Independent Evaluation of SCR Systems for Frame-Type Combustion Turbines

Report for ICAP Demand Curve Reset

PREPARED FOR

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Executive Summary

The New York Independent System Operator (NYISO) operates a capacity market to ensure resource adequacy and reliability in New York. These capacity markets are administered in four capacity zones: the New York Control Area ("NYCA"), and three localities – New York City (Zone J), Long Island (Zone K) and the G-J Locality. The requirement for installed capacity is maintained by an administratively-determined demand curve that reflects, among other considerations, the estimated net cost of new entry (CONE) of a proxy generating unit. In selecting a specific proxy generating unit, previous FERC orders affirm that "only reasonably large scale, standard generating facilities that could be practically constructed in a particular location should be considered,"[1] and the NYISO Market Services Tariff requires the NYISO to base the net CONE estimate on a proxy unit with "the lowest fixed and highest variable cost among all other units' technology that are economically viable."[2]

The criteria "could be practically constructed" and "are economically viable" mean that the generating unit must be able to comply with all applicable environmental limitations and utilize commercially available, proven technology. NERA Economic Consulting (NERA) and Sargent & Lundy (S&L) determined that the lowest fixed and highest variable cost option was a frame-type F-Class simple-cycle combustion turbine (Siemens SGT6-5000F5). However, southeastern New York imposes strict air emission limits on combustion turbines that require the use of a selective catalytic reduction (SCR) system to reduce NO_x emissions. Both F-Class turbines and SCR systems are mature, commercially available technologies. However, frame-type turbines operate with very high exhaust gas temperatures, which have been known to damage some catalysts used in earlier SCR systems. Citing limited successful commercial experience in coupling SCR and F-Class frame combustion turbines, NERA/S&L decided to adopt a different turbine for environmentally constrained regions, the aeroderivative GE LMS100. Compared to the F-Class

1 134 FERC ¶ 61,058, Docket No. ER11-2224-000 (January 28, 2011), at page 14.

2 In this report Brattle concludes that the F-Class frame combustion turbine with Selective Catalytic Reduction emissions control is economically viable technology and as such meets the tariff requirement as lowest fixed, highest variable cost unit to be used in the demand curves for Long Island, New York City, and the G-J demand curve regions.

frame unit, the aeroderivative turbine has much higher fixed cost, slightly lower operating costs due to higher efficiency (lower heat rate), and modestly lower exhaust gas temperatures. The lower exhaust gas temperature makes aeroderivative combustion turbines more compatible with conventional SCR NO_x removal systems, and many examples of such installations exist.

As part of the NYISO's Demand Curve Reset stakeholder process, the issue of whether SCR was viable for F-Class turbines was raised in stakeholder written comments and during oral argument before the NYISO Board of Directors. Of particular importance was the recent installation and successful operation of F-Class frame simple cycle combustion turbines with SCR emissions controls in California, which, like New York, has some of the most stringent air emissions standards in the country. In response to the stakeholder comments, the NYISO Board noted that the difference between the LMS100 and F-Class installed cost was large enough to merit additional due diligence on the viability of F-Class turbines combined with SCR, given the relatively low fixed cost associated with design and installation of SCR. The NYISO engaged The Brattle Group and Licata Energy & Environmental Consulting, Inc. to examine this issue further.

We conclude that the F-Class frame combustion turbine can be and has been successfully coupled with SCR to meet strict environmental standards. These two mature, proven technologies – frame-type combustion turbines and SCR systems – are not inherently incompatible or infeasible to combine, but do require proper design and engineering of exhaust gas tempering and appropriate catalyst selection to work reliably. The primary reasons for reaching this conclusion are:

- Frame technology and SCR emission control systems are both proven technologies.
- There are numerous examples of hot temperature SCR applications functioning well in the electric generating sector. These are mostly aeroderivative combustion turbines, but also include two existing frame-type turbine/SCR installations in California that date from the mid-2000s.
- The Marsh Landing Generating Station (MLGS) comprised of four F-Class turbines that began operation in March 2013, has achieved its performance requirements, including emission limits, using an SCR with an air tempering system designed by Mitsubishi.
- Air tempering or dilution air systems are designed to achieve the proper temperature and velocity distribution of combustion exhaust gas and reagent (ammonia) so that it can pass

through the catalyst to obtain optimal NO_x removal; some SCRs on aeroderivative turbines feature such systems.

- Air tempering or dilution air systems primarily involve designing physical structures to direct and diffuse exhaust gases. Once these engineering solutions are in place and accomplish the proper conditions for effective SCR operation, the system is unlikely to be prone to subsequent failure beyond the normal operating issues that may arise in typical SCR installations.

- The two early frame-type turbine/SCR failures sighted by NERA/S&L (Riverside and PREPA) are readily distinguishable from current applications such as the McClellan, McClure and Marsh Landing plants.

- The significant fixed-cost advantage of frame-type turbines over aeroderivative turbines for simple cycle applications will continue to encourage strong commercial interest in SCR installations on frame-type turbines where emission limits require SCR. The modest expenditure needed to properly engineer, design and construct the SCR for reliable performance does not materially impact this cost advantage.

- The major catalyst vendors all provide catalyst formulations for higher temperature applications suitable for F-Class turbines with air tempering systems and SCRs and are willing to provide performance guarantees for this application.

- Recent advances in SCR design and catalyst formulation, along with commercial experience, have eliminated any engineering basis for distinguishing between aeroderivative and frame-type combustion turbines in terms of the economic viability of using SCR to comply with strict environmental limits.

Given these observations, we find the F class frame turbine with SCR to be economically viable and recommended that S&L and NERA estimate new demand curves for Zones J, K and G-J locality using the S&L estimated costs and performance parameters for SCR on F-Class frame units given in Appendix B of the September 6, 2013 NYISO report. Mitsubishi verified that those parameters were reasonable for such installations. Changes in key demand curve parameters that result from this recommendation are summarized in the following table.

2014/2015 Demand Curve Parameters	NYCA	NYC	LI	NCZ
September 6, NYISO Report				
ICAP Max Clearing Price ($/kW-mo)	13.50	36.83	30.96	28.10
Reference Point ($/kW-mo)	8.84	25.57	13.28	17.86
Zero Crossing (% of req)	112.0	118.0	118.0	115.0
Summer DMNC (MW)	210.1	185.5	188.0	186.3
Annual CONE ($/kW-yr)	107.98	294.6	247.7	224.79
Annual EAS Revenues ($/kW-yr)	18.48	54.5	114.6	53.06
Annual Net CONE ($/kW-yr)	89.50	240.11	133.07	171.73
Brattle-Licata Report				
ICAP Max Clearing Price ($/kW-mo)	13.50	26.14	20.88	18.80
Reference Point ($/kW-mo)	8.84	18.55	7.96	12.14
Zero Crossing (% of req)	112	118	118	115
Summer DMNC (MW)	210.1	208.8	210.7	209.4
Annual CONE ($/kW-yr)	107.98	209.14	167.02	150.44
Annual EAS Revenues ($/kW-yr)	18.48	33.49	86.67	32.77
Annual Net CONE ($/kW-yr)	89.50	175.65	80.35	117.67
Percent Change				
ICAP Max Clearing Price	0%	-29%	-33%	-33%
Reference Point	0%	-27%	-40%	-32%
Zero Crossing	0%	0%	0%	0%
Summer DMNC	0%	13%	12%	12%
Annual CONE	0%	-29%	-33%	-33%
Annual EAS Revenues	0%	-39%	-24%	-38%
Annual Net CONE	0%	-27%	-40%	-31%

I. Background and Motivation

The New York Independent System Operator, Inc. (NYISO) operates a zonal capacity market for electrical generating capacity. Every three years the NYISO, with an independent consultant and its stakeholders, reassesses the administratively determined demand curves, which, when combined with capacity offers from generation owners into the Spot Auction, produces a locational capacity price that is paid to all capacity suppliers in the particular capacity region. A key parameter in determining the position and shape of the demand curve is the net cost of new entry (net CONE) of a peaking unit. The net CONE represents the levelized annual cost of building and operating the peaking unit less any revenues earned in the energy and ancillary service markets. In addition to compliance with all applicable environmental permitting and local performance requirements, a peaking unit must be "the lowest fixed and highest variable cost among all other units' technology that are economically viable" under the NYISO Market Services Tariff (Section 5.14.1.2).

