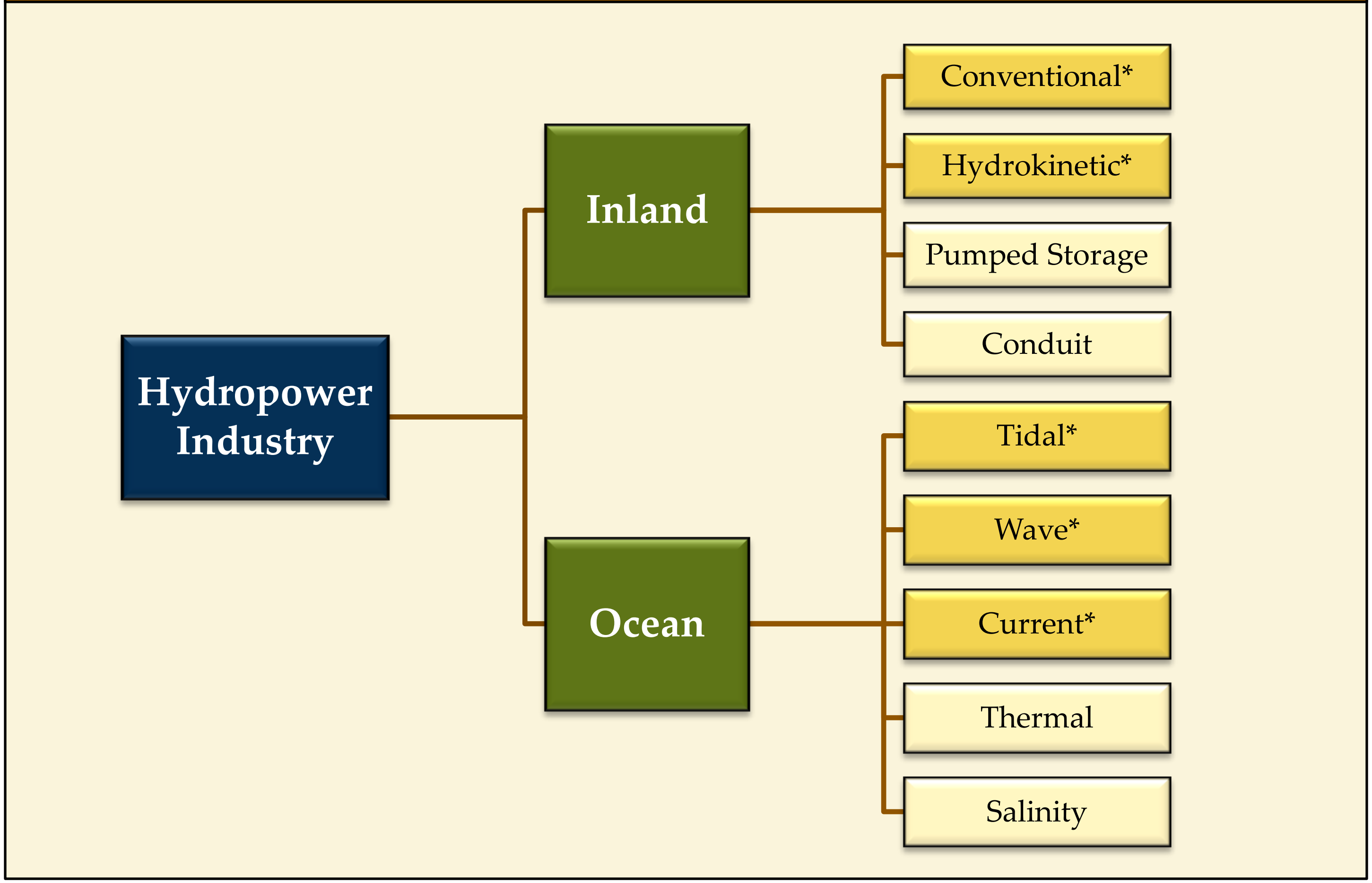
Both inland and ocean hydropower resources and technologies were evaluated.

Hydropower Industry



Hydropower Industry

Inland

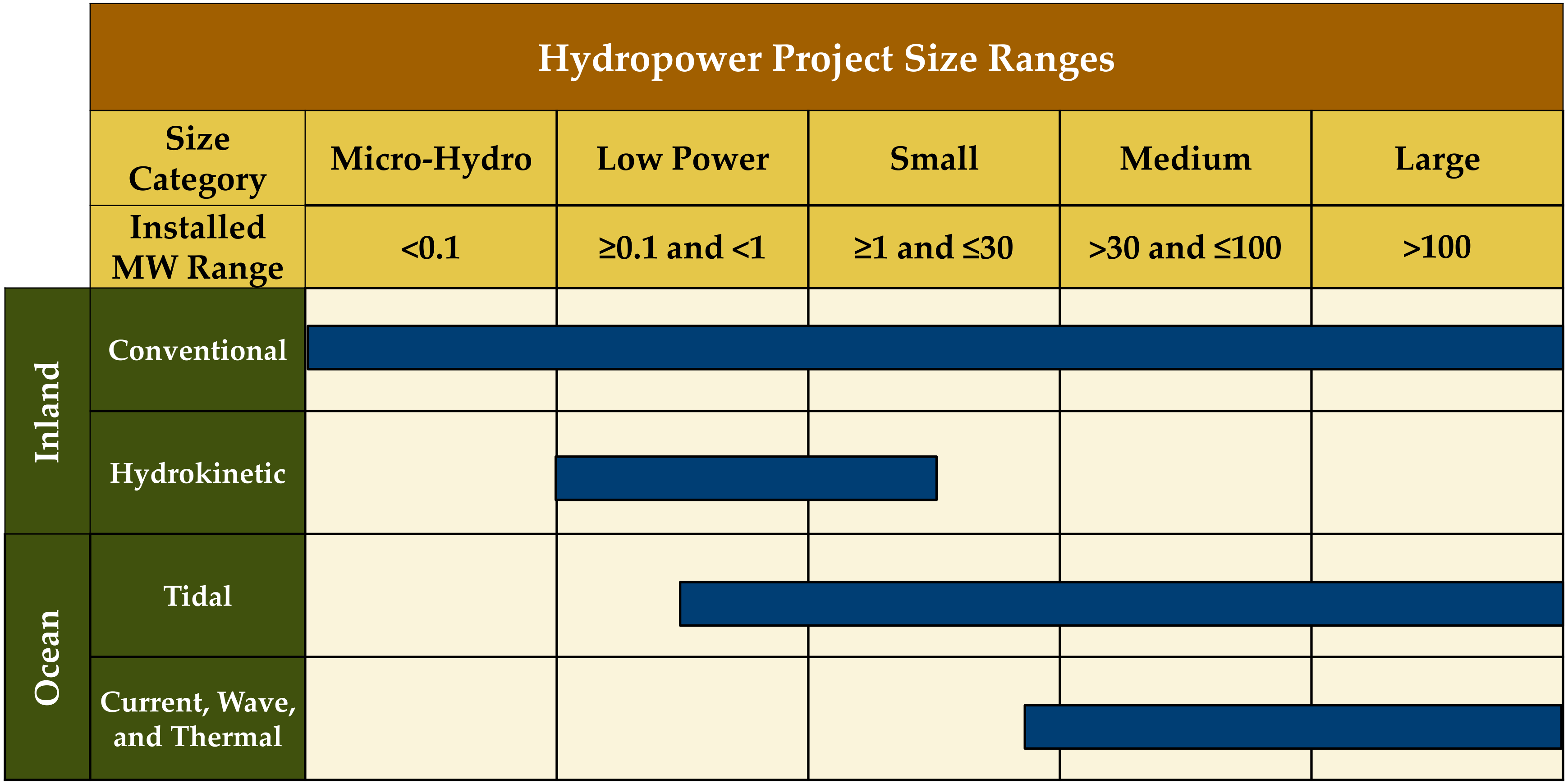
- Conventional*
- Hydrokinetic*
- Pumped Storage
- Conduit

Ocean

- Tidal*
- Wave*
- Current*
- Thermal
- Salinity

Note: Lighter colors indicate (also indicated with *) not considered in this study due to technology maturity or compatibility with NJ state resources.

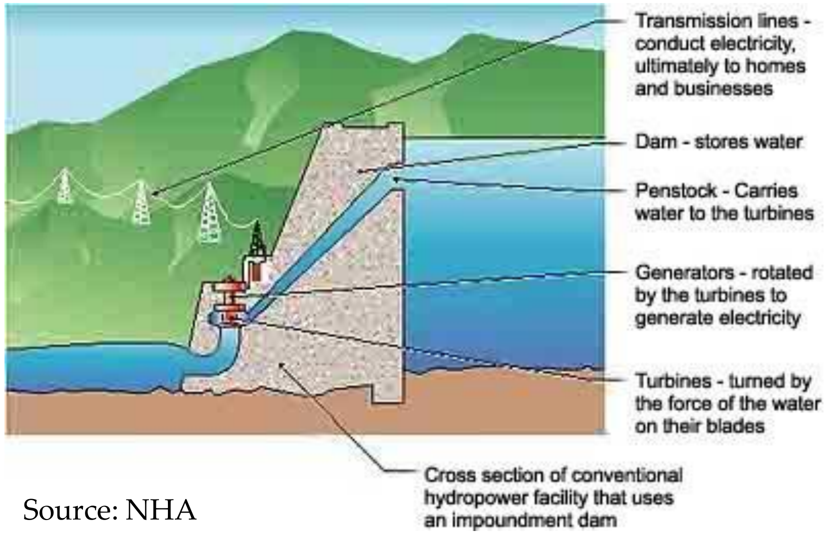
Project sizes are typically grouped as large, medium, small, low power, and micro-hydro by government agencies and developers.



Sources: Electric Power Research Institute; Department of Energy; Navigant report for National Hydro Association, "Job Creation Opportunities in Hydropower", September 2009, http://hydro.org/why-hydro/job-creation/navigant-study/

There are two major categories of inland hydro.

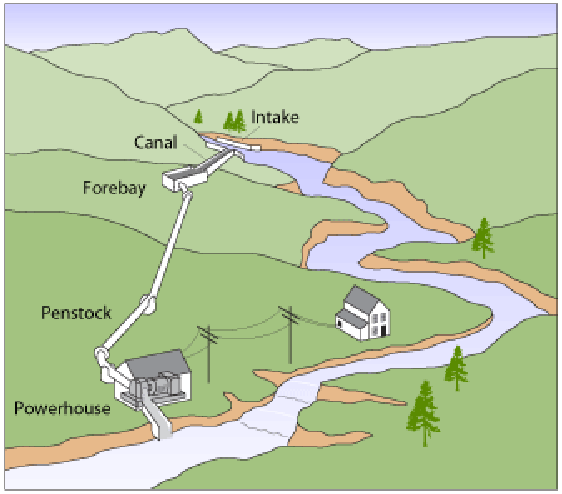
Impoundment



Source: NHA

The most common type of hydroelectric power plant is an impoundment facility. An impoundment facility, typically a large hydropower system, uses a dam to store river water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released either to meet changing electricity needs or to maintain a constant reservoir level

Diversion



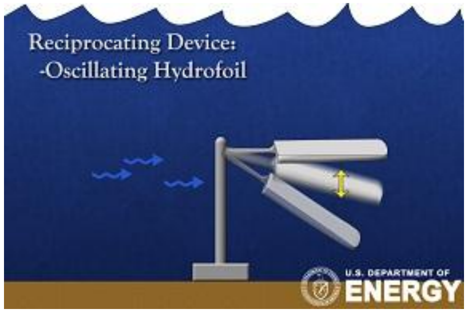
Source: DOE

A diversion, sometimes called run-of-river, facility channels a portion of a river through a canal or penstock. It may not require the use of a dam.

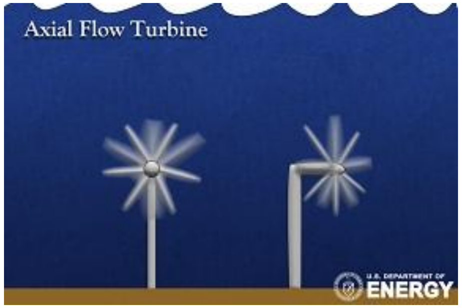
Tidal barrage is a mature ocean hydropower technology. However, most other technologies are still in the research or demonstration stage.

Tidal: Barrage (La Rance, France)

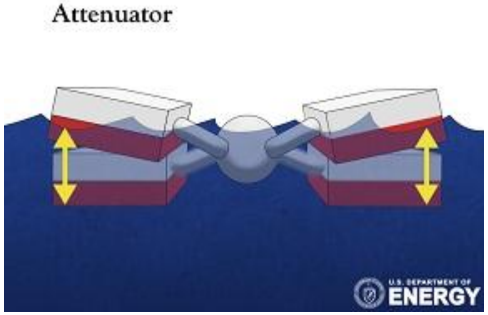
Tidal: In Stream Energy Conversion (TISEC)



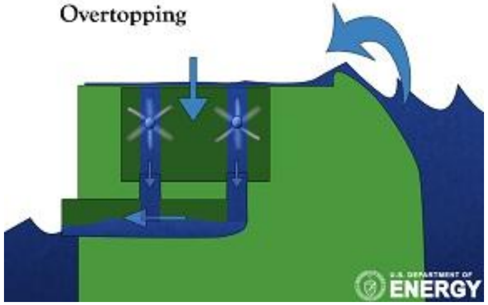
Tidal: Current Turbine



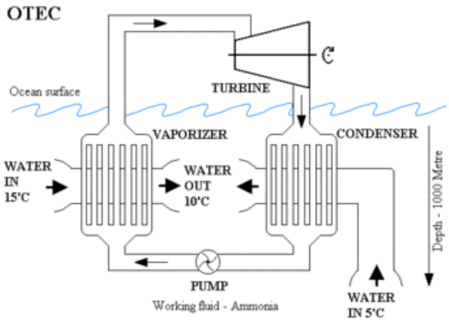
Wave: Attenuator



Wave: Overtopping

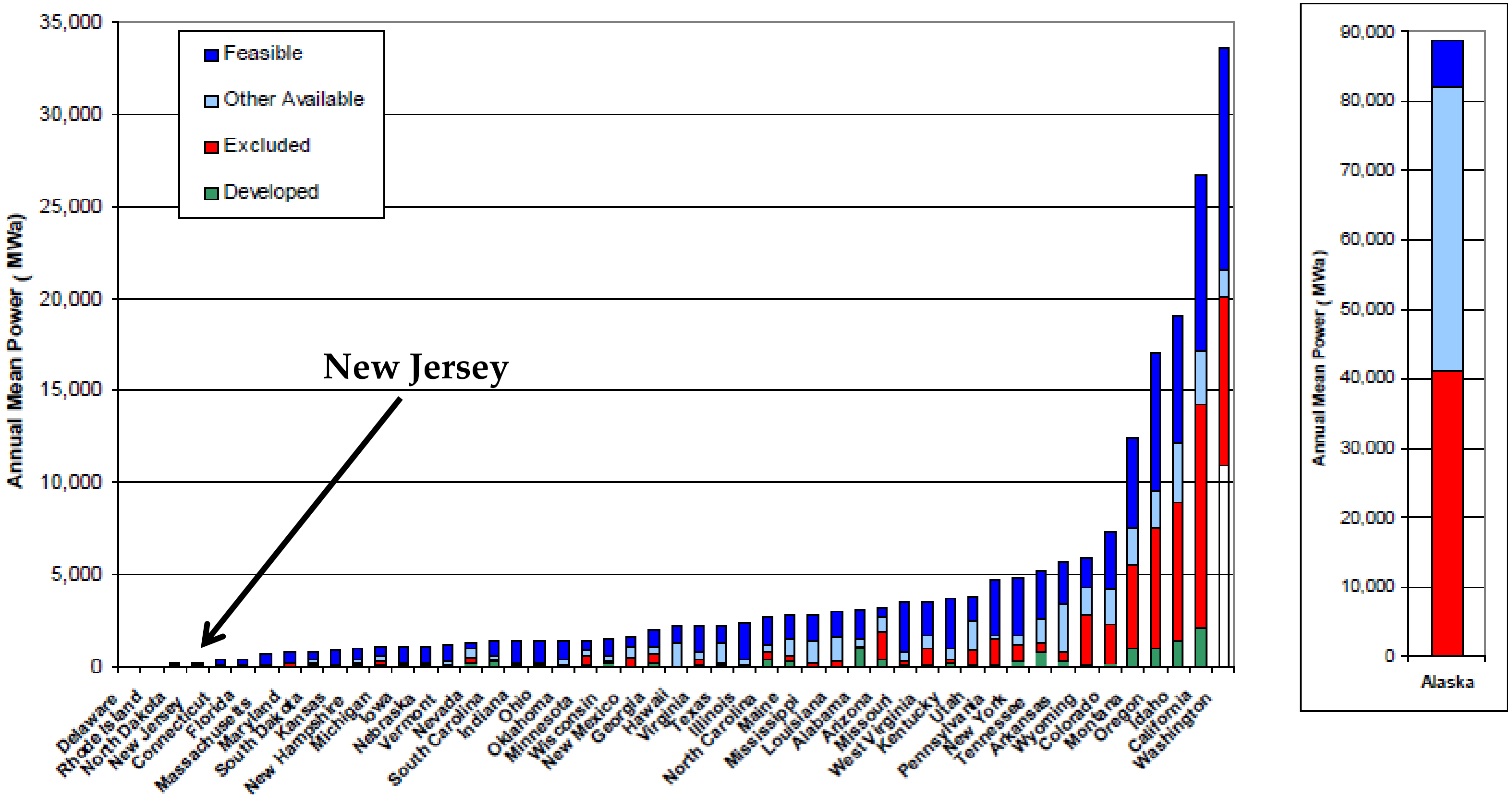


Ocean Thermal Energy Conversion (OTEC)



The theoretical potential* for inland hydropower in NJ is low compared to other US states.