The NYISO retained NERA Economic Consulting (NERA), assisted by Sargent & Lundy (S&L), to make recommendations on the 2014/17 demand curves. NERA and S&L produced a report that utilized two reference technologies: (1) a Siemens F-class frame combustion turbine (CT) for the New York Control Area (NYCA) and a GE LMS100 aeroderivative CT coupled with selective catalytic reduction (SCR) in the more environmentally constrained regions of southeast New York.[3] NERA/S&L selected the significantly more expensive aeroderivative CT with SCR because, in their judgment SCR is "unproven as a control technology for the large frame gas turbines" (p. 8) in simple cycle applications. For heavy duty frame units, NERA/S&L explained "The use of selective catalytic reduction (SCR) technology for NO_X control is problematic because exhaust gas temperatures in simple-cycle mode exceed 850°F. Past experience with SCR control on simple cycle frame units have shown that such high exhaust gas temperatures irreversibly damage the catalyst. Due to the problems with controlling exhaust temperature for

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3 *Independent Study to Establish Parameters of the ICAP Demand Curve for the New York Independent System Operator Final Report*, NERA Economic Consulting, August 2, 2013.

inclusion of selective catalytic reduction technology and the high operating cost, the SGT6-5000F(5) in simple cycle operation with an SCR was not evaluated." (p. 19)[4]

The NYISO Board of Directors received written comments and oral argument that questioned this judgment in light of recent developments in SCR technology and catalysts, commercial interest in the frame CT / SCR configuration, and a recently commissioned and operating plant in California (Marsh Landing) that employs the technology. These comments highlighted the large premium in Net CONE for the LMS100 technology and argued that in light of the Marsh Landing installation the LMS100 does not meet the tariff requirements of "lowest fixed, highest variable cost" proxy plant. The magnitude of this premium can be seen in relative capital cost figures. In Zone J New York City the estimated overnight capital cost of the SGT6-5000F(5) frame unit with SCR is $1,151/kW while the capital cost of the LMS100 with SCR is $1,858/kW, a 61% premium.[5] Higher premiums are observed in Zone K Long Island (67%) and Zone G Lower Hudson Valley (71% for both Dutchess and Rockland Counties). For reference, note that the overnight capital cost of adding an SCR to the SGT6-5000F(5) is about $86/kW in Zone C and F. Capital costs are an important determinant of net CONE, along with operating costs and market revenues.

These large price premiums merit a second look at the feasibility of practicably constructing and operating an F-class frame SCCT with SCR emission controls. In order to examine this issue more closely and to obtain an additional independent opinion, the NYISO retained The Brattle Group (Brattle), who in turn retained Licata Energy & Environmental Consultants Inc. (Licata) to provide engineering expertise and support.

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4 NERA/S&L also cited two previous unsuccessful deployments of frame gas turbines with SCR in Kentucky and Puerto Rico, but do not cite two subsequent successful projects in California, other than to note that a third (Marsh Landing Generating Station) was only recently completed. See *Proposed NYISO Installed Capacity Demand Curves for Capability Years 2014/2015, 2015/2016 and 2016/2017*, New York ISO, September 9, 2013, pp. 13-14.

5 These figures are taken from Table 3 and Appendix B of *Proposed NYISO Installed Capacity Demand Curves for Capability Years 2014/2015, 2015/2016 and 2016/2017*, New York ISO, September 9, 2013. We note that the LMS100 figures include negligible (<1%) capacity adjustments for temperature and relative humidity (see Table 1) while those for the SGT6-5000F(5) do not. The same caveat applies to the net CONE figures.

II. Objectives and Process

A. Economic Viability of Frame Unit with SCR

To assess whether the F-Class frame CT with SCR represents an economically viable option, there are several considerations and key questions that need to be answered, including:

- Feasibility: What engineering challenges are involved and how are they resolved?
- Compliance: Can a frame CT with SCR comply with applicable environmental limits?
- Commercial Status: Is the technology available in the market?
- Operating experience: What is known about the actual performance of frame units with SCR?
- Costs: How much would it cost to construct, operate and maintain?

B. Due Diligence Process

1. Collaboration with NYISO, S&L, NERA and MPSA

Because of the short timeframe, the due diligence process was open and collaborative, involving NYISO staff familiar with the issue, as well as S&L and NERA experts involved with the initial report. In addition, Mitsubishi Power Systems Americas, Inc. (MPSA) provided general information on SCR system design, construction and operation as well as relating their experience in modeling flow dynamics, designing, installing and servicing various high-temperature SCR applications, including the SCR system at Marsh Landing. On October 25, MPSA hosted a day-long meeting at the Savannah Machinery Works that was attended by Brattle, Licata, NYISO staff, and S&L personnel, and presented overviews of SCR design and engineering, catalyst performance characteristics as well as confidential and proprietary information relevant to MPSA design and implementation of successful high-temperature SCR applications.

2. Collection of Data

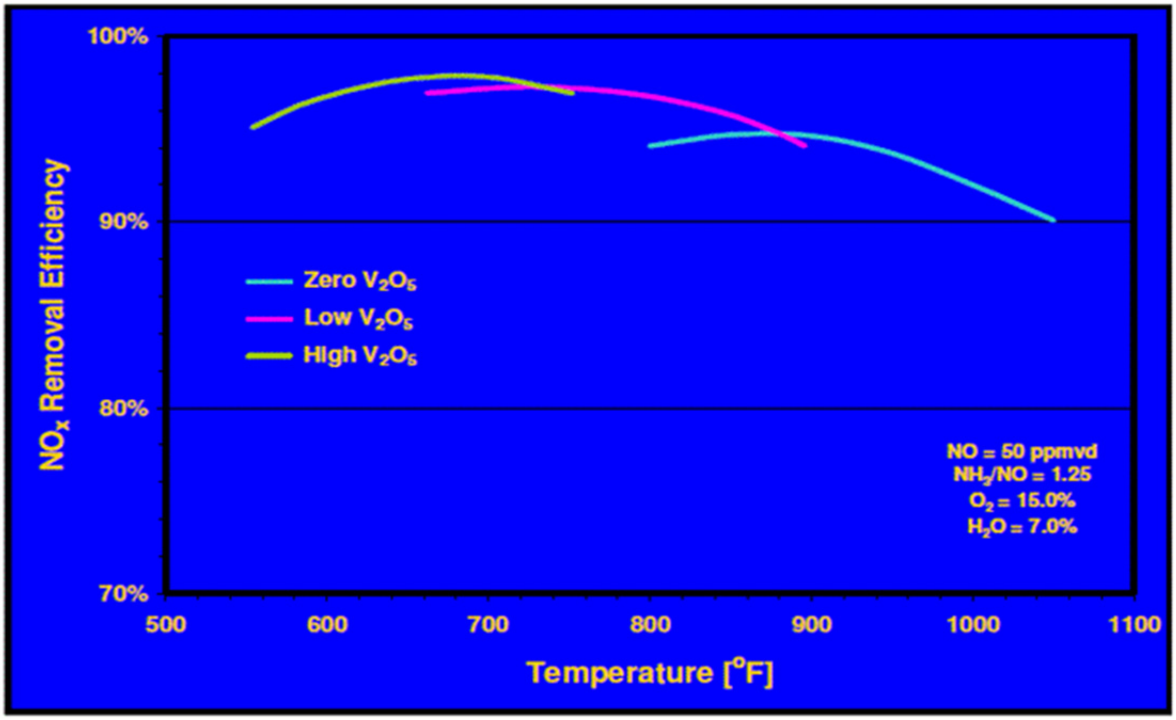
Brattle and Licata also collected technical data in the form of manufacturer's specs, reference lists and published papers, reviewed air permits and siting applications from CT/SCR projects including but not limited to Marsh Landing, and publicly available operational data from Marsh Landing. In addition, we contacted vendors, engineering firms, and catalyst providers to assess the technical and commercial status of relevant components.