Total Power (Theoretical Potential) Low Power and Small Hydro of US Water Energy Recourses, by State

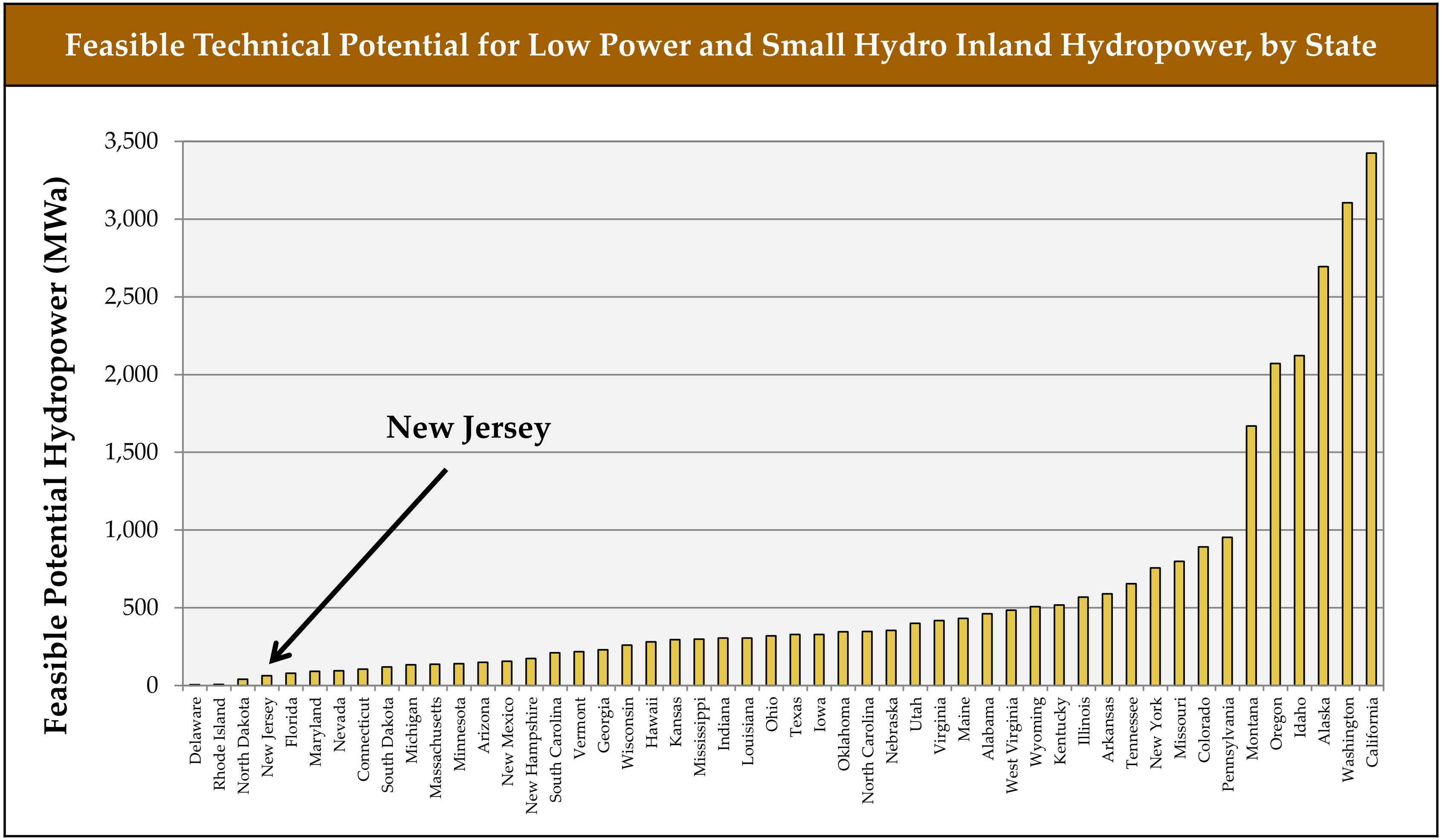


Source: Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants, DOE, 2006

* Theoretical potential includes all the inland resources not taking into account development feasibility.

Note: MWa: MW Annual

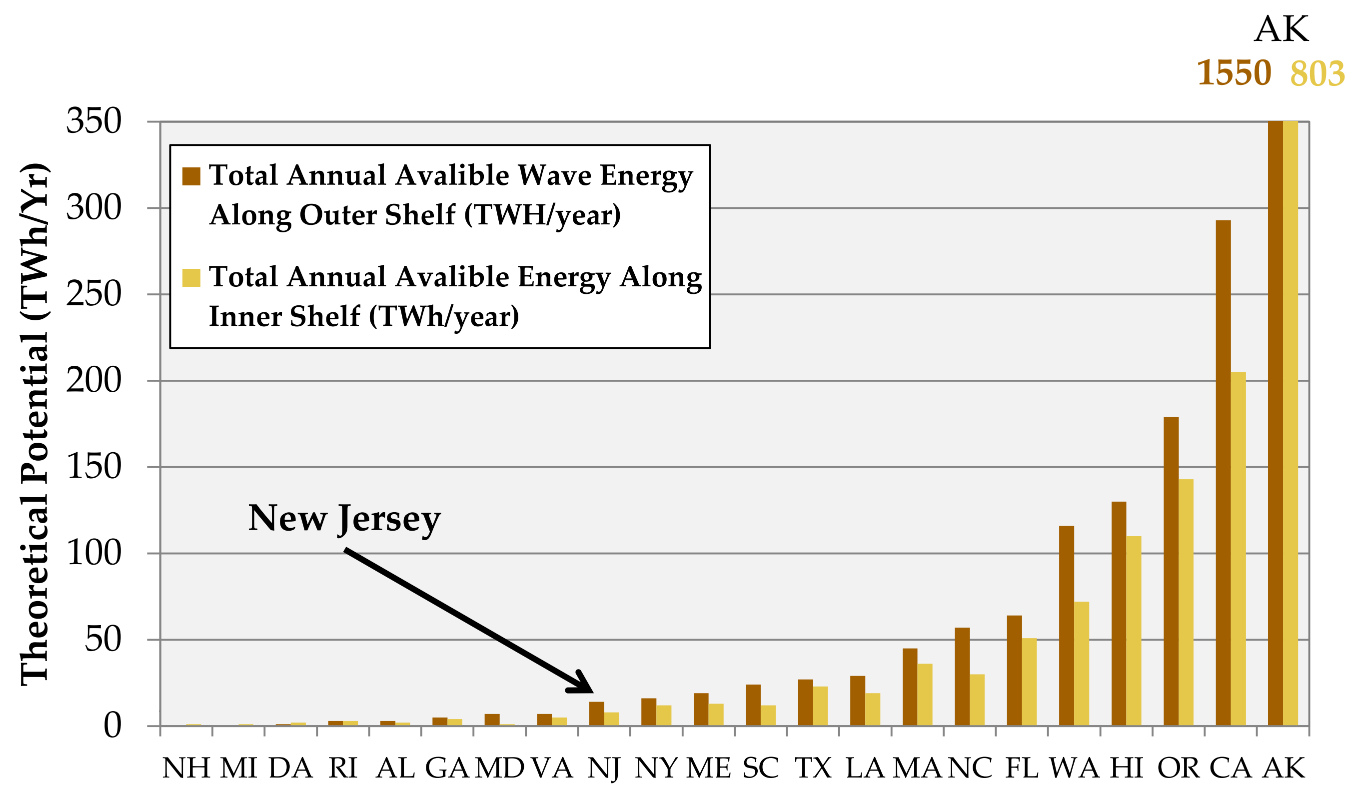
The feasible potential hydropower capacity in NJ is about 65 MW. This is low compared to other US states.



Source: Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants, DOE, 2006 http://www1.eere.energy.gov/water/pdfs/doewater-11263.pdf
* Feasible potential narrows down the overall theoretical potential to include sites that can be developed for hydropower.
Note: MWa: MW Annual

The available wave resource for the East Coast (ME to FL) is about 260 TWh/year. Of this, 3-6% (8-14 TWh/year) are in NJ.

Total Power (Theoretical Potential) of US Wave Energy Recourses, by State



Source: Mapping and Assessment of US Ocean Wave Energy Resource, EPRI, 2011
http://www1.eere.energy.gov/water/pdfs/mappingandassessment.pdf

There is about 126 MW of technical potential for inland hydropower in NJ and about 975 MW of ocean wave hydropower potential.

	NJ Inland Hydropower Technical Potential						
	Size Category	**Micro-Hydro**	**Low Power**	**Small**	**Medium**	**Large**	**Total**
	Installed MW Range	<0.1	≥0.1 and <1	≥1 and ≤30	>30 and ≤100	>100	
Inland	**Conventional**	34		88	-	-	122
	Hydrokinetic						4
Ocean	**Tidal**						-
	Wave						975
	Current						-
	Thermal						-

Note: Areas in black area do not have additional data to support further breakdown.
Sources::

1. National Hydro Association, 2009
2. Electric Power Research Institute; Department of Energy; Navigant report for National Hydro Association, “Job Creation Opportunities in Hydropower”, September 2009, http://hydro.org/why-hydro/job-creation/navigant-study
3. : Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants, DOE, 2006 http://www1.eere.energy.gov/water/pdfs/doewater-11263.pdf
4. Mapping and Assessment of US Ocean Wave Energy Resource, EPRI, 2011 http://www1.eere.energy.gov/water/pdfs/mappingandassessment.pdf

Installed costs can range broadly depending on the size and type of the project.

		Inland Hydro Technology Costs			
		MW Range	**Installed Cost ($/kW)**	**LCOE ($/kWh)**	**Discussion**
Inland Hydro	**Conventional Hydro (impoundment)**	50 MW (avg)	\$1,000-\$5,000	0.04-0.13	• Conventional hydro is a mature technology, cost are expected to change moderately in the future as commodity costs change • The cost of upgrading a site with an existing dam can be <\$1,000/kW while small hydro can be as much as \$4,800/kW. • Higher costs are likely for green field sites which require significant civil works. • Capacity factor was assumed to be 50%
	Microhydro	<0.1	\$4,000-\$6,000	0.12-0.17	• The installed cost for low-impact hydro systems is not expected to decline in the near term
	Run of River (diversion)	~10	\$1,500-\$6,000	0.05-0.25	• Similar to conventional impoundment hydro, installed costs can vary widely and are dependent on commodity costs. • Capacity factor was assumed to be 30-50%

Sources:

1. INL 2003
2. Developer Interviews
3. "Job Creation Opportunities in Hydropower", Navigant, 2009, http://hydro.org/why-hydro/job-creation/navigant-study/
4. Capacity factor estimates for hydrokinetic devices were based on data reported by Argonne National Laboratory. See http://teeic.anl.gov/er/hydrokinetic/restech/scale/index.cfm
5. LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt;

Limited commercial-scale cost data exists for ocean hydropower systems due to lower technology maturity.

		Ocean Hydro Technology Costs			
		Expected Installed Cost	Variable O&M	LCOE ($/kWh)	Discussion
Ocean	Wave	$2.50/W (in year 2020)	$25-$46 /MWh	0.08-0.10	• Based on EPRI report cost estimates for wave development and 2007 interviews with industry representatives, adjusted for inflation and forecast out to 2020 assuming a learning curve cost reduction of 10%-20% each time industry productions doubles • Capacity factor was assumed to be 50%
	Tidal In Stream Energy Conversion (TISEC)	~$3.00/W ($1.00/W - $4.00/W)	$25 /MWh	0.10-0.14	• O&M cost estimates are based on an estimated $1M annual O&M cost for a 15 MW plant operating at 30-45% capacity factor.

Sources:

1. Survey and Characterization, Tidal In Stream Energy Conversion (TISEC) Devices", EPRI, Nov 2005
2. Proceedings of the hydrokinetic and Wave Energy Technologies Technical and Enviromental Issues Workshop. Washington, DC. Oct 2005
3. Discussions with technology and project developers
4. "Job Creation Opportunities in Hydropower", Navigant, 2009, http://hydro.org/why-hydro/job-creation/navigant-study/
5. Capacity factor estimates for hydrokinetic devices were based on data reported by Argonne National Laboratory. See http://teeic.anl.gov/er/hydrokinetic/restech/scale/index.cfm
6. LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt;

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RE in NJ provides storage opportunities; technical potential[1] for RE-related storage is 750 MW for shifting and 52.5 MW for frequency regulation.[2]

Key Points – Storage

- **Renewable Energy Related Storage Applications in NJ**: Based on the amount of intermittent RE installed in NJ, Navigant identified two potential opportunities for storage in the near term (2012 through 2016):
  - Shifting renewable generation to more optimal times of the day
  - Providing some of the additional frequency regulation that may be required with higher levels of intermittent renewable energy
- **Shifting:** For renewable energy shifting in New Jersey, Navigant estimated that the current technical potential for storage is 750 MW, where 250 MW is dependent on offshore wind development and 500 MW is associated with solar PV. Navigant ran a low and high scenario resulting in 375 MW and 1250 MW of current technical potential respectively.
- **Frequency Regulation (FR)**: For the additional FR required due to the growth of intermittent renewables, Navigant estimated that the current technical potential for storage is 52.5 MW, when both offshore wind and solar PV are considered. If only offshore wind is considered the current technical potential for storage falls to 7.5 MW.

NYPA 1.2-MW/7.2-MWh Sodium-Sulfur Battery Facility

1-MW/15-min Beacon Power flywheel in an ISO ancillary service application

1. The current technical potential for storage is defined as the amount of storage that is technically feasible to install based on the opportunities generated by the total installed amount of intermittent renewable in NJ through 2016.
2. These numbers reflect results from the base case, results from a high and low scenario are shown later.

Navigant developed a high-level approach to estimate current technical potential for RE-related storage, since public data were lacking.

Current Technical Potential of RE-related Storage in NJ: Overview of Section

	Scope of Analysis	Relevant Storage Applications	Method for Estimating Potential	Definition of Scenarios	Results of Analysis
Key Question	What was the scope included in the estimates of the current technical potential for storage in NJ?	Which renewable energy-related storage functions are applicable to NJ?	What was the method for estimating current technical potential for storage?	How much intermittent renewable energy was assumed to be installed in NJ by 2016?	What were the results of the analysis?

In this report, the current technical potential for storage is based on opportunities related to the installed base of intermittent RE in NJ.

Scope of Analysis	Included in Scope	Excluded from Scope	Implication of Scope on Results
1. Storage is Related to Intermittent Renewable Energy	This analysis examines storage opportunities that result from of the presence of intermittent renewable energy (e.g., shifting).	This analysis doesn't estimate the opportunity for other types of storage applications in NJ.	
2. Estimate is Based on Current Technical Potential	The current technical potential for storage is defined as the amount of storage that is technically feasible to install based on the opportunities generated by the total installed amount of intermittent renewable in NJ through 2016.	Since this analysis is being performed for the near-term, it doesn't consider how the technical potential will change beyond 2016. This is the reason for using the term "current" technical potential in this report.	• The current technical potential will increase over time as the installed base of intermittent renewable energy expands in NJ. • This analysis will need to be revised when the installed base of RE expands a meaningful amount.
3. Estimate is Geographically Bounded to New Jersey	Only intermittent renewable energy and storage capacity installed within NJ was considered.	Intermittent renewable energy and storage within the rest of PJM wasn't considered. The amount of RE and storage elsewhere in the PJM system will likely impact the current technical potential for storage in NJ since the electricity market is not confined to NJ's boarders.	• Since RE and storage throughout PJM will ultimately impact the opportunities for storage in NJ, the following should be considered: – The current technical potential for storage in NJ could be higher if storage located in NJ could provide services based on the needs generated by intermittent renewable energy systems elsewhere in PJM – Conversely, storage systems elsewhere in PJM could likewise reduce the current technical potential for storage in NJ.

Storage applications can be organized into 3 categories based on grid benefits: load leveling, grid operational support and grid stabilization.

Grid-tied Storage Applications		Benefits														
		Economic										Reliability		Environmental		
		Market Revenue			Asset Utilization					Efficiency	Cost	Interruptions		Air		Water
		Arbitrage Revenue	Capacity Revenue	Ancillary Service Revenue	Optimized Generator Operation	Reduced Congestion Cost	Deferred Generation Capacity Investments	Deferred Transmission Capacity Investments	Deferred Distribution Capacity Investments	Reduced Electricity Losses	Reduced Electricity Cost	Reduced Outages	Improved Power Quality	Reduced CO_2 Emissions	Reduced SO_X, NO_X, and Particulate Emissions	Reduced Water Use
Load Leveling	Renewable Energy Shifting	X			X	X	X	X	X	X	X			X	X	X
	Wholesale Market & Cost Optimization	X			X	X	X	X	X	X	X			X	X	X
	Retail Market				X	X	X	X	X	X	X			X	X	X
	Asset Management				X	X	X	X	X	X				X	X	
Grid Operational Support	Operating Reserves			X	X		X							X	X	X
	Load Following			X	X		X							X	X	X
	Frequency Regulation			X	X		X							X	X	X
	Renewable Energy Firming		X													
	Black Start			X			X									
Grid Stabilization	Renewable Energy Ramping				X		X							X	X	X
	Renewable Energy Smoothing				X									X	X	X
	Backup Power											X				
	Bridging Power												X			

Source: "Valuing Electricity Storage in Utility Applications", Navigant Consulting, ESA Annual Meeting Workshop, May 2, 2012

Of the 13 storage functions, 5 can support RE energy expansion – shifting, frequency regulation (FR), firming, ramping and smoothing.

Categories	Applicati-ons	Description of how storage is used to support renewable energy
Load Leveling	Shifting	This application involves storing electricity from renewable sources when the price of electricity is low and discharging that stored electricity when the price of electricity is high. The energy that is discharged from energy storage could be sold via the wholesale market, sold under terms of a power purchase agreement, or used by an integrated utility to reduce the overall cost of providing generation during peak times. Shifting can also be used to over come transmission constraints.
Grid Operational Support	Frequency Regulation	Called an ancillary service, frequency regulation is dispatched to reconcile momentary differences between supply and demand. This service is provided by on-line generation equipped with automatic generation control (AGC) that can change output quickly to track the moment-to-moment fluctuations in customer loads and correct for the unintended fluctuations in generation. The demand for frequency regulation can increase with the share of intermittent renewable energy. Energy storage facilities can also provide frequency regulation services, often with a more rapid response time than conventional generation.
	Firming	Firming involves using ES to guarantee a dispatchable source of capacity. In a deregulated market, this energy storage could possibly be used to earn a capacity credit. This market for firming energy is still evolving, and in some markets generation capacity cost is included in wholesale energy prices.
Grid Stabilization	Ramping	As renewable generation penetration increases, the electricity grid stabilization requirements for ramping will also increase. Ramping involves using energy storage to mitigate the volatility in sudden load changes, including sudden changes in wind speed, low wind conditions and high wind cutout.
	Smoothing	Storage can provide smoothing capability on a second- by-second basis when a renewable energy system's output varies over a short period of time due to intermittent cloud cover or wind speed volatility, improving power quality.

Source: "Valuing Electricity Storage in Utility Applications", Navigant Consulting, ESA Annual Meeting Workshop, May 2, 2012

Navigant identified renewable shifting and FR as the 2 main storage applications that can support near-term NJ renewable energy expansion.

Categories	Applications	Possible Fit for NJ in Near-Term? [1]	Discussion
Load Leveling	**Shifting**	Y	• Renewable energy shifting could be useful if wind resources would otherwise be spilled or if there are congestion issues.
Grid Operational Support	**Frequency Regulation**	Y	• PJM has a frequency regulation market with some of the most attractive pricing nationally. • Increased integration of intermittent renewable energy sources may result in increased need for frequency regulation. • However, the frequency regulation market is relatively small, and narrowing it to NJ makes it even smaller.
	Firming	N	• Renewable energy firming is still fairly conceptual. It remains to be seen whether storage can qualify for a capacity credit or if it can increase the capacity credit of a renewable resource.
Grid Stabilization	**Ramping**	N	• Regulatory mandates for renewable energy ramping and smoothing are not currently in place in NJ. • Ramping and smoothing are generally not a significant concern until renewable resources reach a relatively high penetration level (e.g. 20%).
	Smoothing	N	

[1] For the purposes of this study, we consider "near-term" the years 2012 – 2016.

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Navigant developed a high-level approach to estimate current technical potential for RE-related storage for shifting and FR due to lack of existing public information.

Navigant Methodology

Renewable Energy Shifting

1. Estimated total installed intermittent renewable energy in New Jersey, including solar PV and wind.
2. Developed ratios to define the amount of storage used at renewable energy facilities where renewable energy shifting is performed. Based ratios on studies and existing facilities. Also considered the type of shifting that may be required in New Jersey based on the wind profile and potential transmission constraints within the state.
3. Estimated the potential for storage to provide renewable energy shifting in New Jersey based on the results of the two steps above.

Frequency Regulation (related to increased renewables)

1. Estimated total intermittent renewable energy, including solar PV and wind
2. Estimated the amount of conventional FR required in NJ, as a reference
3. Developed relationships for the amount of additional FR required for additional intermittent RE in NJ
4. Estimated the amount of additional RE-related FR that may be required in NJ
5. Estimated the potential for storage to provided the additional RE-related FR

Since the installed capacity of PV and wind is a key input for the current technical potential of RE-related storage, Navigant developed 3 scenarios.

Scenarios: Installed Intermitted RE in NJ through 2016			
Scenario Name	Solar PV (MW)	Wind (MW)	Assumptions
Low	1,500	0	• Current rate of solar uptake slows • Stalled off-shore wind development
Base	2,000	500	• Current rate of solar uptake continues • Progress with off-shore wind development
High	3,000	1,000	• Current rate of solar uptake increases • proposition to end-customers • Initial off-shore wind development targets met on time

Note: Additional detail on how these estimates were derived is found in the Appendix.

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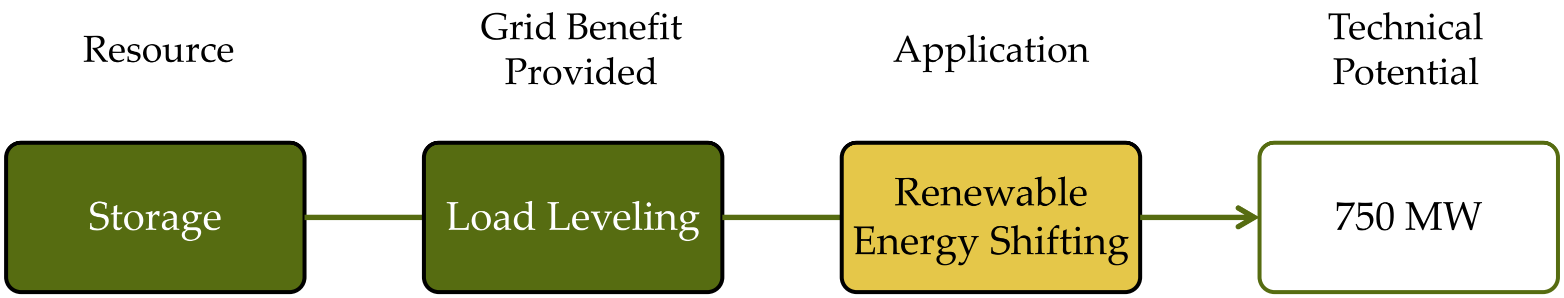
Current technical potential for storage in NJ to support RE energy expansion is 750 MW for shifting, assuming the base case.

Current Technical Potential of Storage in NJ to Provide RE Shifting[1]


Resource

Grid Benefit Provided

Application

Technical Potential

Storage

Load Leveling

Renewable Energy Shifting

750 MW

Overview of Analysis

- The installed base of intermittent renewable energy in NJ is 780 MW, predominately solar PV; with 1,000 MW of planned offshore wind.
- For the purpose of estimating the near-term technical potential for RE-related storage, Navigant assumed 2,000 MW of installed solar PV and 500 MW of offshore wind would be installed by 2016.
- Based on a review of cases where storage is being used for shifting, Navigant assumed that storage capacity equivalent to 50% of offshore wind and 25% solar PV nameplate capacity in NJ can be installed for shifting.
- Using the assumptions above, Navigant estimated a storage potential of 750 MW for RE shifting NJ; 250 MW is dependent on offshore wind development and 500 MW on solar PV.

Note: Additional detail on how these estimates were derived is found in the Appendix.

For the low and high cases, Navigant estimated current technical potential of 375 MW and 1250 MW for RE shifting in NJ, respectively.

Current Technical Potential of Storage in NJ to Provide RE Shifting - Scenarios

		MW RE				MW Storage		
Resource		**Low**	**Base**	**High**	**% storage per MW RE**	**Low**	**Base**	**High**
Wind	**Off-shore**	0	500	1000	50%	0	250	500
Solar PV		1500	2000	3000	25%	375	500	750
Current Technical Potential for Shifting						**375**	**750**	**1250**

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Current technical potential for storage in NJ to provide additional FR requirements due to intermittent RE is 52.5 MW, assuming base case.

Current Technical Potential of Storage in NJ to Provide RE-Related Frequency Regulation[1]

Resource	Grid Benefit Provided	Application	Technical Potential
Storage	Grid Operational Support	Frequency Regulation	52.5 MW

Overview of Analysis[1]

- To estimate additional RE-related FR requirement in NJ, Navigant used a relationship it developed for DOE (which is based on major studies) to estimate the relationship between RE-related FR requirement, wind share of generation, and the nameplate capacity of wind.[2]
- For the base case, Navigant estimated that intermittent RE would represent 4.8% of annual generation in NJ. Based on the relationship mentioned above, a 4.8% share of generation translates to an additional need for FR equivalent to 4.2% of RE nameplate capacity, or 105 MW for Navigant's base case of 2500 MW.
- Technically 100% of this additional FR could be supplied by storage. However, by using fast-following storage to provide FR, the amount of FR required could fall by 50% to 52.5 MW. [3]
- As a reference point to compare the RE-related FR requirement, Navigant estimated to the amount of FR that grid operators are required to have for normal grid operations without considering renewable energy. Navigant estimated that 200 MW of frequency regulation (FR) capacity is required in NJ based on NJ's peak demand of 20,000 MW.

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1. Additional detail on how these estimates were derived is found in the Appendix.
2. Navigant Consulting analysis of wind integration studies performed by Oak Ridge National Laboratory (ORNL), the New York Independent System Operator (NYISO) and the California Independent System Operator (CAISO) (full cites are the in the appendix).
3. KERMIT Study Report, *To determine the effectiveness of the AGC in controlling fast and conventional resources in the PJM frequency regulation market*, December 12, 2011, KEMA. https://www.pjm.com/~/media/committees-groups/committees/mrc/20111221/20111221-item-04-rpstf-kema-study-report.ashx

However, current technical potential could be as low as 7.5 MW (base case/wind only scenario) and as high as 108 MW (high case scenario).

Current Technical Potential of Storage in NJ to Provide RE-Related Frequency Regulation - Scenarios

Item	Scenarios				Comments
	Low	Base, wind only[1]	Base	High	
Additional FR (MW)	51	15	105	216	• See estimate of the need for additional frequency regulation in the appendix.
Reduction in the FR based on use of Storage	50%	50%	50%	50%	• A recent study commissioned by PJM showed that frequency regulation requirements could be cut in half if fast-response storage was used instead of conventional generators. *(KERMIT Study Report, December 12, 2011, KEMA)*
Current Technical Potential for Storage (MW)	**25.5**	**7.5**	**52.5**	**108**	

1. Navigant ran a wind-only case as literature on additional frequency regulation requirements for renewable energy is primarily focused on an increases in wind share.

Navigant and BPU identified 3 types of storage technologies to include in the analysis, flywheels, batteries and flow batteries.

Resources Included in Analysis	Navigant considered the following storage technologies because they are, or are close to being, commercially viable, will work in New Jersey and also are used to integrate renewable resources elsewhere: • Flywheels • Batteries • Flow Batteries
Other Potential Resources (not included in this assessment)	Other storage technologies were not considered because of lack or limited resources in New Jersey: • Pumped hydro • Thermal (solar thermal) • Compressed air energy storage

For frequency regulation a number of storage technologies could provide quick response; for RE shifting battery and flow battery are options.

Application	**Function**	**Storage Technologies**			**Comment**
		Fly-wheel	**Battery**	**Flow Battery**	
Load Leveling	Shifting	○	◑	◑	• Flywheels lack capacity for large-scale shifting of renewable energy loads. • Batteries and flow batteries can provide storage for energy shifting, but at a relatively higher cost than the other bulk storage technologies (pumped hydro and compressed air) that were previously eliminated from the analysis due to resource constraints.
Grid Operational Support	Frequency Regulation	●	◕	◑	• Flywheels and batteries provide quick response to changing grid frequencies. • Flow batteries still require demonstration to validate cycle life and performance.

Excellent Fit				Not A Fit
●	◕	◑	◔	○

Flywheels are a viable small-scale grid storage technology with well understood cost structures.

	Storage – Flywheel[1]	
	2012	Comments
Installed Cost ($/kW)	1,950-2,200	Based on mature flywheel technologies from various manufacturers.
O&M ($/kW-yr)	5-10	
Efficiency	85-87%	
LCOE ($/kWh)[2]	N/A	Depends on the charging costs
Project Life (cycles)	>100,000 cycles	A typical flywheel cycle lasts approximately .25 hours.
Project Life (years)	20	
Federal Incentives	NA	No incentives available for storage
State Incentives	NA	No incentives available for storage

1. EPRI Energy Storage December 2010 with Navigant modifications June 2012. http://www.electricitystorage.org/images/uploads/static_content/technology/resources/ESA_TR_5_11_EPRIStorageReport_Rastler.pdf
2. LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt.

Navigant chose Sodium-Sulfur (NaS) to represent battery technology, as it is a proven grid-scale technology.

	Storage – Battery[1]	
	2012	Comments
Installed Cost ($/kW)	1,700-4,900	Represents a range of costs for various battery storage systems. One example, Sodium-Sulfur, one of the more mature grid-scale battery technologies on the market, ranges from 3100-3300.
O&M ($/kW-yr)	10-50	Example: Sodium-Sulfur range 15-50
Efficiency	75-90%	Example: Sodium-Sulfur efficiency 75%.
LCOE ($/kWh)[2]	N/A	Depends on the charging costs
Project Life (cycles)	2,200-4,500 cycles	Example: Sodium-Sulfur lasts 4500 cycles, with a typical cycle length of 6 hours.
Project Life (years)	15	Based on a Sodium-Sulfur battery (NaS)
Federal Incentives	NA	No incentives available for storage
State Incentives	NA	No incentives available for storage

1. EPRI Energy Storage December 2010 with Navigant modifications June 2012. http://www.electricitystorage.org/images/uploads/static_content/technology/resources/ESA_TR_5_11_EPRIStorageReport_Rastler.pdf
2. LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt.