III. Selective Catalytic Reduction for NO_X Control on Gas Turbines

Selective catalytic reduction (SCR) is a widely-used post-combustion emission control technique whereby vaporized ammonia is injected into the combustion exhaust gases before they pass through a catalyst bed. In the presence of the catalyst, nitrogen oxides (NO_x) react with oxygen and ammonia to produce nitrogen and water. Small amounts of ammonia that are not consumed in the reaction result in small levels of ammonia stack emissions, known as ammonia slip, which increase as the catalyst degrades over time. Catalyst has a finite lifetime, and must be replaced when no longer effective and/or ammonia slip reaches impermissible levels.

The performance of an SCR system depends primarily on the temperature of the exhaust gas as it passes through the catalyst. Although catalyst formulations have provided a continuum of temperature ranges, these are typically described by three temperature ranges for optimal NO_x reduction. A "normal" catalyst operates well at approximately 650° F, a "mid range" catalyst operates well between 800 and 900 °F, and a "hot" catalyst (generally zeolite based) can operate above a temperature of 1,100 °F, although the effectiveness of NO_x removal declines as a function of the exhaust gas temperature. This is shown in Figure 1.

Figure 1: Typical Effective Catalyst Ranges



Conventional vanadium/titanium catalysts are commonly used in SCR applications, and have an optimal operating temperature in the 600 to 750 °F range. Temperatures above 900 °F can cause permanent damage to vanadium/titanium catalysts, thus requiring the use of high temperature zeolite catalysts and/or air tempering systems that can reduce exhaust gas temperatures prior to introduction into the catalyst.

Air dilution or tempering systems inject unheated air into the turbine exhaust stream, where the amount of air injected is a function of the desired temperature reduction corresponding to the choice of catalyst. Another factor that contributes to catalyst performance is the degree of temperature variation in the flue gas as it passes through the catalyst bed. Optimal catalyst performance requires a fairly narrow range of temperature distribution:

> In addition, the exhaust flue gas temperature distribution at the inlet to the oxidation catalyst is typically restricted to ±10°F of the given design bulk average temperature, and at the same time typically should not to exceed ±25°F absolute

temperature mal-distribution at the catalyst face. For instance, for a given temperature of 850°F the allowable temperature mal-distribution is 840 ±25°F to 860 ±25°F.[6]

Catalyst vendors also have to stipulate other SCR inlet distribution conditions in order to maintain guaranteed levels of ammonia slip. For example, the ratio of ammonia to NO_x, and the inlet gas velocity has to be within ±10% and ±15% of design values, respectively, for Haldor Topsoe and Cormetech to guarantee 5 ppm ammonia slip.

The efficacy of air dilution systems for temperature reduction and uniformity depends primarily on engineering design, which is validated through the use of various proven modeling techniques. Catalysts that operate at higher temperatures tend to be more expensive, less efficient, and less durable. Vanadium-based catalysts also can be regenerated, which lowers operating costs. This creates a fundamental tradeoff between the cost of using a high temperature catalyst and the capital and operating costs of an air dilution system.

SCRs are used extensively in power generation applications including coal, oil, and combined cycle power plants. The application of SCR for gas combined cycle is more straightforward because exhaust gas temperatures are lower, near the 600-700 °F range, allowing for the use of "normal" catalysts. With the significant increase of the use of SCRs in coal-fired and gas combined cycle plants, both the catalyst and OEM vendors have developed significant improvements in computational fluid dynamics (CFD) and physical flow modeling. These enhanced modeling techniques are being applied to simple cycle projects.

The majority of recent SCR applications in simple cycle mode have been in aeroderivative gas turbines. These turbines have exhaust gas temperatures in the 750-975 °F range. In these applications, the high temperature and non-uniformity of the exhaust gas make it harder to effectively utilize the catalyst surface area. A number of aeroderivative simple-cycle gas turbines have been built with air dilution systems to protect the catalyst and extend catalyst life. These systems exhibit the same type of tradeoffs among the cost of the catalyst, the cost of the air dilution system and potential performance penalties (e.g., backpressure from air tempering that

6 "Integrated Exhaust System for Simple Cycle Power Plants" by Dr. Mark Buzanowski, *Energy Tech Magazine,* April 2011.

might reduce turbine output). Our review of SCR and catalyst vendor reference lists reveals dozens of mid-to high-temperature simple cycle turbine SCR installations in the U.S. since the mid-1990s. For these applications, catalyst vendors formulate a substantial variety of catalysts with a wide range of optimal temperatures between 800 and 1000 °F, and both the SCR systems and the catalysts are mature technologies that continue to improve through experience and innovation. F-class frame gas turbines exhibit exhaust gas temperatures can be in the range of 1050 to 1150 °F, ideal for combined cycle and cogeneration applications. The heat recovery systems in combined cycle configurations lowers exhaust gas temperatures into a range where conventional catalysts can be used without dilution air for SCRs. The application of SCRs on simple cycle frame turbines presents significant challenges due to the very high temperatures of the exhaust gas stream. However, these challenges are not fundamentally different than those faced when applying SCR to aeroderivative turbines. In both applications, potential engineering solutions need to balance tradeoffs between catalyst choice, and the cost and performance impacts of air tempering systems. These tradeoffs are more difficult to manage in frame-type turbines, but are not insurmountable with proper design, testing and construction. SCRs for any thermal power plant are not "off-the-shelf" products in any case, as there are a significant number of engineering and design intricacies that need to be solved for any given application and site-specific conditions. The challenge of applying SCR to simple cycle frame-type turbines has led to few installations of SCRs and comparatively less data available on the operational performance of such systems. Nevertheless, there are numerous SCR applications that experience exhaust gas temperatures well in excess of 800 °F as verified through catalyst vendor reference lists. The issue to consider here, therefore, becomes how engineering tradeoffs are managed and solved, and at what cost.

The nature of the engineering solutions implies that existing publicly available information will be sufficient to judge the commercial status of the technology. The primary engineering challenges of installing an SCR on a simple cycle combustion turbine (both frame and aeroderivative) is threefold: (1) reduce exhaust gas temperature into an economic/reliable catalyst range, typically with dilution air; (2) achieve a uniform distribution of temperature, velocity, and NO_x in a vertical plane as the combustion gas combined with vaporized ammonia enters the catalyst banks; and (3) accomplish the combustion gas conditioning with minimal backpressure. If an engineering design accomplishes these three things simultaneously, the back-end SCR is a conventional, proven technology, provided that one has selected an appropriate catalyst for the resulting temperature/conditions. Moreover, accomplishing (1) - (3) is primarily a matter of engineering a system that, aside from air fans and ammonia injection (both mature technologies) has no moving parts and (provided thermal expansion issues have been properly accounted for), is thus not prone to fail over time due to typical failure mechanisms. Other things can and do go wrong with turbines and SCRs - but that is endemic to the conventional proven technologies, not necessarily a function of the engineering design required to match a combustion turbine unit to an SCR. This perspective suggests that the efficacy of an engineering solution to applying SCR to a frame turbine is revealed mostly in the fact that it works initially, e.g., once it is commissioned and operating within permitted levels. It may not require years of operating data to prove commercial viability of the approach.