Navigant chose vanadium redox as the basis for flow battery costs, as it is one of the more mature flow battery technologies on the market.

	Storage – Flow Battery[1]	
	2012	Comments
Installed Cost ($/kW)	1,450-3,700	One example, Vanadium Redox flow battery, one of the more mature flow battery technologies on the market, ranges from 3100-3700.
O&M ($/kW-yr)	10-50	Example: Vanadium Redox range 15-50.
Efficiency	60-75%	Example: Vanadium Redox ranges in efficiency from 65-75%.
LCOE ($/kWh)[2]	N/A	Depends on the charging costs
Project Life (cycles)	>10,000 cycles	Standard across flow battery technologies, with a typical cycle length of 5 hours.
Project Life (years)	➢ 15	Based on a Vanadium Redox flow battery
Federal Incentives	NA	No incentives available for storage
State Incentives	NA	No incentives available for storage

1. EPRI Energy Storage December 2010 with Navigant modifications June 2012. http://www.electricitystorage.org/images/uploads/static_content/technology/resources/ESA_TR_5_11_EPRIStorageReport_Rastler.pdf
2. LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt.

Agenda

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Current technical potential in NJ for renewable fuel cells at wastewater and landfill is 22 MW; potential could be higher if other markets are included.

Key Points – Fuel Cells

- **Standard vs. Renewable Fuel Cell Potential**: The majority of potential for fuel cells in New Jersey is for fuel cells operating on standard fuel (i.e., natural gas). For example, based on the NJ FC Report there is a current market potential of 223 MW for standard fuel cells and 1 MW for those fueled by renewable fuel.
- **Current Technical Potential for Renewable Fuel Cells**: The current technical potential for fuel cells operating directly at sites with renewable fuel, including wastewater treatment plants and landfills, is 22 MW.
- **Additional Market Segments to Consider**: Additional potential for renewable-fuel fuel cells may be found at facilities with food and animal waste using anaerobic digesters to produce the renewable fuel.

Photo from FuelCell Energy, Spotlight on the City of Tulare, CA fuel cell at a wastewater treatment plant.

Note: Three terms referring to potential are used throughout the fuel cell section (current theoretical potential, current technical potential, and current market potential). These terms are defined on the following slide.

The terms *current theoretical potential, current technical potential*, and *current market potential* are defined for the fuel cells section.

Definitions	
Current Theoretical Potential	The current theoretical potential for fuel cells is based on the total number of physical sites where a fuel cell system could be installed. This is unlike renewable resources like wind, solar, biomass, and hydro, for which the theoretical potential is based on the availability of the resource. Unlike other renewable resources that generally have a fixed theoretical potential, the current theoretical potential for fuel cells will change as the number of possible sites changes. For example, wastewater treatment plants are one of many types of locations where fuel cells can be installed. Since New Jersey currently has 51 wastewater treatment plants, the current theoretical potential is based on these 51 sites.
Current Technical Potential	The current technical potential for fuel cells is the total number of sites in New Jersey where it would be technically feasible to site a fuel cell. For example, New Jersey currently has 51 wastewater treatment plants. A technical limitation of anaerobic digesters is the requirement of a flow greater than 3 million gallons per day to collect and use the methane. Eighteen of the 51 facilities have the required flow rate. Therefore, the current technology potential is based on these 18 sites.
Current Market Potential	The current market potential is derived by reducing the current technical potential based on a number of factors that account for how realistic it is that in today's market condition the site will be developed to include a fuel cell system. The types of factors considered are relative cost attractiveness, the regulatory environment and ease of installation.

The current technical potential in NJ was based on results from the 2012 NJ Hydrogen Fuel Cell and Development Plan (NJ FC Report).

Approach

- Navigant based the potential estimates on the results of the *2012 NJ Hydrogen and Fuel Cell Industry Development Plan*.
- Navigant completed calculations to convert total number of sites identified in the report to a total capacity estimate in MWs and to define an upper potential range for renewable-fuel fuel cells.
- The *2012 NJ Hydrogen and Fuel Cell Development Plan* included a number of key assumptions:
  - The number of potential sites was based on a number of factors, including an assumption that 25% of the possible renewable fuel sites would potentially be developed.
  - There were no sites considered feasible for renewable fuels outside of wastewater treatment plants and landfills.
  - The potential focus was on fuel cells with an installed capacity between 300 to 400 kW.

Key Data Sources

Potential:

- *2012 NJ Hydrogen and Fuel Cell Industry Development Plan*[1]
- Discussions with Andrew Brzozowski and Alexander Barton at the Connecticut Center for Advanced Technology (authors for the NJ FC Report)

Costs:

- Connecticut Center for Advanced Technology
- Clean Energy States Alliance
- U.S. Department of Energy

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[1] Clean Energy States Alliance and Northeast Electrochemical Energy Storage Cluster. “2012 – Hydrogen and Fuel Cell Development Plan: New Jersey.” April 10, 2012. Available at http://neesc.ccat.us/publications/development_plans.

Navigant considered fuel cells for large commercial and industrial applications because of project economics and available infrastructure.

Fuel Cell Applications		Included in study?	Comment
Stationary	**Large Commercial and Industrial**	Y	Included in the study due to project economics and available infrastructure.
	Small Commercial and Residential	N	Smaller fuel cell applications can be very expensive and the economics can make the smaller projects challenging. Therefore, Navigant did not consider fuel cells at small commercial or residential sites in this study.
Transportation		N	No public hydrogen fueling stations currently exist in New Jersey, according to a Fuel Cells 2000 list. In addition, infrastructure would need to be installed in NJ to produce hydrogen from renewable sources (e.g, wind or solar electricity is used to split water through electrolysis, the hydrogen is stored and available as a vehicle fuel). Because of the lack of fueling stations, fuel cells in a transportation application were not considered in this study.
Portable Power		N	These smaller fuel cells used for military applications, external battery chargers and portable electronics are considered out of the scope of this project.

Based on the NJ FC Report, Navigant estimated a current market potential of 223 MW for standard fuel cells and 1 MW for RE fuel cells.

Large Commercial and Industrial NJ Fuel Cell Potential
(Based on Assumptions in NJ FC Report)

Large Commercial and Industrial Fuel Cell Market Segments	Total Sites (#)	Potential Sites (#)	Fuel Cells Per Site	MW Per Fuel Cell	Current Theoretical Potential[1] (MW)[2]	Current Market Potential (MW)[3]
Fuel cells using standard fuel (i.e., natural gas)	**31,465**	**1,456**	**NA**	**NA**	**8,041**	**223**
Food Sales	10,000	311	1	0.3	3,000	93.3
Lodging	1,511	246	1	0.3	453	73.8[4]
Energy Intensive Industries	1,207	121	1	0.3	362	36.3
Impatient Healthcare	822	81	1	0.3	247	24.3
Food Service	13,000	79	1	0.3	3,900	23.7
Education	3,778	73[3]	1	0.3	1,133	21.9
Public Order and Safety	860	35	1	0.3	258	10.5
Government Owned Buildings	181	11	1	0.3	54	3.3
Military	5	5	1	0.3	2	1.5
Airports	101	4	1	0.3	30	1.2
Fuel cells using renewable fuels	**72**	**3**	**NA**	**NA**	**21**	**0.9**
Wastewater Treatment Plants	51	2	1	0.3	15	0.6
Landfill Methane	21	1	1	0.3	6	0.3

[2] Navigant calculations based on numbers reported in the NJ FC Report.

[3] NJ FC Report. Values are for potential sites and are assumed to be the market potential based on the report descriptions and discussions with the authors of the report.

[4] Value does not match the NJ FC Report. The values were changed for mathematical consistency with other sectors as there was no explanation in the text for the inconsistency.

The NJ FC Report estimates a current market potential of 223 MW for large commercial and industrial applications.

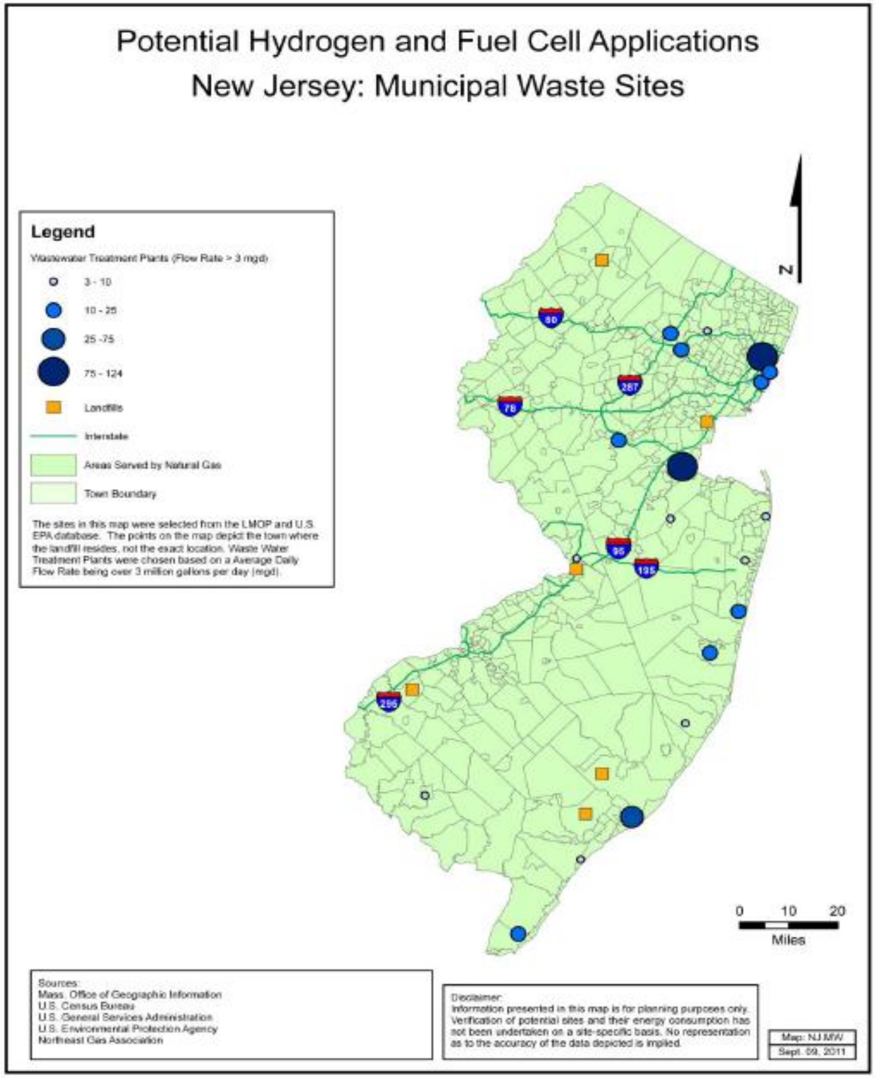
NJ: Current Market Potential for Fuel Cells Operating on Standard Fuel	
Current Market Potential	• There is **223 MW** of current market potential capacity for fuel cells operating on standard fuel (i.e., natural gas).
Potential Market Segments	• The potential market segments for standard fuel cells in New Jersey includes sectors that have a need for thermal energy or have high electrical consumption.
Need for Thermal Energy	• Utilizing the waste heat from the fuel cell can increase the system efficiency and reduce facility energy costs. • Thermal energy can be used for hot water, space heating, or steam for manufacturing needs.
High Electrical Consumption	• Most fuel cells need to run on a 24x7 schedule because ramp-up and ramp-down times can be significant. Commercial and industrial market segments with high electricity consumption make good target markets for standard-fuel fuel cells. High electricity consumption leads to larger fuel cell installations and better project economics. • In NJ, these market segments include food sales, energy intensive industries (manufacturing), impatient health care, food service, education, public order and safety and lodging.

According to the NJ FC Report, current market potential for RE-fueled fuel cells is 1 MW; siting is limited to 2 wastewater plants and 1 landfill.

NJ: Current Market Potential for Fuel Cells Operating on Renewable Fuel	
Current Market Potential	• There is **1 MW** of current market potential capacity for fuel cells operating directly at sites with renewable fuel.
Potential Market Segments	• The potential renewable fuel market segments in New Jersey include wastewater treatment plants and landfills.
Wastewater Treatment Plants	• Digester gas produced at the plants contains about 60% methane and can be used to power a fuel cell. • Wastewater treatment plants typically operate 24x7. • There are 51 wastewater treatment plants in New Jersey with design flows ranging from 12,000 gallons per day – 124 million gallons per day (MGD). • Only 2 of the 51 wastewater treatment plants were deemed potential sites in the NJ FC Report. • The heat produced by the fuel cell may be used to optimize the anaerobic digestion process.
Landfills	• The U.S. Environmental Protection Agency has identified 21 landfills in New Jersey through the Landfill Methane Outreach Program.[1] • The methane produced at the landfill can be used as fuel for a fuel cell. Of the total sites, 15 are operational and 1 is considered a potential site.

[1] EPA. "Landfill Methane Outreach Program." www.epa.gov/lmop/basic-info/index.html. April 7, 2011 (Source from the NJ FC Report)

In NJ there are 51 wastewater treatment plants and 21 landfills. These facilities are spread across the state.


Potential Hydrogen and Fuel Cell Applications
New Jersey: Municipal Waste Sites

The sites in this map were selected from the LMOP and U.S. EPA database. The points on the map depict the town where the landfill resides, not the exact location. Waste Water Treatment Plants were chosen based on a Average Daily Flow Rate being over 3 million gallons per day (mgd).

Sources:
Mass. Office of Geographic Information
U.S. Census Bureau
U.S. General Services Administration
U.S. Environmental Protection Agency
Northeast Gas Association

Disclaimer:
Information presented in this map is for planning purposes only. Verification of potential sites and their energy consumption has not been undertaken on a site-specific basis. No representation as to the accuracy of the data depicted is implied.

Key

- ● (Blue dots) : Wastewater facilities
- 🟧 (Orange squares) : Landfills

Source: Clean Energy States Alliance and Northeast Electrochemical Energy Storage Cluster. "2012 – Hydrogen and Fuel Cell Development Plan: New Jersey." April 10, 2012. Available at http://neesc.ccat.us/publications/development_plans.

By refining assumptions in the NJ FC Report, Navigant estimated the current technical potential for RE-fueled fuel cells as 22 MW.

Large Commercial and Industrial NJ Fuel Cell Potential
(Assumptions in NJ FC Report vs. Navigant's Adjustments)

Large Commercial and Industrial Fuel Cell Market Segments	Total Sites (#)	Potential Sites (#)	Fuel Cells Per Site	MW Per Fuel Cell	Current Theoretical Potential (MW)	Current Market Potential (MW)
Fuel cells using renewable fuels (per the NJ FC Report)	**72**	**3**	**NA**	**NA**	**21**	**0.9**
Wastewater Treatment Plants	51	2	1	0.3	15	0.6
Landfill Methane	21	1	1	0.3	6	0.3
Large Commercial and Industrial Fuel Cell Market Segments	Total Sites (#)	Potential Sites (#)	Fuel Cells Per Site	MW Per Fuel Cell	Current Theoretical Potential (MW)	Current Technical Potential (MW)
Fuel cells using renewable fuels (per Navigant additional analysis)	**72**	**22**	**NA**	**NA**	**72**	**22**
Wastewater Treatment Plants	51	18	1	1.0	51	18
Landfill Methane	21	4	1	1.0	21	4

The following page explains the adjustments Navigant made to assumptions in the NJ FC Report to develop an estimate of current technical potential.

To estimate current technical potential, Navigant assumed 1 MW for an average fuel cell installation (vs. 300 kW) and included more sites.

Navigant's Adjustments to Estimate Technical Potential	
Current Market vs. Technical Potential	• The NJ FC Report estimated a current market potential for fuel cells in NJ. Navigant's study is of current technical potential. • To arrive at potential sites, the NJ FC Report reduced their total sites (wastewater treatment plants and landfills) based on a combination of factors including cost, ease of installation, and a 25% realism factor. Therefore, the estimate of potential sites in the NJ FC Report is closer aligned with an assumed current market potential. The true current technical potential is likely higher than the estimates in the NJ FC Report.
Average Size of Fuel Cell Installation	• The NJ FC Report assumes a fuel cell capacity of 300 kW per site. However, the installation may be larger depending on the site. The Navigant analysis assumed an average of 1 MW per site. This is in-line with national data which shows the average fuel cell installation moving from 250 kW in 2005 to close to 1 MW in 2010. (Source: Clean Energy States Alliance. "Fuel Cells: Briefing Papers for State Policymakers." August 2011)
Wastewater Treatment Plants	• Anaerobic digesters generally require a wastewater flow rate of greater than 3 million gallons per day (MGD) to economically collect and use the methane in a fuel cell application. Eighteen wastewater treatment plants in New Jersey have an average wastewater flow rate between 3 – 124 MGD. • The NJ FC Report identified 2 of these 18 wastewater treatment plants as potential sites; however, the potential may be greater depending on the market for fuel cells in New Jersey. • Navigant included all 18 sites with sufficient wastewater flow in the current technical potential.
Landfills	• The NJ FC Report notes that there are four potential landfill sites for the production and recovery of landfill gas. However, the NJ FC Report applies a 25% realism factor to arrive at a market potential of 1 site. • Navigant assumes that for the current technical potential, all four sites can be developed.

The data indicates that the current technical potential for RE-fueled fuel cells could be higher if sites with food and animal waste were also included.

Other Market Segments to Consider

- Other sites outside of wastewater treatment plants and landfills may be candidates for renewable-fuel fuel cells such as sites with food or animal waste.
- For example, an onion processing plant in California uses onion waste in an anaerobic digester to produce biogas for fuel cells on site.
- Navigant believes that the current technical potential for RE-fueled fuel cells, could be higher if sites with food and animal waste were also included.
- A next step for BPU would be examining the potential at these sites.

Onion processing at Gills Onions, Oxnard, California. Source: Biomass Power and Thermal Magazine

Fuel Cell Energy equipment at Gills Onions, Oxnard, California. Source: Biomass Power and Thermal Magazine

Standard fuel cell costs for 2012 are highly dependent on application and fuel cell type; renewable-fuel fuel cells incur additional costs.

	Fuel Cells (2012)
Installed Cost ($/kW)	4,000 - 5,500[1,2,3,4] (1-3 MW systems); 7,000 (300 – 400 kW) Adder for fuel cells at wastewater treatment plants: 500 – 900[4] (1-3 MW)
O&M ($/MWh)	30 -40[1,4]
Electric Efficiency	45% (Lower heating value basis)[1,3]
Total System Efficiency	77% (Lower heating value basis)[3]
Project Life	5-10 year cell stack life, 15-20 year product life[5]
LCOE - Standard fueled fuel cell ($/kWh)	0.09 – 0.14[3,4]
LCOE - Standard fueled fuel cell ($/kWh)	0.15-0.21[3,4]
Federal Incentives	30% of cost up to $1000/kW Federal ITC[6]
State Incentives	$1.00 - $3.00/W (varies by capacity, fuel, and use of CHP)[7]

Sources:

[1] Connecticut Center for Advanced Technology Regional Resource Center. Electric efficiency does not assume use of waste heat.

[2] Clean Energy States Alliance. "Fuel Cells: Briefing Papers for State Policymakers." August 2011.

[3] U.S. DOE. "Fuel Cell Technologies Overview." March 14, 2012. Estimated cost of electricity for a commercial-scale stationary fuel cell running on natural gas with a total system efficiency of 77% (LHV basis) and a system of 1.4 MW.

[4] Navigant research based on manufacturer input.

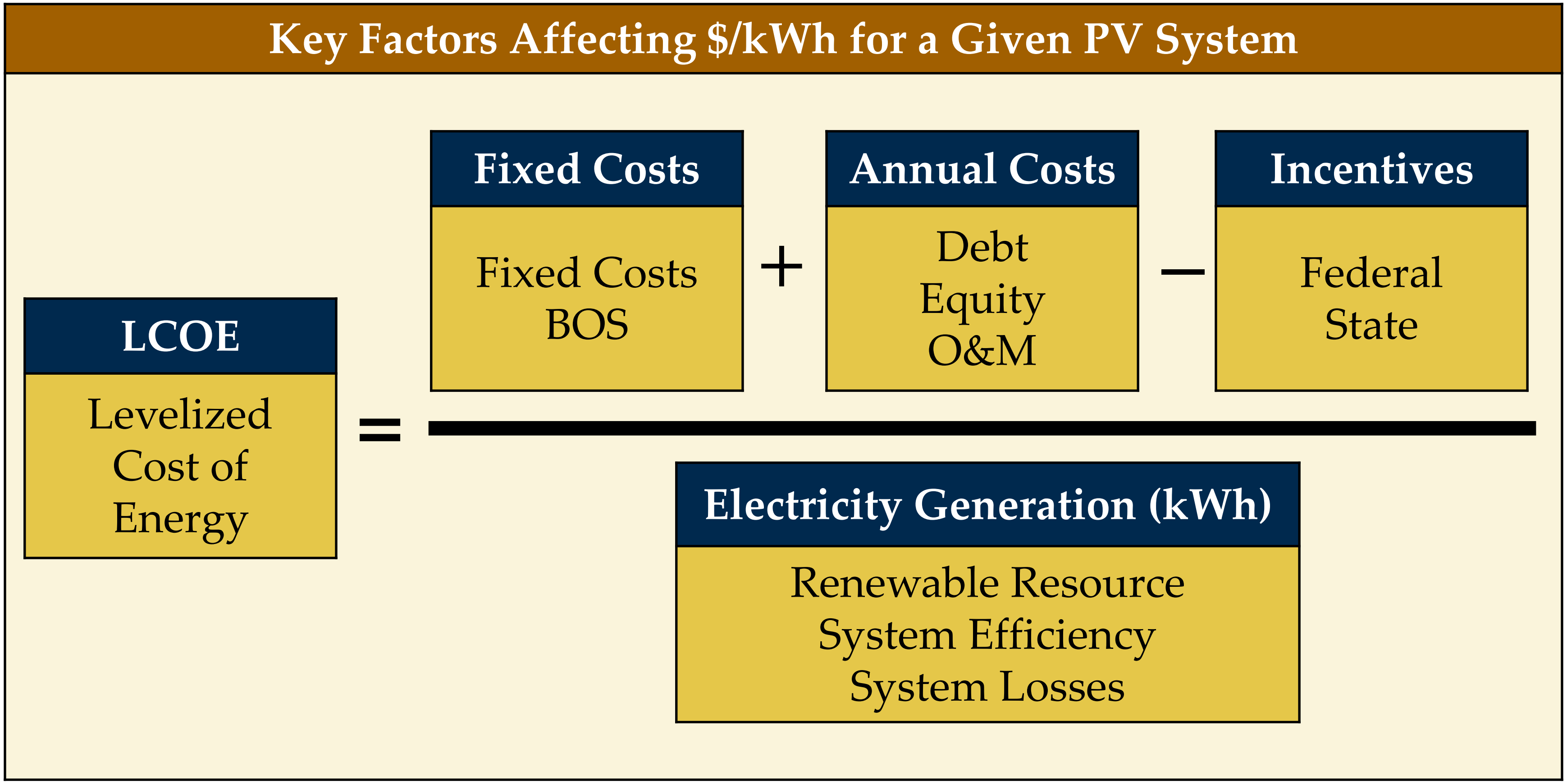
[5] U.S. DOE. "2010 Fuel Cell Technologies Market Report." June 2011.

[6] http://www1.eere.energy.gov/hydrogenandfuelcells/education/pdfs/200810_itc.pdf

[7] http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NJ04F&re=1&ee=1

[8] LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt;

Levelized cost of electricity (LCOE), in $/kWh, is determined by the system cost, O&M, financing considerations, and system performance.



Key Factors Affecting $/kWh for a Given PV System

LCOE

Levelized Cost of Energy

=

Fixed Costs

Fixed Costs
BOS

+

Annual Costs

Debt
Equity
O&M

−

Incentives

Federal
State

Electricity Generation (kWh)

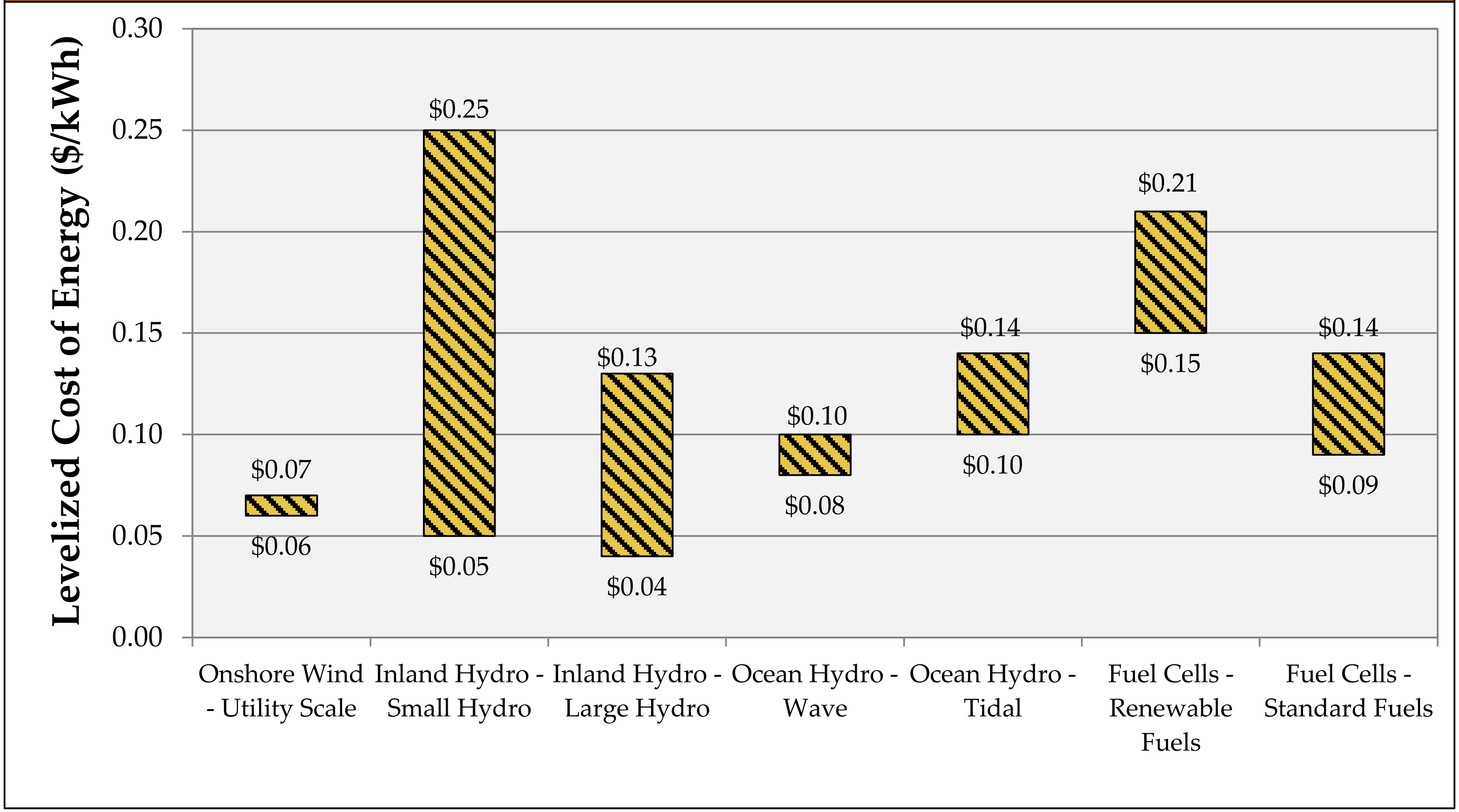
Renewable Resource
System Efficiency
System Losses

Note: LCOE alone has limitations when evaluating technology costs. In cases where the power is sold on the wholesale market rates depend on the time of sale. The availability of the resource will therefore determine the revenue streams.

Note: LCOE calculations were done by Navigant using assumptions detailed in the report.

The levelized cost of energy (LCOE) for the various technologies are presented below.

U.S. Levelized Cost of Electricity (cents per kWh, 2012 $), by Technology



LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt; Assumptions for installation costs, O&M costs, capacity factor, and system efficiency are presented in the technology sections of the report.

Energy storage and inland hydro have the lowest capital requirements. However, site specific requirements can significantly impact costs.

● Good ◒ Fair ○ Poor

		Technology Screening and Results					
		NJ Resource Availability	NJ Current Technical Potential		LCOE ($/kWh)[3]	Installed Costs ($/W)	Analysis Level
Onshore Wind	**Utility Scale**	◒	◒	132 MW	0.06-0.07	1.60-1.70	1
	Customer Sited	◒	◒	▨	▨	▨	2
Inland Hydro	**Small Hydro (≤30MW)**	○/◒	○/◒	126 MW	0.05-0.25	1.50-6.00	1
	Large Hydro (>30MW)	○	○	▨	0.04-0.13	1.00-5.00	2
	Pumped Hydro	○	○	▨	▨	▨	3
Ocean Hydro	**Wave[2]**	◒	◒	975 MW	0.08-0.10	~2.50 (in 2020)	1
	Tidal	◒	◒		0.10-0.14	1.00-4.00	1
Energy Storage[5]	**Fly Wheels**	◒	◒	800 MW[4]	▨	1.95-2.20	1
	Batteries	◒	◒		▨	1.70-4.90	1
	Flow Batteries	◒	◒		▨	1.45-3.70	1
	Compressed Air	○	○	▨	▨	▨	3
	Thermal Energy	○	○	▨	▨	▨	3
Fuel Cells	**Renewable Fuels**	○/◒	○/◒	22 MW	0.15-0.21	Adder: 0.50-0.90	1
	Standard Fuels	◒	◒	223 MW[1]	0.09-0.14	4.00-5.50	2

Analysis Level: 1 – Detailed Market Assessment; 2 – Brief Description; 3 – Not Included

1. Market Potential (see Fuel Cell section for detailed explanation)
2. Ocean Hydro Wave Power LCOE price is estimated price for 2020.
3. LCOE Assumptions: debt rate 8%; equity rate 10%; debt:equity 70:30; 20 years debt; Assumed 2012$
4. NJ Current Technology Potential rates to applications associated with renewable energy applications only.
5. For storage, Navigant only presented the installed costs, as the final LCOE depends on the varying nature of charging costs.

Agenda

NAVIGANT ENERGY

On-shore wind barriers in NJ include land constraints and power quality issues due to the wind resource. Federal policy changes may also increase project costs.

On-shore Wind – Market Barriers

Land Constraints for Large Wind Farms. To achieve most favorable economies of scale, cost estimates assume large scale wind farms that are tens of MWs in size.

- In NJ, large wind farms are less likely due to land constraints in the areas with the best wind resource.
- Smaller sites and clusters of up to 10 MW are more likely to be developed. Such sites will have less opportunity to take advantage of economies of scale resulting in higher installation costs up to 30% higher than large scale wind farms.

Power Output and Reliability issues have also been a challenge for NJ on-shore wind sites as many sites are producing power below stated performance claims.

- This is largely a result of the turbulent nature of the wind resource most common in NJ.

Policy Uncertainty. If both the PTC and ITC expire or are significantly reduced this will negatively impact the wind industry in the US and NJ. Project costs will likely increase making it more difficult to obtain financing for wind projects.

Resource availability is a significant barrier for development of inland hydropower in NJ. Most ocean hydropower systems are still in the early development stages.

Hydropower – Market Barriers

Technology Readiness. Ocean hydro technologies are in various stages of development:

- Tidal barrage is a mature ocean hydropower technology. However, most other technologies are still in the R&D stage.
- Due to the lower technology maturity of ocean hydropower systems, there is currently limited commercial-scale project cost and performance data.
- Inland hydropower plant costs can range broadly depending on the size and type of the project. However, conventional inland hydro technologies are mature technologies, installed costs are expected to change moderately in the future as commodity costs change.

Resource Availability. The technical potential for inland hydropower in NJ is low compared to other US states.

- In NJ there is about 126 MW of technical potential for inland hydropower and about 975 MW of ocean wave hydropower potential.

Much of the current technical potential for storage is dependent on off-shore wind development and widespread adoption of storage with PV.

Energy Storage – Market Barriers

Regulatory Mandates. As renewable generation penetration increases, the electricity grid stabilization requirements for ramping will also increase. Storage can provide smoothing capability when a renewable energy system's output varies over a short period of time due to intermittency, improving power quality. However, regulatory mandates for renewable energy ramping and smoothing are not currently in place in NJ. Ramping and smoothing are generally not a significant concern until renewable resources reach a relatively high penetration level (e.g. 20%).