IV. Environmental Requirements

A. Air Emission Limits

1. BACT and LAER

In order to obtain permits, new stationary electric generating sources must undergo technical reviews that set limits on air emissions. Table II-5 of the NERA report outlines the requirements for air emissions. Most relevant to this assessment is the Lowest Achievable Emission Rate (LAER) which NERA and S&L determine is <2.5 parts per million (ppm) for nitrogen oxides (NO_x) in non-attainment areas such as New York City, Long Island, and the lower Hudson Valley, an emission rate obtainable only through SCR. Other applicable limits include 3 ppm for carbon monoxide (CO) and 1 ppm for volatile organic compounds (VOCs), achieved through an oxidation catalyst installed in the SCR; and 5 ppm for ammonia slip.

Based on the review of the USEPA's RACT/BACT/LAER Clearinghouse, recent air permits issued in the U.S. for gas turbine installations (combined and simple cycle), published technical papers, and performance guarantees provided by SCR OEMs and catalyst vendors, we believe the following table contains the permitting levels likely to apply to new sources in the near future (emissions stated in ppmdv corrected to 15% O_2):

Table 1: BACT and LAER Emissions Limits

	NO_x	Ammonia Slip
BACT	2.5	5-10
LAER	2	5

These levels are slightly lower than estimated by NERA/S&L, however that should not affect the assessment of either SCR option for BACT or LAER compliance. In particular, although NERA/S&L assessed BACT as 3 – 5 ppm for NO_x, this limit was avoided by restricting hours of operation below the project significance threshold established in the NYSDEC regulations (6 NYCRR part 231), and therefore did not require the use of SCR on the frame combustion turbine outside of southeastern New York.

2. US EPA NSPS for CO_2

On September 20, 2013, the US EPA re-proposed New Source Performance Standards for CO_2 emissions from electric generating units under Section 111(b) of the Clean Air Act. The NSPS for natural gas-fired combustion turbines was set at 1,100 lb. CO_2/MWh for units at or below 850 mmBTU/hr and 1,000 lb. CO_2/MWh for units above 850 mmBtu/hr. These standards are readily met for combustion turbines in combined cycle application, but are challenging for many simple cycle turbines. Neither the LMS100 nor the SGT6-5000F5 with SCR in simple cycle mode would comply with these limits.[7] However, the EPA exempted units with annual capacity factors below 33% from the emission rate requirement on the premise that new combustion turbines intended for peaking applications would be dispatched below the 33% capacity factor. A capacity factor of 33% is equivalent to 2,920 hours of operation at maximum output. This capacity factor was not exceeded in the NERA analysis for any unit evaluated except for the units located in Zone K Long Island, where both the LMS100 and the F-class frame units operated at capacity factors above 33%.

7 Using S&L figures, the LMS100 in New York City has a heat input of 914 mmBtu/hour and 1,085 lb. CO_2 per MWh, while the larger SGT6-5000F5 has a CO_2 emission rate of 1,209 lb. per MWh.

The proposed NSPS is not a current requirement for either frame or aeroderivative simple cycle combustion turbines and therefore does not impact the proxy plant recommendations. While the proposed NSPS for CO_2 may be promulgated as a final regulation during the 2014/17 Demand Curve Reset period, it is currently a proposed rule that will be subject to public comment once it is published in the Federal Register. As such, it is uncertain how a final NSPS for electric generating units will impact the combustion turbine technology evaluated in this demand curve reset. Further, the proxy plant recommendations we are suggesting here would remain unchanged if the proposed NSPS, as currently drafted, was a current regulatory requirement for combustion turbines. Each technology (LMS100 and the SGT6-5000F5) would be required to take an annual operating limit of 2,920 hours in order to qualify for the exemption from the NSPS.[8] Taking such an operational limitation would not change the determination of the "lowest fixed, highest variable cost" unit for any of the demand curve areas. An annual limit on operating hours, however, would lower the energy revenues available for the Long Island proxy plant and therefore raise the Net CONE value for the proxy plant.

B. Other Requirements

Dry closed cycle cooling will be required in most regions in New York. It is possible that local safety requirements may be imposed for ammonia delivery and storage; however, they would apply equally to the any SCR installation and thus do not affect our assessment. Different options such as anhydrous, aqueous or (dry) urea have different capital, operating and reagent costs. NERA/S&L assumed 19% aqueous ammonia in their assessment.

V. Commercial Experience

A. Permitting

We found several permit applications for new frame combustion turbines with SCR, with the earliest being the application for the Pastoria facility expansion proposed in 2005. While at least two proposed new frame CT peaking plants with SCR were never built (Pastoria in California and Bridgeport in Connecticut) the permit applications contain information regarding projected

8 This assumes all hours at maximum MW output, so the hourly limit could be expanded somewhat to account for partial load operation.

performance characteristics and perspectives on the commercial development of SCR technology relevant for frame turbine applications. These are discussed in Appendix A.

B. Existing Installations and Operating Record

Several SCRs have been installed on simple cycle frame units. While it is true that two early installations failed to operate properly (the Puerto Rico Electric Power Authority [PREPA] plant in Puerto Rico and the Riverside Plant in Kentucky) there are also examples where the technology has been made to work, such as the Marsh Landing, SMUD McClellan, and McClure generating stations. The fact that SCRs do not always perform as intended is in many cases due to an engineering shortcoming rather than a technical infeasibility. SCR systems are engineered products that need to be customized to the particular application and site being considered. Thus material selection, flow distribution, air tempering and vaporizing systems, among others, play an important role in the successful performance of an SCR. The challenges with SCR operation are not unique to frame units; we are also aware of a number of operational shortcomings of SCRs in aeroderivative gas turbine applications, despite a generally successful track record over time.

1. SMUD McClellan

The Sacramento Municipal Utility District (SMUD) owns and operates the McClellan power plant, which commenced commercial operations in 1986 and consists of a General Electric 7E simple cycle frame turbine with a 77 MW nameplate rating. The unit was fitted with an SCR in 2004 but operates very infrequently, averaging about 50 hours per year. The maximum exhaust gas temperature is over 1,000 °F, and although it does not include a tempering air system the system achieves a 90% NO_x removal rate. As far as we are able to determine, the SCR system has worked as intended.

2. MID McClure

Another frame simple cycle gas turbine with an SCR that is currently in operation is the Modesto Irrigation District (MID) McClure power plant in California. It consists of a simple cycle GE MS7001B gas turbine that can fire on both natural gas and ultra-low sulfur diesel (ULSD). In late 2005 the plant was fitted with an SCR including a tempering air fan system to reduce gas turbine flue gas temperature from its maximum operating temperature of about 970 °F. The plant operates about 500 hours per year (about 25% on ULSD) and achieves 90% NO_x removal using 29% aqueous ammonia as the SCR reagent.

3. Marsh Landing

The Marsh Landing Generating Station consists of four Siemens SGT6-5000 F4 simple cycle gas turbines (190 MW each) each fitted with tempering air systems, SCR and oxidation catalyst for NO_x and CO control. It began commercial operations in early 2013. The turbines have maximum operating temperature of over 1,100 °F and the SCR reactor and tempering air fans were designed to minimize back pressure. The Marsh Landing design exit temperature from the turbine was 1,146 °F. During acceptance testing the flue gas was cooled at the catalyst face to the average 849 °F with a maximum variation of + 20 °F and - 30°F, all of which meet the catalyst vendor's specification and demonstrated that the cooling system worked as modeled. The system achieves an 87% NO_x removal rate, and is permitted at 2.5 ppm (1-hour average) and 20.83 lb/hour for NO_x emissions during normal operation, with allowances made for startup, shutdown, and periods of significant (25 MW/Min) ramping.

We reviewed publicly available CEMS data to assess the performance of these units. [9] Data was available starting in March of 2013 for units 1 and 2, and starting in April 2013 for units 3 and 4. The data in Table 2 shows the distribution of hours that each unit has operated at a certain output level. Although the units were originally rated at 190 MW, the units each have exceeded this output level between 11% and 26% of their operating hours, and each has attained over 200 MW.

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[9] CEMS data was available from the Ventyx Energy Velocity Suite through June 30, 2013, spanning a total of 425 operating hours. Preliminary CEMS data for the third quarter of 2013 was made available on the EPA website on October 31, 2013 and included a total of 82 operating hours. In the preliminary CEMS data NO_x emissions were rounded down to the nearest integer, and only gross generation was reported.

Table 2: Marsh Landing Hourly Output Levels

Output Range	Unit 1	Unit 2	Unit 3	Unit 4
0 < MW < 50	26	23	27	20
50 <= MW < 100	11	11	17	10
100 <= MW < 150	36	34	63	34
150 <= MW < 190	39	21	18	22
190 <= MW	39	20	16	20
Total	151	109	141	106
Maximum Hourly Output, MW	203	201	205	205

Source:
CEMS data from EPA

We have also analyzed the emissions performance of each unit using the CEMS data. In Table 3 we show the number of hours in which each unit appears to exceed an emission limit according to the CEMS data. We have distinguished normal operating hours from hours that include a startup, a shutdown, or significant hour-to-hour ramping.[10]

Table 3: Marsh Landing NO_x Emissions Performance

Unit	Start EPA Reporting	End EPA Reporting	Startup, Shutdown, and Ramping Hours	Hours Over Limits	Normal Hours	Hours Over Limit	Total Operating Hours	Total Hours Over Limits	% Over Limits
1	3/12/2013	9/30/2013	66	2	85	0	151	2	1.3%
2	3/12/2013	9/30/2013	57	0	52	2	109	2	1.8%
3	4/14/2013	9/30/2013	74	0	67	3	141	3	2.1%
4	4/17/2013	9/30/2013	60	0	46	0	106	0	0.0%
		Total	257	2	250	5	507	7	1.4%

Source:
CEMS data from EPA

10 The hourly CEMS data is not granular enough to accurately account for startup, shutdown, or ramping periods as defined in the permit. Given these limitations, for example, we define startup hours as spanning the two operating hours that include the initial hour of initial power output.

Although the CEMS data is very limited (and not generally suited for determining compliance with complex permit conditions) we have identified a small number of hours where the data shows emissions apparently over the applicable limits (in allowable lb. NO_x per hour), accounting for 1.4% of the total operating hours. Data limitations prevent us from identifying the particular circumstances that led to these observations, although some hours appeared to have data anomalies. Significant intra-hour ramping, permissible combustor tuning, equipment tests, turbine operating issues, or upsets from various causes could explain these figures and remain compliant with permit terms, but that information is not available from CEMS data. In Table 4 we show the fraction of normal operating hours in which emissions rates were below the 1-hour 2.5 ppm limit set in the permit.[11]

Table 4: Marsh Landing Distribution of Hourly NO_x Emissions

	Unit				
	1	2	3	4	Total
Number of Normal Operating Hours	85	52	67	46	250
Hours with emissions < 2.5 ppm					
Number of Hours	76	48	58	44	226
As % of Normal Hours	89%	92%	87%	96%	90%
Hours with emissions < 2 ppm					
Number of Hours	5	46	35	41	127
As % of Normal Hours	6%	88%	52%	89%	51%

Source:
CEMS data from EPA

This table shows that hourly NO_x emissions were below 2.5 ppm in 90% of the hours, and emissions were below 2 ppm about half of the time. In order to benchmark these results, we examined CEMS data for two facilities with LMS100 turbines and SCRs (Waterbury in Connecticut and Panoche in California). These plants displayed similar patterns of dispersion in emissions or emission rates, with occasional excursions beyond simple permit terms. This suggests that a frame class gas turbine fitted with an SCR operating in simple cycle mode can meet operational requirements consistently and as effectively as SCRs fitted on aeroderivative turbines. Graphs depicting the emission performance of the Marsh Landing units are provided in

[11] We note that the permit allowed 3-hour averaging for any hour that included a ramping minute above 25 MW/min, a flexibility not captured in this analysis.

Appendix B. These graphs show that there were only 4 hours where emissions exceeded the 45.1 lb/hr startup limit. We cannot tell if any special testing was conducted during these periods or if an excusable equipment malfunction occurred. Two of the excursions occurred during startup on Unit 1. Unit 4 (the last unit to startup) had no excursions which may indicate that plant personnel are gaining experience holding emissions within the permit conditions.

4. Early Failed Units

a. PREPA

The Puerto Rico Electric Power Authority (PREPA) Central Cambalache unit in Puerto Rico consists of three diesel-fired frame combustion turbines. SCR and air tempering systems were retrofitted to lower NO_x emissions from 42 to 10 ppm. The SCRs failed to operate as expected from 1999 to 2001, when the SCR systems were eventually removed. The failure appears to have been caused by catalyst poisoning resulting from SO_2 and heavy metals emissions arising from the use of a grade of fuel oil which did not meet the manufacturer's requirements. Because the failure mechanism appears to arise from mis-fueling the unit, the PREPA facility does not inform an assessment of SCR applicability to frame combustion turbines. Further, the proxy plant recommended will predominately fire natural gas and burn ultra low sulfur diesel (ULSD), considered a much "cleaner" blend than the fuel oil used in Puerto Rico, for limited hours as a backup fuel. Finally, a coated catalyst was used on this project. This type of catalyst is no longer used and has been replaced by more advanced catalyst designs.

b. Riverside

Another installation of a SCR system with tempering air took place in 2001 at the Riverside Generating Company facility in Kentucky, consisting of five Siemens 501F combustion turbines fired exclusively on natural gas. The SCRs were installed voluntarily to reduce emissions in order to increase permitted operating hours, but did not successfully achieve the desired emission reductions and eventually were deactivated. We could not identify or locate public information regarding the failure mechanism or causes of the underperformance of the system. However, sources at MPSA that evaluated the specifics of the SCR issues at Riverside reported that the cooling air fans were rated at 400 HP and believed that the fans were not properly sized (by comparison, the fans at Marsh Landing are rated at 2,300 HP). In interviews with personnel involved in the design of the unit, one stated that there were issues with the selection of material used in construction and the unit experienced problems with thermal growth, causing seals to fail. Another source reported that the catalyst was installed improperly and was heavily damaged in operation. In addition, a coated catalyst was used on this project. This type of catalyst is no longer used and has been replaced by more advanced catalyst designs.

VI. Commercial Status: Conclusion

A. SCR Systems for Frame Units

SCR systems are commercially available for frame combustion turbine units, which have demonstrated performance in line with their environmental permits. Although this market is in early stages of development, there has been significant commercial interest in serving this market for roughly a decade. Advances in cost, operation and achieved emission rates have occurred incrementally. Accordingly, we believe that enough experience has been obtained to make this option commercially available to achieve applicable environmental standards in New York. Given the economics of a frame-type turbine relative to an aeroderivative turbine in peaking applications, we expect that suppliers will continue to innovate and improve the technology in order to capture significant share of new plant builds.

The experience of Marsh Landing represents a significant milestone, although it represents a logical progression in SCR innovation. Mitsubishi has applied for a patent on the air tempering system, although this should not constrain the market from the standpoint of suppliers, either through licensing or parallel innovation. For example, we understand that both Siemens and Vogt Power (part of Babcock Power) plan to enter this market. Mitsubishi continues to develop and market the frame combustion turbine SCR combination, and has actively bid on several projects.

B. Catalysts

There are several catalyst manufacturers that supply catalysts for combustion turbines. Although most of the catalyst deliveries thus far were undoubtedly made to aeroderivative units, these vendors clearly have formulated a variety of mid- to high-temperature catalysts that may be applicable to frame unit applications with tempering air systems. These vendors include:

Cormetech: The Cormetech reference list has 75 high temperature projects with 160 units. 52 of the projects were on gas turbine applications. Cormetech performed their first SCR installation in 1995 and their temperature applications range from 800 °F to 1,000 °F.

BASF: BASF has a reference list that shows that they provided catalyst on 9 simple cycle turbines, including units served by Research Cottrell. BASF began providing catalysts for SCR applications in 1999 and currently produces only high temperature catalysts.