Asset Classification. The way that the NJ Public Utility Commission decides to classify energy storage (e.g., as a generation asset, transmission and distribution asset, or as it's own asset class) and whether storage can be rate-based will impact whether utilities can deploy storage.

The high cost of fuel cells is one of the main barriers to their wide spread deployment.

Fuel Cells – Market Barriers

High Initial Costs. Costs of fuel cells is one major barrier to their wide spread deployment.

- Project costs vary widely depending on the fuel cell application.
- The varying quality of renewable fuels is highly site dependent and can have a significant impact on the overall installed system costs as well as O&M costs.

Lack of Information about Fuel Cell Value Proposition. The market's knowledge about the value and performance of fuel cells is increasing with fuel cell installations. However, the market (e.g., facility owners, financers, and permitting agencies) still lacks sufficient knowledge about the advantages of fuel cells.

Competing Technologies. Other technologies can also be a barrier to the installation of fuel cells.

Sources: Navigant's research on the California fuel cell market; The Connecticut Center for Advanced Technology, Inc. "Northeast Hydrogen Fuel Cell Industry Status and Direction 2012."

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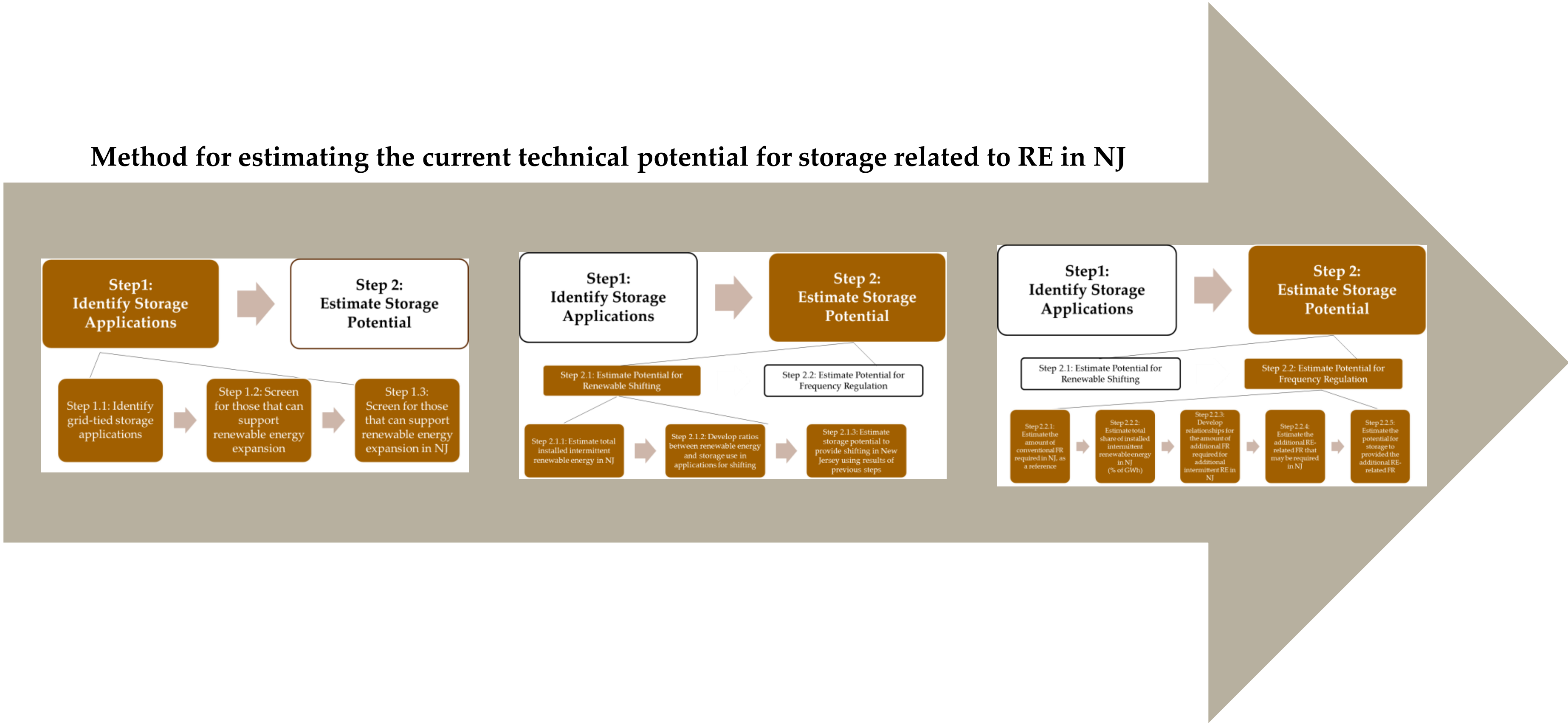
The terms theoretical potential and technical potential are defined below.

Potential Definitions	
Theoretical Potential	The theoretical potential is defined as the rated capacity that could be installed for each technology if 100% of the NJ resource would be developed.
Technical Potential	The technical potential refers to the potential capacity that could be installed on the available area after excluding areas that are unlikely or unfit to be developed. Examples of such areas may include wilderness areas, parks, urban areas, and water features.

Note: in some sections the definitions may vary from the descriptions above. If additional clarification is needed regarding the potential definitions this is done at the beginning of the section.

This section contains further detail regarding how current technical potential was estimated for storage related to RE in NJ.

Method for estimating the current technical potential for storage related to RE in NJ



Step1: Identify Storage Applications

Step 2: Estimate Storage Potential

Step 1.1: Identify grid-tied storage applications

Step 1.2: Screen for those that can support renewable energy expansion

Step 1.3: Screen for those that can support renewable energy expansion in NJ

Step1: Identify Storage Applications

Step 2: Estimate Storage Potential

Step 2.1: Estimate Potential for Renewable Shifting

Step 2.2: Estimate Potential for Frequency Regulation

Step 2.1.1: Estimate total installed intermittent renewable energy in NJ

Step 2.1.2: Develop ratios between renewable energy and storage use in applications for shifting

Step 2.1.3: Estimate storage potential to provide shifting in New Jersey using results of previous steps

Step1: Identify Storage Applications

Step 2: Estimate Storage Potential

Step 2.1: Estimate Potential for Renewable Shifting

Step 2.2: Estimate Potential for Frequency Regulation

Step 2.2.1: Estimate the amount of conventional FR required in NJ, as a reference

Step 2.2.2: Estimate total share of installed intermittent renewable energy in NJ (% of GWh)

Step 2.2.3: Develop relationships for the amount of additional FR required for additional intermittent RE in NJ

Step 2.2.4: Estimate the additional RE-related FR that may be required in NJ

Step 2.2.5: Estimate the potential for storage to provided the additional RE-related FR

Navigant first identified the storage applications that support expansion of renewable energy in NJ, and then estimated their technical potential.

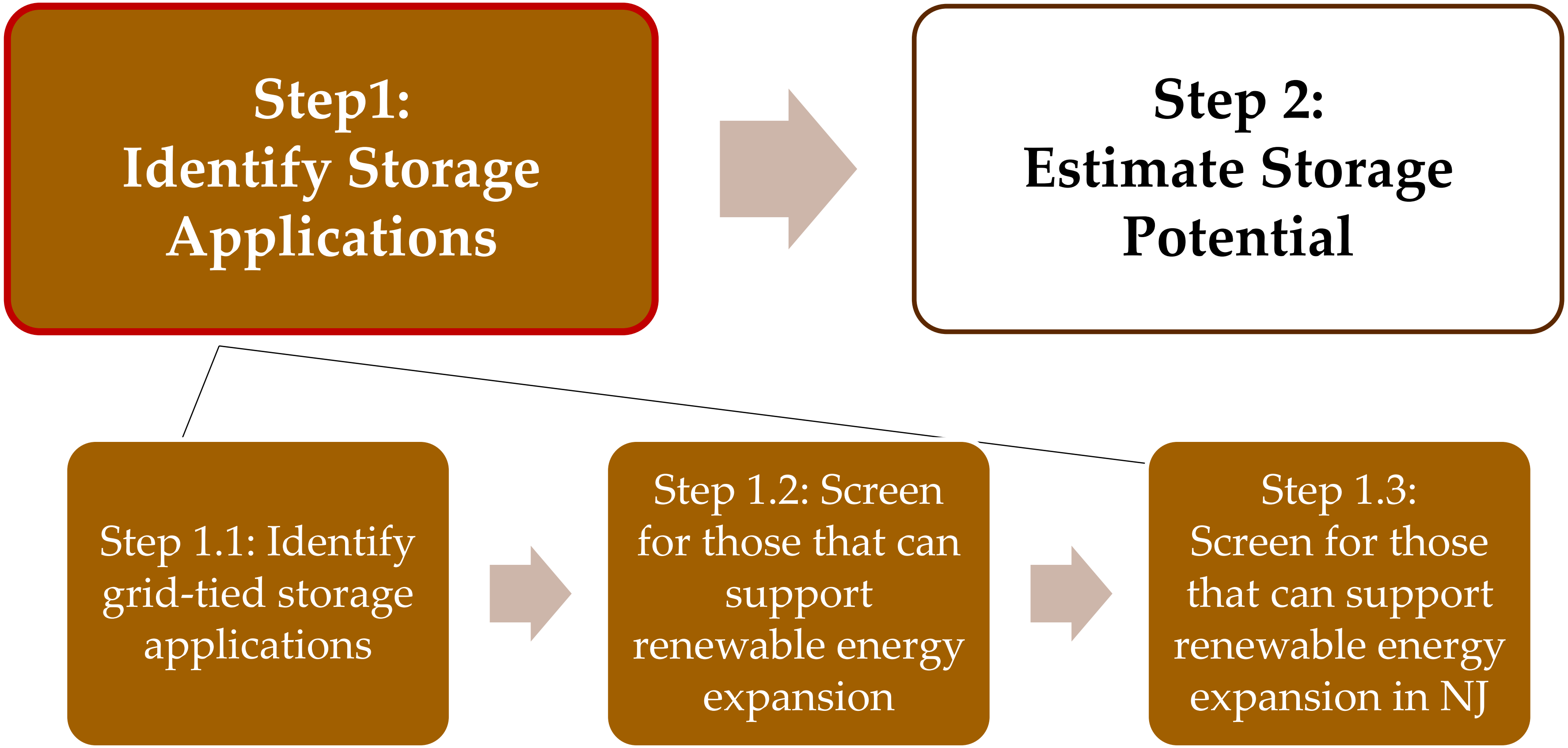
Step1: Identify Storage Applications

Identify storage applications that support the expansion of renewable energy in New Jersey.

Step 2: Estimate Storage Potential

Estimate the technical potential of the storage applications identified as candidates to support renewable energy expansion in New Jersey.

In Step 1, Navigant had three steps to identify storage applications with potential to support renewable energy expansion in New Jersey.



Step1:
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Storage applications can be organized into 3 categories based on grid benefits: load leveling, grid operational support and grid stabilization.

Grid-tied Storage Applications		Benefits														
		Economic										Reliability		Environmental		
		Market Revenue			Asset Utilization					Efficiency	Cost	Interruptions		Air		Water
		Arbitrage Revenue	Capacity Revenue	Ancillary Service Revenue	Optimized Generator Operation	Reduced Congestion Cost	Deferred Generation Capacity Investments	Deferred Transmission Capacity Investments	Deferred Distribution Capacity Investments	Reduced Electricity Losses	Reduced Electricity Cost	Reduced Outages	Improved Power Quality	Reduced CO_2 Emissions	Reduced SO_X, NO_X and Particulate Emissions	Reduced Water Use
Load Leveling	Renewable Energy Shifting	X			X	X	X	X	X	X	X			X	X	X
	Wholesale Market & Cost Optimization	X			X	X	X	X	X	X	X			X	X	X
	Retail Market				X	X	X	X	X	X	X			X	X	X
	Asset Management				X	X	X	X	X	X				X	X	
Grid Operational Support	Operating Reserves			X	X		X							X	X	X
	Load Following			X	X		X							X	X	X
	Frequency Regulation			X	X		X							X	X	X
	Renewable Energy Firming		X													
	Black Start			X			X									
Grid Stabilization	Renewable Energy Ramping				X		X							X	X	X
	Renewable Energy Smoothing				X									X	X	X
	Backup Power											X				
	Bridging Power												X			

Source: "Valuing Electricity Storage in Utility Applications", Navigant Consulting, ESA Annual Meeting Workshop, May 2, 2012

NAVIGANT
ENERGY

Of the 13 storage functions, 5 can support RE energy expansion – shifting, frequency regulation (FR), firming, ramping and smoothing .

Categories	Applications	Description of how storage is used to support renewable energy
Load Leveling	Shifting	This application involves storing electricity from renewable sources when the price of electricity is low and discharging that stored electricity when the price of electricity is high. The energy that is discharged from energy storage could be sold via the wholesale market, sold under terms of a power purchase agreement, or used by an integrated utility to reduce the overall cost of providing generation during peak times. Shifting can also be used to over come transmission constraints.
Grid Operational Support	Frequency Regulation	Called an ancillary service, frequency regulation is dispatched to reconcile momentary differences between supply and demand. This service is provided by on-line generation equipped with automatic generation control (AGC) that can change output quickly to track the moment-to-moment fluctuations in customer loads and correct for the unintended fluctuations in generation. The demand for frequency regulation can increase with the share of intermittent renewable energy. Energy storage facilities can also provide frequency regulation services, often with a more rapid response time than conventional generation.
	Firming	Firming involves using ES to guarantee a dispatchable source of capacity. In a deregulated market, this energy storage could possibly be used to earn a capacity credit. This market is still evolving, and in some markets generation capacity cost is included in wholesale energy prices.
Grid Stabilization	Ramping	As wind generation penetration increases, the electricity grid effects that are unique to wind generation will also increase. Ramping involves using energy storage to mitigate volatility from these effects, including sudden changes in wind speed, low wind conditions and high wind cutout.
	Smoothing	Storage can provide smoothing capability on a second- by-second basis when a renewable energy system's output varies over a short period of time due to intermittent cloud cover or wind speed volatility, improving power quality.

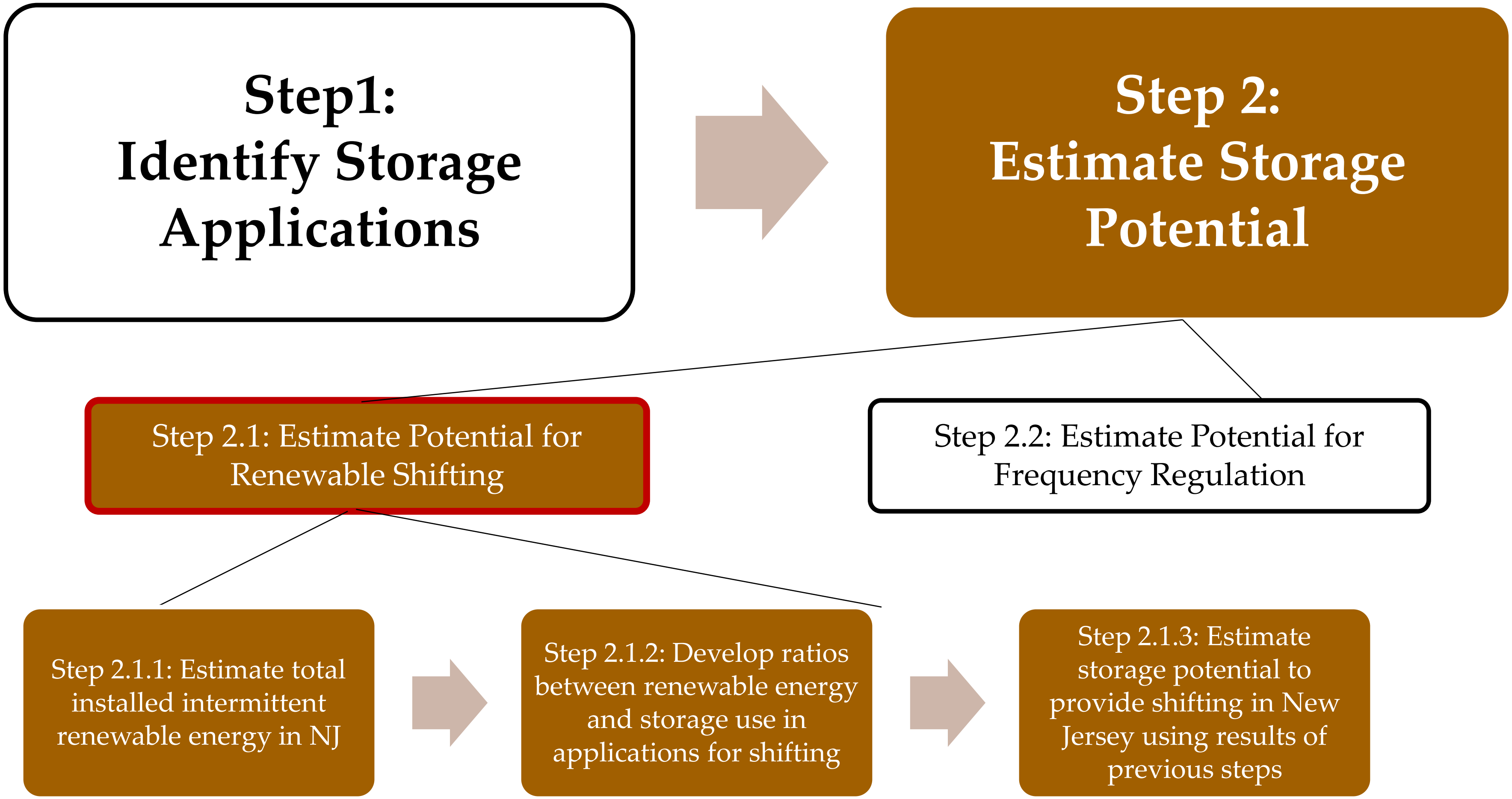
Source: "Valuing Electricity Storage in Utility Applications", Navigant Consulting, ESA Annual Meeting Workshop, May 2, 2012

Navigant identified renewable shifting and FR as the 2 main storage applications that can support near-term NJ renewable energy expansion.