Ceram: Their reference list has 26 gas turbine applications including sites in the US and worldwide.

Haldor Topsoe: Has an extensive list of simple cycle applications. Their list shows 134 installations, most of which are located in the US. Haldor Topsoe's first SCR application was in 1999. Their 9xx series catalyst is designed to operate 800 °F, the 6xx series operates at 930 °F, and for units not using cooling air the 3xx series can operate at 1,000 °F.

These four catalyst manufactures have confirmed in writing that they provide performance guarantees on their products that will meet the BACT and LAER permitting requirements presented in Section IV.

VII. Considerations for Selecting Proxy Unit and Recommendation

A. NYISO Proxy Unit Criteria

The criterion that a reference unit be "economically viable" is open to some degree of interpretation. At a minimum, the unit should comply with environmental requirements and be commercially available. SCR's have demonstrated compliance with applicable emission limits when installed on frame-type combustion turbines. Although in an earlier stage of commercial experience than SCR on aeroderivative units, the technology is sufficiently mature in the commercial market to be considered economically viable.

We note that an earlier Demand Curve Reset recommendation was made based on a newer generation turbine that at the time had not yet gained widespread use in the utility-scale power market. In the 2007 Demand Curve Reset, NERA/S&L recommended using the GE LMS100 aeroderivative turbine despite the fact that only one such plant was then currently in operation. NERA/S&L examined the LMS100 technology and determined that its performance and cost characteristics made it a likely choice in the future, supported by significant order queue and a proposal for LMS100 then being evaluated in the NYISO interconnection study process. We believe that the likely performance and costs for frame-type combustion turbines with SCR will encourage more widespread adoption of this technology in the future, albeit at a slower pace than anticipated in the 2007 analysis of LMS100 turbines.

B. Recommendation

Given our analysis we recommend that a frame unit with SCR be considered as the proxy unit for zones in New York that require strict NO_x controls.

VIII. Cost and Revenue Estimates

A. Parameters and Assumptions

The involvement of MPSA enabled review of the assumptions that S&L made for costs of an SCR applicable to the Siemens SGT6-5000F(5), which was requested in the NYISO report.[12] The units at Marsh Landing were slightly earlier version Siemens SGT6-5000F(4) units that had slightly lower nominal capacity ratings and minor differences in performance characteristics, such as slightly higher exhaust gas temperature and did not have dual-fuel capability. The SCR that required for the Siemens F5 turbine would be about 18% larger by volume than the Siemens F4 turbines in Marsh Landing project. This larger application for the F5 turbine is within normally accepted scale-up parameters and new physical flow and CFD models would be run to validate any specific necessary changes in design.

S&L authorized the limited release of proprietary model data to MPSA so that MPSA could provide an indicative cost estimate for an applicable SCR. In its request, The Brattle Group included the following:

> This is a request for engineering data on an SCR system capable of achieving specific emissions limits when installed on the reference unit frame combustion turbine currently modeled in the New York Independent System Operator Demand Curve Reset process. When preparing the requested engineering data and/or indicative costs, please provide information that in your judgment provides the maximum degree of confidence in the long-run performance of the system to consistently attain the emission limits and expected performance of the turbine. The engineering design should be consistent with one that Mitsubishi would provide warranty coverage for a time period consistent with industry standards for commercial unit operation.

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12 *Proposed NYSIO Installed Capacity Demand Curves For Capability Years 2014/2015, 2015/2016 and 2016/2017 Final,* New York Independent System Operator, September 6, 2013.

In reply, MPSA indicated that they had "reviewed the performance data and input assumptions and can confirm that these are very similar design considerations to ours and the resulting costs that were in the NERA [report] for the simple cycle SGT6-5000F(5) are comparable to what we would estimate."[13] This was additionally confirmed in discussions held on October 25, 2013 in Savannah.

B. Costs and Performance Parameters

We have identified no material changes in costs or performance attributes from the NERA/S&L estimates summarized in the NYISO Report of September 9, 2013. Accordingly, those costs should be used to estimate net CONE and derive new demand curve recommendations for ISO consideration.

Additionally, we confirmed through discussions with MPSA that although they believe that the Marsh Landing units could be capable of 10 minute start to full capacity output (or that it could be designed to do so at some additional cost) the commissioning tests conducted prior to operation did not demonstrate that capability. Therefore, we also recommend retaining the assumption that the proxy unit qualify only for 30-minute non-spin reserve for estimating operating revenues.

IX. Effects on CONE and Demand Curve Parameters

NERA and S&L agreed to run their models for demand curve estimation with the costs and performance parameters of the F-Class frame turbine with SCR, which were previously reported in Appendix B: SGT6-5000F (5) GT with SCR of the September 6, 2013 NYISO Report. Table 5 shows the impact on demand curve parameters from adopting a single F-Class frame turbine with SCR as the proxy unit in New York City, Long Island and the new Capacity Zone Z (the New York Control Area NYCA did not change), and the corresponding parameters from Appendix A: NYISO's Recommended Demand Curve Parameters and Demand Curves from the September 6, 2013 NYISO Report. These figures include the adjustments for temperature/relative humidity and the NYISO recommended Zero Crossing Points that were indicated in that report.

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13 E-mail from Rand Drake (MPSA) to Marc Chupka (Brattle), October 22, 2013.

Table 5: Changes in Demand Curve Parameters

2014/2015 Demand Curve Parameters	NYCA	NYC	LI	NCZ
September 6, NYISO Report				
ICAP Max Clearing Price ($/kW-mo)	13.50	36.83	30.96	28.10
Reference Point ($/kW-mo)	8.84	25.57	13.28	17.86
Zero Crossing (% of req)	112.0	118.0	118.0	115.0
Summer DMNC (MW)	210.1	185.5	188.0	186.3
Annual CONE ($/kW-yr)	107.98	294.6	247.7	224.79
Annual EAS Revenues ($/kW-yr)	18.48	54.5	114.6	53.06
Annual Net CONE ($/kW-yr)	89.50	240.11	133.07	171.73
Brattle-Licata Report				
ICAP Max Clearing Price ($/kW-mo)	13.50	26.14	20.88	18.80
Reference Point ($/kW-mo)	8.84	18.55	7.96	12.14
Zero Crossing (% of req)	112	118	118	115
Summer DMNC (MW)	210.1	208.8	210.7	209.4
Annual CONE ($/kW-yr)	107.98	209.14	167.02	150.44
Annual EAS Revenues ($/kW-yr)	18.48	33.49	86.67	32.77
Annual Net CONE ($/kW-yr)	89.50	175.65	80.35	117.67
Percent Change				
ICAP Max Clearing Price	0%	-29%	-33%	-33%
Reference Point	0%	-27%	-40%	-32%
Zero Crossing	0%	0%	0%	0%
Summer DMNC	0%	13%	12%	12%
Annual CONE	0%	-29%	-33%	-33%
Annual EAS Revenues	0%	-39%	-24%	-38%
Annual Net CONE	0%	-27%	-40%	-31%

As expected, the substitution of the F-Class frame turbine for the LMS100 resulted in a significant reduction in Reference Points and Maximum Clearing Prices, while the Dependable Maximum Net Capability (DMNC) increased due to the larger frame unit. The reference points fell by 27% in New York City, 32% in the New Capacity Zone and 40% in Long Island (although the potential impact of reduced operating hours due to the CO_2 NSPS was not modeled for Long Island). The Maximum Clearing Price was also lower, particularly in Long Island where it was 33% lower and in the New Capacity Zone where it was also 33% lower. The adoption of the F-Class frame unit with an SCR as a proxy unit in environmentally constrained areas of New York would have a significant impact on capacity prices in the relevant zones. Appendix C shows additional results and graphs depicting the resulting demand curves for 2014/2015, 2015/2016 and 2016/2017.