Categories	Applications	Possible Fit for NJ in Near-Term? [1]	Discussion
Load Leveling	**Shifting**	**Y**	• Renewable energy shifting could be useful if wind resources would otherwise be spilled or if there are congestion issues.
Grid Operational Support	**Frequency Regulation**	**Y**	• PJM has a frequency regulation market with some of the most attractive pricing nationally. • Increased integration of intermittent renewable energy sources may result in increased need for frequency regulation. • However, the frequency regulation market is relatively small, and narrowing it to NJ makes it even smaller.
	Firming	**N**	• Renewable energy firming is still fairly conceptual. It remains to be seen whether storage can qualify for a capacity credit or if it can increase the capacity credit of a renewable resource.
Grid Stabilization	**Ramping**	**N**	• Regulatory mandates for renewable energy ramping and smoothing are not currently in place in NJ. • Ramping and smoothing are generally not a significant concern until renewable resources reach a relatively high penetration level (e.g. 20%).
	Smoothing	**N**	

1.For the purposes of this study, we consider "near-term" the years 2012 – 2016.

In Step 2.1, Navigant estimated the storage potential to provide shifting for intermittent RE in New Jersey using three sub-steps.



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The installed based of intermittent renewable energy in New Jersey is 780 MW, predominately solar PV; with 1 GW of planned offshore wind.

New Jersey Intermittent Renewable Energy Capacity (2012)			
Resource		**MW**	**Comments**
Wind	**Onshore**	8	April 30, 2012, NJ Clean Energy Program[1]
	Offshore	0	OWEDA targets 1,100 MW of offshore wind subsidized by OREC. Draft 2011 NJ Energy Master Plan notes that offshore wind could get as high as 3000 MW
Solar PV		770	April 30, 2012, NJ Clean Energy Program[1]. Over 500 MW of additional PV projects are approved
Installed Total		**780**	

1. http://www.njcleanenergy.com/renewable-energy/project-activity-reports/installation-summary-technology/installation-summary-technology

NAVIGANT ENERGY

For the purpose of estimating the current technical potential for storage, Navigant assumed 2000 MW of installed solar PV and 500 MW of wind for the base case.

- **Solar PV Capacity Used for Storage Potential Estimate – 2,000 MW**: Currently the installed base of solar PV is 770MW and is steadily increasing. For the purpose of estimating technical potential for storage, Navigant assumed 2,000 MW of installed solar PV as additional approved projects exceed 500MW and the scope of this study is over the near-term (through 2016) during which the additional 500MW would likely be installed along with additional capacity.

- **Wind Capacity Used for Storage Potential Estimate – 500 MW**: The current installed capacity of wind in New Jersey is on-shore is small at 8 MW. Onshore wind isn't expected to increase dramatically. However, there is an OWEDA goal of 1,100 MW for offshore wind. For the purpose of estimating the technical potential for storage, Navigant assumed that over the near-term 500 MW of the targeted offshore wind is built.

Since the installed capacity of PV and wind is a key input for the current technical potential of storage, Navigant developed 3 scenarios.

Scenarios : Installed Intermitted RE in NJ through 2016			
Scenario Name	Solar PV (MW)	Wind (MW)	Assumptions
Low	1500	0	• Current rate of solar uptake slows • Stalled off-shore wind development
Base	2000	500	• Current rate of solar uptake continues • Progress with off-shore wind development
High	3000	1000	• Current rate of solar uptake increases • proposition to end-customers • Initial off-shore wind development targets met on time

Of the projects reviewed, the amount of storage installed to support RE projects varied from 24-53% for wind and 50-100% for solar.

Project Name	Location	Function	Renewable		Storage		Storage %	Comments
			Type	MW	Type	MW		
Tehachapi Wind Farm Demonstration[1]	California	Testing	Wind	1500	Li Ion Battery	8	<1%	Test project will involve voltage control and energy shifting applications with Li-Ion batteries.
Sempra Utilities	Maui, Hawaii	Smoothing	Wind	21	Li Ion Battery	11	53%	Project expected to improve stability of Maui's grid.
Duke Notrees	Texas	Smoothing and FR	Wind	153	Battery	36	24%	Large scale battery for demonstration of energy storage.
Sapporo - VRB[1]	Japan	Demonstration	Wind	32	Vanadium Redox Flow Battery (VRB)	4	12%	Demonstration of VRB for grid applications.
Public Service Company of New Mexico	New Mexico	Voltage Smoothing and Shifting	Solar	0.5	Battery	0.5	100%	Demonstration project funded by the DOE.
Poipu Solar	Kauai, Hawaii	Smoothing	Solar	3	Battery	1.5	50%	Battery system will compensate for high RE penetration on island.

Source: Navigant, May 2012

1. Projects excluded from analysis as projects are for testing and demonstration purposes and don't represent amount of storage that would be used in commercial projects.

Large offshore wind projects could change the RE profile in the state quickly and create an opportunity for storage to help integrate this resource.

Need for Renewable Energy Shifting in NJ	
Area	**Comments**
Wind Profile	• **Onshore**: Installed amount of wind in New Jersey is relatively small, with only 8 MW of onshore wind currently operational. While there may be potential for as much as 130 MW of onshore wind[1], this represents a small fraction of overall generation capacity in the state, and is dwarfed by existing and planned solar projects. For onshore wind it is not anticipated that significant amounts of storage would be required or helpful with respect to grid integration. • **Offshore**: Proposed offshore projects, one measuring 1GW in size, could change the realities of wind integration in the state. Integrating a large source of renewable energy on the scale New Jersey is proposing could result in curtailed wind and grid integrity issues, both of which storage may be able to mitigate.
Transmission Constraints	• **Offshore wind location**: Offshore wind farms would likely be off the southern coast of the New Jersey, relatively far from the population centers of the northern and central regions of the state. • **Impact on transmission**: Transmission systems would likely have to be upgraded and modernized to handle the increased intermittent load, and storage could play a key role in both shifting and regulating this load and in the transmission process. Onshore storage could compliment the offshore capacity, delivering the energy to the grid when it is needed.

Source: Navigant, June 2012.

Navigant assumed that storage capacity equivalent to 50% of offshore wind and 25% PV nameplate capacity in NJ can be installed for shifting.

Shifting: Suggested relationship in NJ between storage and renewable energy capacity

Resource		% storage per MW RE	Comments
Wind	**Onshore**	0%	• Given the relatively small onshore wind market and distribution of current and potential wind sites, it is not anticipated that significant amounts of storage would be required or helpful with respect to grid integration.
	Offshore	50%	• Navigant assumed that storage's technical potential for shifting offshore wind in New Jersey is 50% of nameplate capacity for the following reasons: – Theoretically storage capacities could exceed 100% of RE capacity for shifting applications, though this scale of application is rarely feasible. – Studies by Sandia suggest that as much as 65% of nameplate capacity may be useful for shifting of wind energy, specifically due to diurnal changes in wind speeds.[1] – Storage applications of 24-53% of renewable energy nameplate capacity are already in use commercially to provide shifting. – Given the massive amount of offshore wind that is being planned in New Jersey on the southern coast relatively far from population centers, onshore storage could compliment the offshore capacity, delivering the energy to the grid when it is needed.
Solar PV		25%	• Cases show a range of 50-100% capacity can be effective for small scale demonstration projects in locations with high penetration. • Navigant assumed storages technical potential for shifting solar PV in New Jersey is 25% of the installed solar PV nameplate capacity, as during 2013 -2016 PV penetration likely won't widely reach the high penetration levels seen in Hawaii.

1. Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide, Sandia 2010

For the base case, Navigant estimated a storage potential of 750 MW for renewable energy shifting in New Jersey.

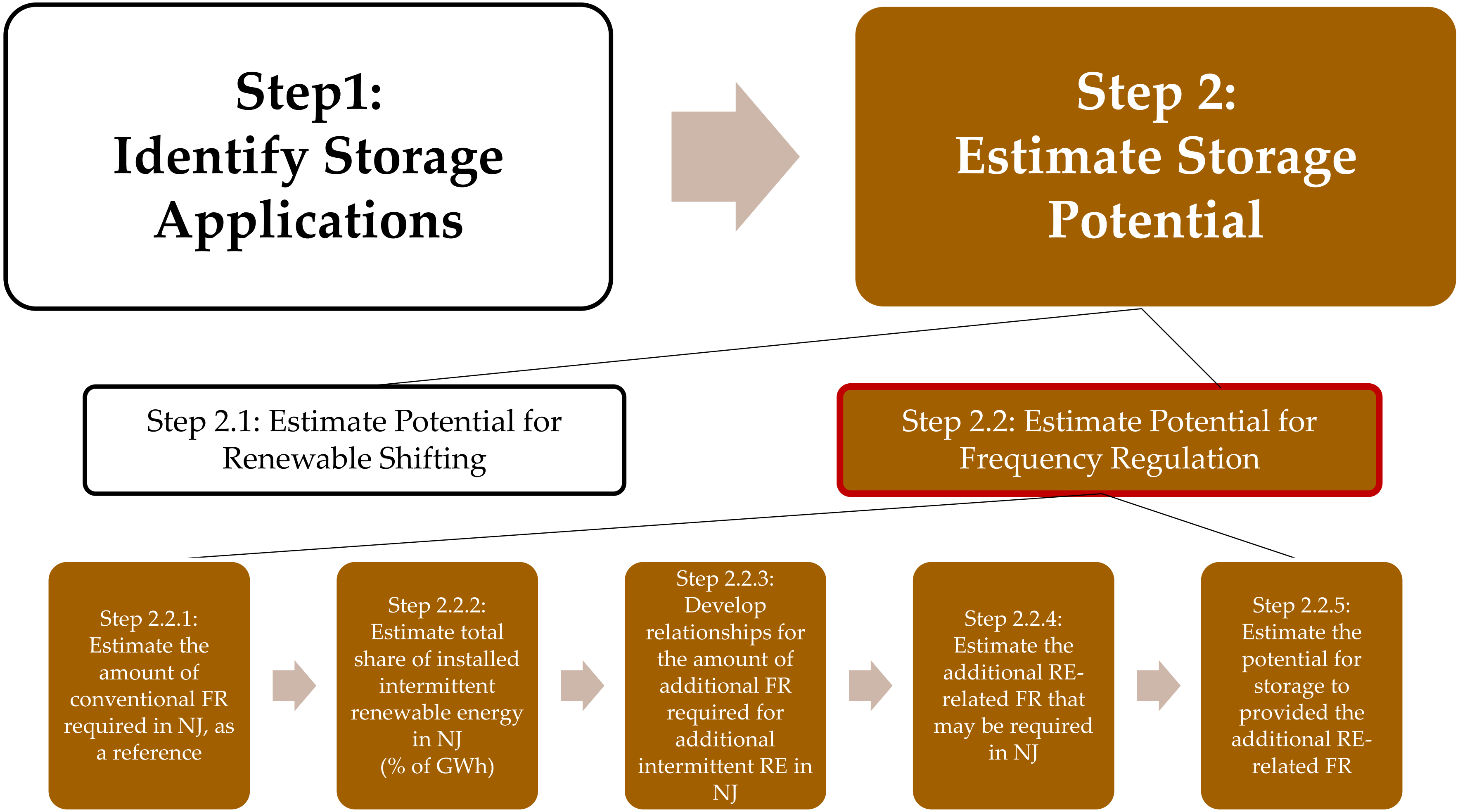
Storage Potential for Renewable Energy Shifting in NJ					
Resource		**MW RE**	**% storage**	**MW Storage**	**Comments**
Wind	**On shore**	8	0%	0	
	Off-shore	500	50%	250	Highly dependent on offshore wind development
Solar PV		2000	25%	500	Unlikely to be a near-term application due to cost of storage relatively to benefit
Current Technical Potential for Shifting				**750**	

For the low and high cases, Navigant estimated a storage potential of 375 MW and 1250 MW for RE shifting in New Jersey, respectively.

Storage Potential for Renewable Energy Shifting in NJ

		MW RE				MW Storage		
Resource		**Low**	**Base**	**High**	**% storage**	**Low**	**Base**	**High**
Wind	**Off-shore**	0	500	1000	50%	0	250	500
Solar PV		1500	2000	3000	25%	375	500	750
Current Technical Potential for Shifting						**375**	**750**	**1250**

In Step 2.2, Navigant estimated storage's current technical potential based on additional frequency regulation in NJ due to intermittent RE.



Step1: Identify Storage Applications

Step 2: Estimate Storage Potential

Step 2.1: Estimate Potential for Renewable Shifting

Step 2.2: Estimate Potential for Frequency Regulation

Step 2.2.1: Estimate the amount of conventional FR required in NJ, as a reference

Step 2.2.2: Estimate total share of installed intermittent renewable energy in NJ (% of GWh)

Step 2.2.3: Develop relationships for the amount of additional FR required for additional intermittent RE in NJ

Step 2.2.4: Estimate the additional RE-related FR that may be required in NJ

Step 2.2.5: Estimate the potential for storage to provided the additional RE-related FR

As a reference point, Navigant estimated that 200 MW of "conventional" frequency regulation (FR) is required in NJ based on NJ's peak load level.

Conventional Frequency Regulation in NJ – Based on Peak Load Requirements		
Frequency Regulation Requirement (% of peak load)	1.0%	• In PJM "Regulation" refers to the control action that is performed to correct for load changes that may cause the power system to operate above or below 60 Hz. In this report this is what Navigant referrers to as frequency regulation (FR). • To estimate the amount of FR required, PJM uses NERC requirements for on-peak (0500-2359) of 1% of the forecasted peak load for the operating day. *(Source: PJM Regulation Services RPSTF Training, May 9, 2011, page 12.)*
NJ Peak Load	20,000 MW	• 2011 Draft Energy Master Plan indicates that NJ peak load is around 20,000 MW today and while demand may increase through 2020, there are aggressive EE and DR targets to eventually get peak load down below 20,000 MW. For the purposes of this analysis we used 20,000 MW as a proxy for peak load in the near-term, realizing that there will be years where load is slightly greater, and then later years when it might be slightly less. (*Source: 2011 Draft Energy Master Plan for NJ)*
Frequency Regulation Requirement	200 MW	• Based on the information above, Navigant estimated that the FR capacity required to meet NJ peak load is approximately 200 MW (1% x 20,000 MW). • In this report Navigant refers to this as "conventional" FR. • Navigant considers that this estimate is likely on the high-end as PJM is examining reducing the frequency regulation requirement in cases where fast-response storage is available. A recent study commissioned by PJM showed that 0.5% of capacity could be considered for frequency regulation when more fast-response storage. *(KERMIT Study Report, December 12, 2011, KEMA)*

While 200 MW serves as a guide for “NJ-based” peak-load related FR, the amount of FR that NJ-based storage could provide is uncertain.