Appendix A: Permitting

In assessing the viability of the use of SCR technology on simple cycle frame class gas turbines to meet the required NO_x emissions limits we have reviewed the permitting experience in other jurisdictions. We have found that a number of permits have been issued for gas turbines with SCR in simple cycle configuration for both new builds and retrofits. In general, emissions limits are set by comparison with similar facilities (i.e. other simple cycle turbines), and are not different for frame and aeroderivative turbines. We note the relevance of new build versus retrofit permits. If a retrofit were to perform below expectations, the owner may have the option to continue to operate the plant without the SCR. The stakes are much higher for new builds, given that the inability to meet the performance standards set forth in its permit could prevent the plant from commercial operations and put the entire project investment at risk.

The record shows that other jurisdictions have permitted the development of simple cycle gas turbines with an SCR. Below we discuss the experience in the MID McClure and Marsh Landing power plants in California, a state with some of the tightest emission control requirements in the country. We also reviewed permitting issues for the proposed Pastoria Energy Facility Expansion (CA) and the Bridgeport Peaking Station (CT).

A. MID McClure

The Modesto Irrigation District (MID) McClure power plant is located in Modesto, CA, and is comprised of two generating units. On November 7, 2005, the San Joaquin Valley Air Pollution Control District issued a permit to modify one of the turbines at the site. The permit allowed for modification of one dual-fuel capable 49.5 MW General Electric MS-7000-1-B industrial frame gas turbine engine fitted with an SCR. The project also includes a fresh air inlet blower used to reduce the 969 °F exhaust gas temperatures to allow for the proper functioning of the SCR. Emission limits are based on a three hour rolling average for NO_x, and a 24 hour rolling average for ammonia slip. The unit is also limited to a maximum of 1,500 operating hours per year.

Table A-1: Operating Emission Limits for McClure Power Plant

	McClure	
	Natural Gas	Diesel
NO_x Emissions, lb/hr	8.64	15.31
NO_x Emissions, ppm	3.0	5.0
Ammonia Slip, ppm	10.0	10.0

Sources and Notes:
All emissions stated in ppmvs @ 15% O2.
McClure Authority to Construct Conditions. November, 2005.

B. Pastoria Energy Facility Expansion

The California Energy Commission issued an order approving the Pastoria Energy Facility Expansion in December 2006, located near the city of Bakersfield, California. The expansion consisted of the installation of a 160 MW gas-fired General Electric 7FA combustion turbine operating in simple cycle mode with a projected startup date of December 2011. The BACT chosen to reduce NO_x emissions was an SCR using anhydrous ammonia vapor, and included an exhaust air dilution system to reduce exhaust temperatures below 850 degrees Fahrenheit. The expansion was never pursued and the permit has since expired. Emissions limits are based on a one-hour average for NO_x and a 24 hour rolling average for ammonia slip.

Table A-2: Operating Emission Limits for Pastoria Energy Facility Expansion

	Pastoria	
	Natural Gas	Diesel
NO_x Emissions, lb/hr	16.25	
NO_x Emissions, ppm	2.5	
Ammonia Slip, ppm	10.0	10.0

Sources and Notes:
All emissions stated in ppmvs @ 15% O2.
Pastoria Energy Facility Expansion. California Energy Commission Final Decision. December, 2006.

The Commission stated that staff believes that an ammonia slip of 10 ppm is appropriate, and that no performance data was available at the time for existing 7F simple cycle turbines to suggest that a lower ammonia slip level would be feasible.

C. Bridgeport Harbor Application to Construct

In June 2007 Earth Tech, Inc. prepared a Permit to Construct Application for Bridgeport Energy II, LLC to support the proposed Bridgeport Peaking Station in Bridgeport, CT. Although the plant was never built, the application supported the concept that an SCR on a simple cycle frame gas turbine was feasible. The Application was for the installation of either two General Electric model 7FA gas turbines or two Siemens model SGT6-5000F turbines for a total 350 MW of simple cycle generating capacity. The units would fire primarily on natural gas, but would have the capability to run on ultra-low sulfur diesel fuel. The units were proposed to have a limit on operating hours and to be equipped with SCR technology to reduce NO_x emissions to the Lowest Achievable Emission Rate (LAER) prevailing at the time for combustion turbines. The Application reflected an aim to "achieve the lowest NO_x emissions of any simple-cycle "F" class turbine operating in the United States."

The application recognized the difficulty associated with installing an SCR in a frame turbine due to the high temperatures of the exhaust gases. Thus they proposed the use of a cooling air system to reduce exhaust temperature to a range in which the SCR can effectively operate.

Table A-3: Proposed Operating Emission Limits for Bridgeport Peaking Station

	Bridgeport	
	Natural Gas	Diesel
NO_x Emissions, lb/hr	21-25	107-125
NO_x Emissions, ppm	3.0	15.0
Ammonia Slip, ppm	6.0	6.0

Sources and Notes:
All emissions stated in ppmvs @ 15% O2.
Bridgeport Permit to Construct Application. June, 2007.

D. MARSH LANDING

On August 8, 2010 the Bay Area Air Quality District issued a Permit to Construct the Marsh Landing Generating Station, located near the city of Antioch, California. The plant was approved as a peaker plant to supply energy during times of high demand as well as provide reliability to manage intermittent sources. The permit was issued for the installation of four simple cycle Siemens SGT6-5000 F(4) gas turbines, each rated at 190 MW. Each GT is equipped with a Mitsubishi SCR system for NO_x using 19% aqueous NH3 and an oxidation catalyst for CO and VOC control. The unit was permitted for natural gas fuel only.

The units at Marsh Landing were subject to BACT under the Bay Area Air Quality District's New Source Review regulations. For the case of nitrogen oxides, the District identified SCR, SNCR, and EMx as post combustion NO_x controls that can remove NO_x from turbine exhaust gas. SCR is a widely used post combustion control technology use on gas turbines at the utility scale.

In this permit the applicant selected SCR as the BACT for NO_x. The District evaluated the risk associated with ammonia slip, as well as potential environmental risks associated with the transportation and storage of ammonia. In addition the District also evaluated the potential for ammonia slip to contribute to the formation of particulate matter. While the District concluded that these risks do not justify the elimination of SCRs as a control alternative, these risks must be evaluated in a site specific context, given that particulate matter formation from ammonia slip can be increased by cold temperatures.

The BACT emissions limit for NO_x was set to 2.5 ppm at 15% O_2 averaged over one hour. In cases when changes in load are greater than 25 MW per minute the District allowed the 2.5 ppm limit to be achieved over 3 hours, due to the inability to the NO_x control to respond to rapid changes in load. Ammonia slip was limited to 10 ppm three-hour average. The maximum NO_x emission during any one hour containing a startup period shall not exceed 45.1 lb/hr

Table A-4: Operating Emission Limits for Marsh Landing Generating Station

	Marsh Landing	
	Natural Gas	Diesel
NO_x Emissions, lb/hr	20.83	
NO_x Emissions, ppm	2.5	
Ammonia Slip, ppm	10.0	10.0

Sources and Notes:
All emissions stated in ppmvs @ 15% O2.
Marsh Landing Final Determination of Compliance. June, 2010.