Caveats to analysis:

- **200 MW requirement may be high**: Frequency regulation requirements could dip with the increased use of fast-following storage (e.g., storage). A PJM committee is currently examining the relationship between the use of storage and the amount of frequency regulation needed to maintain grid stability. Initial report by KEMA indicated that a 0.5% relationship might be sufficient, when adequate fast-following storage is available versus the 1.0% of peak load NERC requirement used today.
- **Storage market share unclear**:
  - **Competition exists from incumbents**: Currently other technologies are providing frequency regulation, including existing generators. It is unclear what portion of the 200 MW frequency regulation requirement could technically (and economically) be met by storage.
  - **However, storage positioned to receive better price**: FERC 755 (October 2011) opens market for fast-ramping storage systems by allowing system operators to pay these providers more to value their responsiveness. *(“Energy Storage Solutions: barriers and breakthroughs to a smarter grid”, Public Utilities Fortnightly, May 2012)*
- **Demand for and supply of frequency regulation services is not bound to NJ**: Since ancillary services, like frequency regulation, are provided through PJM, regulation services can be procured by PJM from facilities throughout PJM to meet the NJ peak load requirement. It is false to imply that there is a technical potential for frequency regulation of 200 MW specific to NJ, as some of this demand could be met from facilities outside of NJ (but within PJM’s territory). Conversely, facilities in NJ could provide regulation services for PJM to use outside of NJ.

Based on the base case for intermittent RE in NJ from Step 2.1, Navigant estimated that intermittent RE would represent 4.8% of annual generation.

New Jersey Intermittent Renewable Energy Estimate (by 2016) – Base Case

Resource		Base Case Capacity (MW)	Est. Generation (GWh/y)	Share of Generation[2]	Comments
Wind	**Offshore**	500	1,250	1.6%	• Wind annual generation in NJ: 288 MW offshore plant estimated to generate 717GWh/y[1], implies 1,244GWh/y for 500 MW • If NJ were to hit the 1,100 MW offshore target, wind share would increase to ~3.5% • If NJ were to have 3000 MW of offshore identified in the 2011 NJ Energy Master Plan, wind share would increase to close to 10%
Solar PV		2000	2,600	3.2%	PV annual generation in NJ = 2000 MW*15% capacity factor*8760 h/y
Installed Total		**2500**	**3,850**	**4.8%**	

1. Source: An Assessment of the potential costs and benefits of offshore wind turbines, Global Insight, September 2008.
2. Navigant assumed 80,000 GWh for New Jersey demand. Source: 2011 New Jersey Energy Master Plan (EMP) (80,000 GWh is current demand and consistent with EMP goal through 2020)

For the low and high cases of intermittent RE in NJ, Navigant estimated that the share of annual generation is 2.5% and 8.2%, respectively.

New Jersey Intermittent Renewable Energy Estimate (by 2016) – All Cases									
	MW			GWh/y			Share of Demand[1]		
Resource	Low	Base	High	Low	Base	High	Low	Base	High
Wind	0	500	1000	0	1,250	2,500	0	1.6%	3.2%
Solar PV	1500	2000	3000	2,000	2,600	4,000	2.5%	3.2%	5.0%
Total	1500	2500	4000	2,000	3,850	6,500	**2.5%**	**4.8%**	**8.2%**

1. Navigant assumed 80,000 GWh for New Jersey demand. Source: 2011 New Jersey Energy Master Plan (EMP) (80,000 GWh is current demand and consistent with EMP goal through 2020)

To explain the relationship between wind share and need for additional FR, Navigant used a formula it developed for the DOE.

Frequency Regulation (FR) – Additional Requirements Due to Intermittent RE

- ORNL, NYISO, and CAISO have performed studies to understand how much additional FR will be required with additions of wind capacity. (Sources below)
- Based on these studies, Navigant developed a relation that shows that as wind's share of generation increased so would the amount of FR required for each MW of wind generation, according to the following relationship:
    - The percentage of wind nameplate required for frequency regulation will grow linearly from 2.5% of nameplate at 0% wind share, to 6% of nameplate at 10% wind share, after which it declines as: FR(wind share) = e -0.5(wind share)
- For the purposes of this analysis, Navigant assumed that this relationship also applies to solar PV.

Sources:
Hudson, R., Kirby, B,. and Wan, Yih-Huei. *Regulation Requirements for Wind Generation Facilities*. Oak Ridge National Laboratory and the National Renewable Energy Laboratory. 2004.
Adams, John. *NYISO Wind Integration Study Status Report*. New York Independent System Operator. December 16, 2008. (presentation at SOAS/MIWG)
Adams, John. *NYISO Wind Integration Study Status Report*. New York Independent System Operator. October 2008. (presentation at MIWG, TPAS, and SOAS Monthly Meetings)
California ISO. *Integration of Renewable Resources: Transmission and Operating Issues and Recommendations for Integrating Renewable Resources on the CA ISO-controlled Grid*. California Independent System Operator Corporation. November 2007.

Navigant estimated additional FR requirement of 105 MW in NJ for the base case; the low and high cases required 51 MW and 216 MW respectively, and the wind-only case required only 15 MW.

Additional FR Based on Intermittent RE (by 2016) – All Cases

	Scenarios				Comment
Item	**Low**	**Base, wind only[1]**	**Base**	**High**	
Share of Generation (%)	2.5%	1.6%	4.8%	8.2%	• From previous page with scenarios
Additional FR (% of RE Nameplate Capacity)	3.4%	3%	4.2%	5.4%	• Estimated based on Navigant's relationship on previous page, where at 0% wind share additional FR is 2.5% and 10% wind share additional FR is 6% with a linear relationship in between 0 and 10% windshare
RE Nameplate Capacity (MW)	1500	500	2500	4000	• From previous page with scenarios
Additional FR (MW)	**51**	**15**	**105**	**216**	

1. Navigant ran a wind-only case since literature as literature on additional frequency regulation requirements for renewable energy is primarily focused on an increase in wind share.

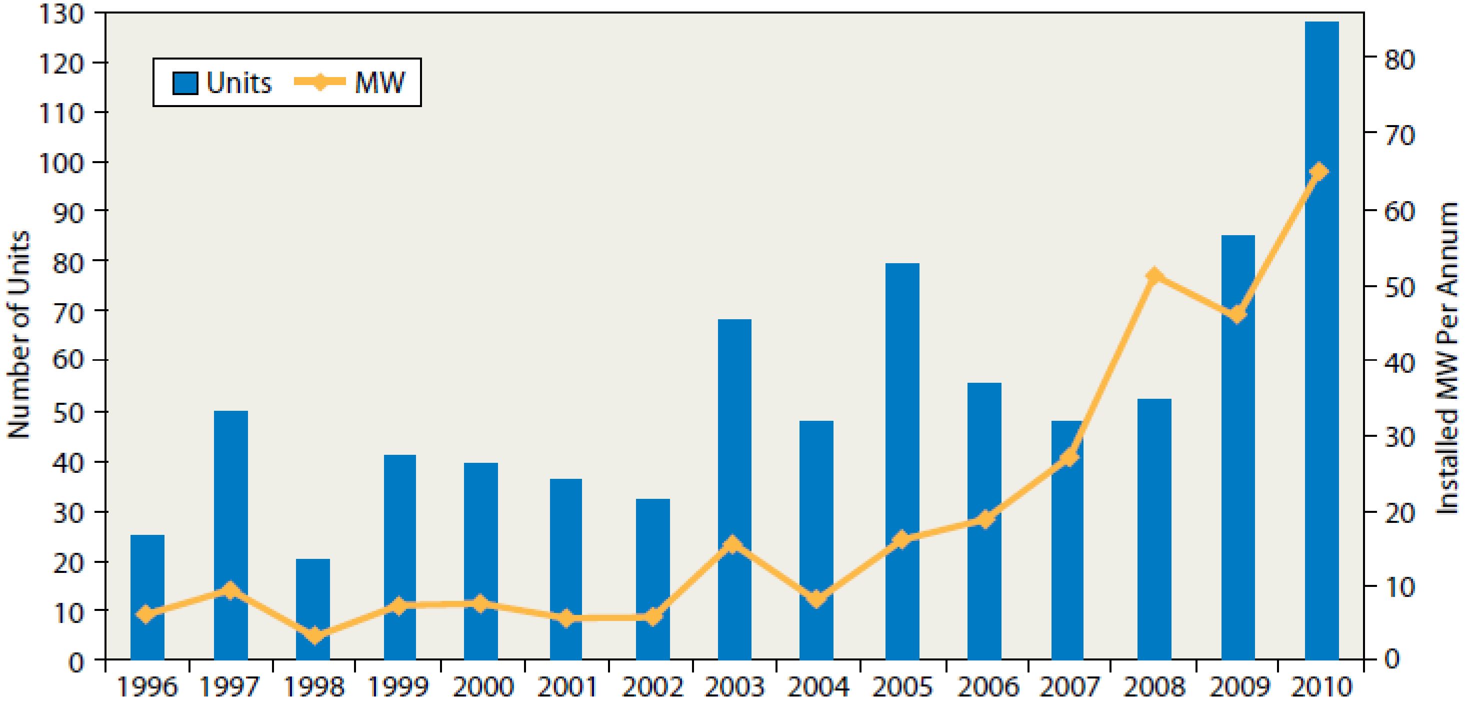
While technically 100% of the additional FR could be provided by storage, using storage could reduce the amount of FR required by 50%, resulting in 7.5 MW to 108 MW of current technical potential for storage.

Storage Technical Potential Related to the Additional FR Based on Intermittent RE (by 2016) – All Cases

	Scenarios				Comment
Item	**Low**	**Base, wind only[1]**	**Base**	**High**	
Additional FR (MW)	51	15	105	216	• From previous page
Reduction in the FR based on use of Storage	50%	50%	50%	50%	• A recent study commissioned by PJM showed that frequency regulation requirements could be cut in half if fast-response storage was used instead of conventional generators. *(KERMIT Study Report, December 12, 2011, KEMA)*
Current Technical Potential for Storage (MW)	**25.5**	**7.5**	**52.5**	**108**	

As context, in 2010 the US fuel cell market was 65 MW and 130 units; the average stationary fuel cell approached 1 MW (up from 250 kW in 2005).

Figure 2: Annual Number of Large Fuel Cell Units and MW Installed



Source: Fuel Cell Today, *2008 Large Stationary Survey*; Pike Research, *Research Report Stationary Fuel Cells* (2011); DOE, *2010 Fuel Cell Technologies Market Report*

Source:
1. Clean Energy States Alliance. “Fuel Cells: Briefing Papers for State Policymakers.” August 2011. Available at http://neesc.ccat.us/publications/other_publications.

As background, fuel cell types vary in their typical size (referred to as “stack size”) and their most likely application.

		Fuel Cell Characteristics		
		Size	**Markets**	**Manufacturers**
Fuel Cell Type	**Polymer electrolyte membrane (PEM)**	< 1 kW – 100 kW	• Large stationary (e.g., large commercial and industrial facilities) • Small stationary (e.g., telecommunications, residential, small commercial) • Portable power (e.g., battery chargers, mobile lighting, soldier power) • Materials handling (e.g., forklifts) • Transportation (e.g., vehicles)	• ClearEdge Power • UTC Power (transport)
	Molten carbonate (MCFC)	300 kW – 3 MW	• Large stationary	• Fuel Cell Energy
	Phosphoric acid (PAFC)	100 kW, 400 kW	• Large stationary	• UTC Power
	Solid oxide (SOFC)	1 kW – 2 MW	• Large stationary	•Bloom Energy
	Alkaline (AFC)	10 – 100 kW	• Military • Space	

Sources:

1. “Northeast Hydrogen Fuel Cell Industry Status and Direction 2012,” The Connecticut Center for Advanced Technology, Inc., 2012
2. Fuel Cells 2000, “Markets”
3. US DOE, EERE, Fuel Cell Technologies Program

Fuel cells types vary by the electrolyte, the operating temperature, the catalyst, and the tolerance and performance characteristics.

Fuel Cell Types					
	PEM	**MCFC**	**PAFC**	**SOFC**	**AFC**
Electrolyte	Polymer membrane	Molten carbonate	Liquid H_3PO_4 (immobilized)	Ceramic	Liquid KOH (immobilized)
Charge carrier	H^+	CO_3^{2-}	H^+	O^{2-}	OH^-
Operating temperature	80°C (176°F)	650°C (1202°F)	200°C (392°F)	600-1000°C (1112-1832°F)	60-220°C (140-428°F)
Catalyst	Platinum	Nickel	Platinum	Perovskites (ceramic)	Platinum
Cell components	Carbon based	Stainless steel	Carbon based	Ceramic based	Carbon based
Fuel Compatibility	H_2, methanol	H_2, CH_4	H_2	H_2, CH_4, CO	H_2

Source: O'Hayre, Ryan, Suk-Won Cha, Whitney Colella, and Fritz B. Prinz. *Fuel Cell Fundamentals*. 2nd ed. New York: John Wiley & Sons, 2009.

Different fuel cell types require different complexities of fuel processing subsystems.

		Fuel Cell Characteristics
		Fuel Processing Subsystem
Fuel Cell Type	**Polymer electrolyte membrane (PEM)**	Sensitive to impure gases – generally need expensive fuel processing subsystems
	Molten carbonate (MCFC)	Operate at high temperatures so can have internal reforming
	Phosphoric acid (PAFC)	Sensitive to impure gases – generally need expensive fuel processing subsystems
	Solid oxide (SOFC)	Operate at high temperatures so can have internal reforming
	Alkaline (AFC)	Not applicable – focused on military and space applications

Fuel cell electrical efficiencies range from 25% to 47%. When used in a CHP configuration efficiencies of 90% can be achieved.

		Fuel Cell Characteristics		
		Electrical Efficiency	**CHP Efficiency[1]**	**Key Advantages**
Fuel Cell Type	**Polymer electrolyte membrane (PEM)**	25 - 35%	70 – 90% (low grade heat)	Low temperature, quick startup
	Molten carbonate (MCFC)	45 – 47%	> 80%	High efficiency, fuel and electrolyte flexibility
	Phosphoric acid (PAFC)	> 40%	> 85%	Tolerance to hydrogen impurities
	Solid oxide (SOFC)	35 – 43%	<90%	High efficiency, use of solid electrolyte

Source: U.S. Department of Energy. Hydrogen Program

1. Assumes use of by-product heat.

In addition to the major types of fuel cells that are commercially available, other fuel cells are in development.

Additional Fuel Cell Technologies	
Direct liquid-fueled fuel cells	Fuel cells produce electricity directly from liquid fuels such as methanol, ethanol, formic acid, and borohydride solutions. Direct methanol produces CO2 as a product at the anode.
Biological fuel cell	Fuel cells that use living cells, biological catalysts, microorganisms, and/or enzymes.
Membraneless fuel cell	Fuel cells that use laminar flow in micro-fluidic channels. To date, these exhibit low power densities and poor efficiencies.
Metal-air fuel cells	Fuel cells that blend a fuel cell and a battery. They have a limited life once the solid metal fuel is expended.

Sources:
1. Source: O'Hayre, Ryan, Suk-Won Cha, Whitney Colella, and Fritz B. Prinz. Fuel Cell Fundamentals. 2nd ed. New York: John Wiley & Sons, 2009.

For non-pure hydrogen fuels, the processing of the fuel can occur through different methods.

Fuel Processing for Non-Pure Hydrogen Fuels	
Direct electro-oxidation	Electrons are directly stripped from the fuel molecule (methanol, ethanol, formic acid). This process leads to reduced energy efficiency.
External reforming	Heat, catalysts, and/or steam are used to break down fuel to H_2
Internal reforming	Reforming occurs inside of fuel cell stack. This process occurs with high temperature fuel cells and fuel quality.

Sources:
1. Source: O'Hayre, Ryan, Suk-Won Cha, Whitney Colella, and Fritz B. Prinz. Fuel Cell Fundamentals. 2nd ed. New York: John Wiley & Sons, 2009.