Appendix B: Marsh Landing CEMS Data

Figure B-1: Generation and emissions data for Marsh Landing Unit 1

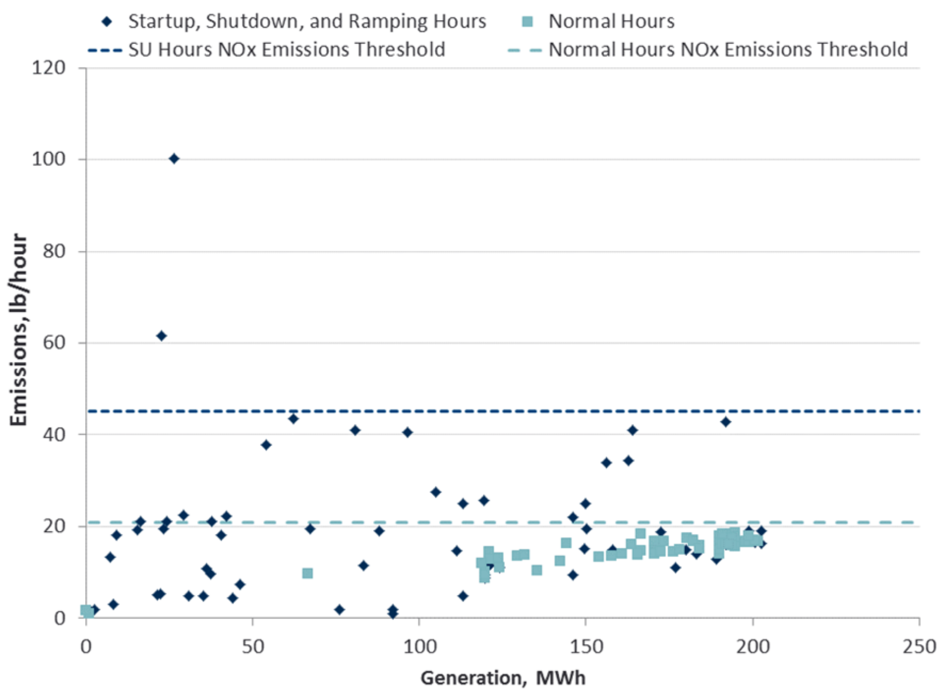


Figure B-2: Generation and emissions data for Marsh Landing Unit 2

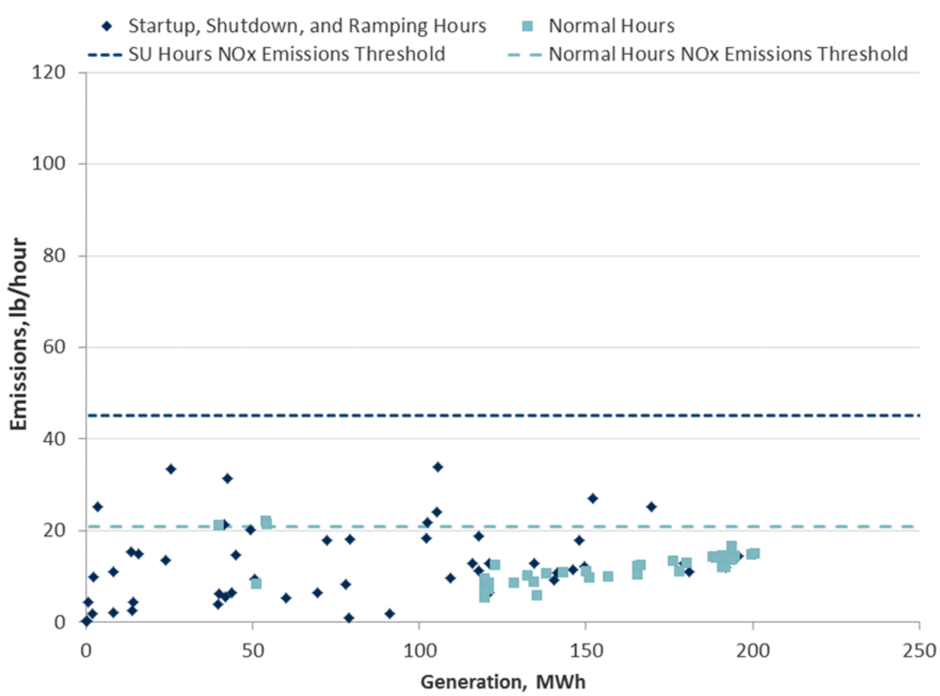


Figure B-3: Generation and emissions data for Marsh Landing Unit 3

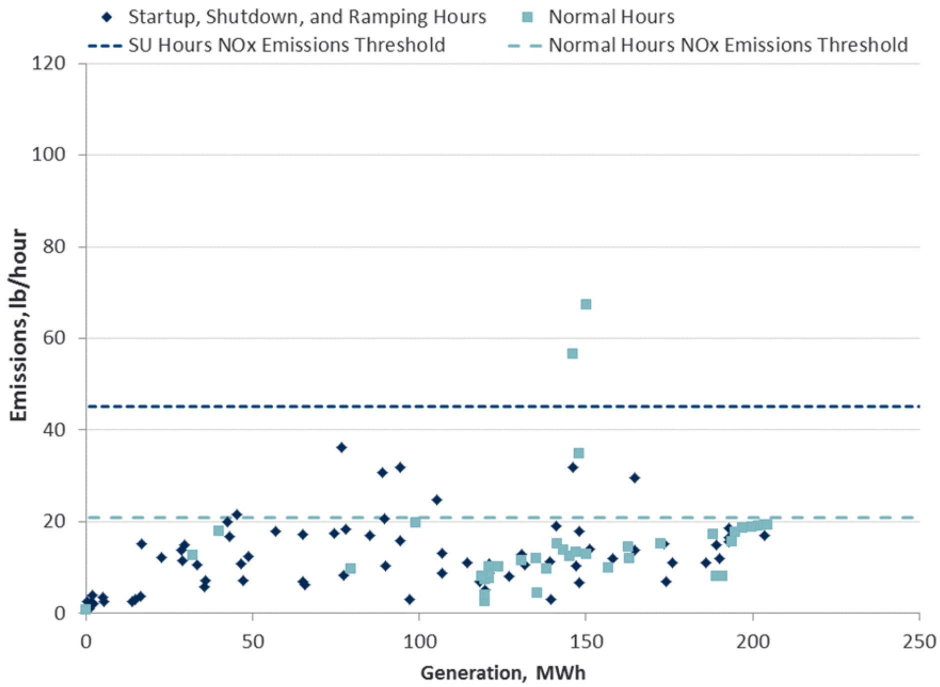
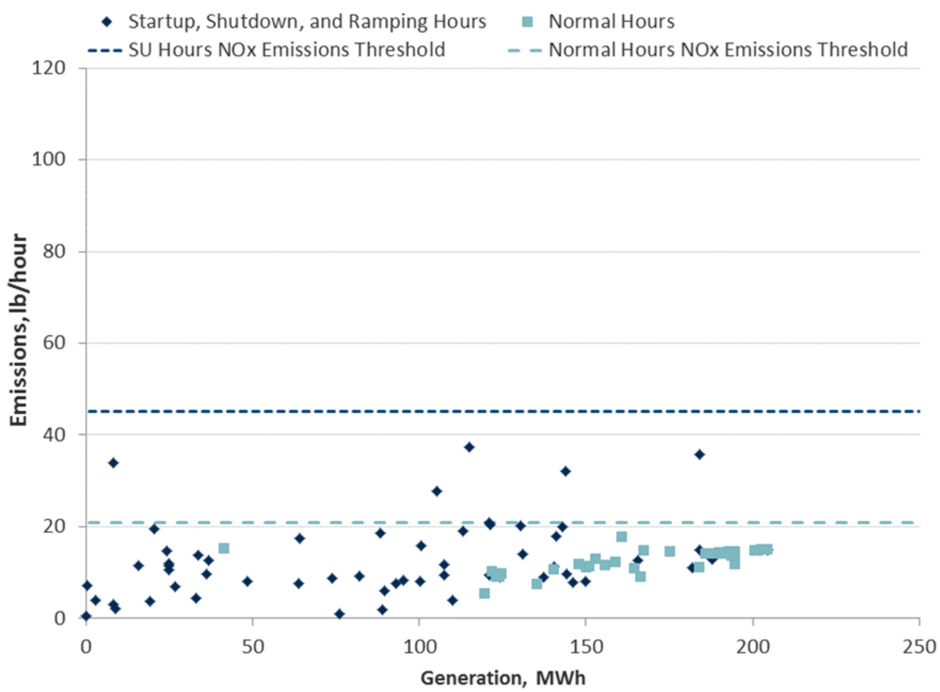


Figure B-4: Generation and emissions data for Marsh Landing Unit 4

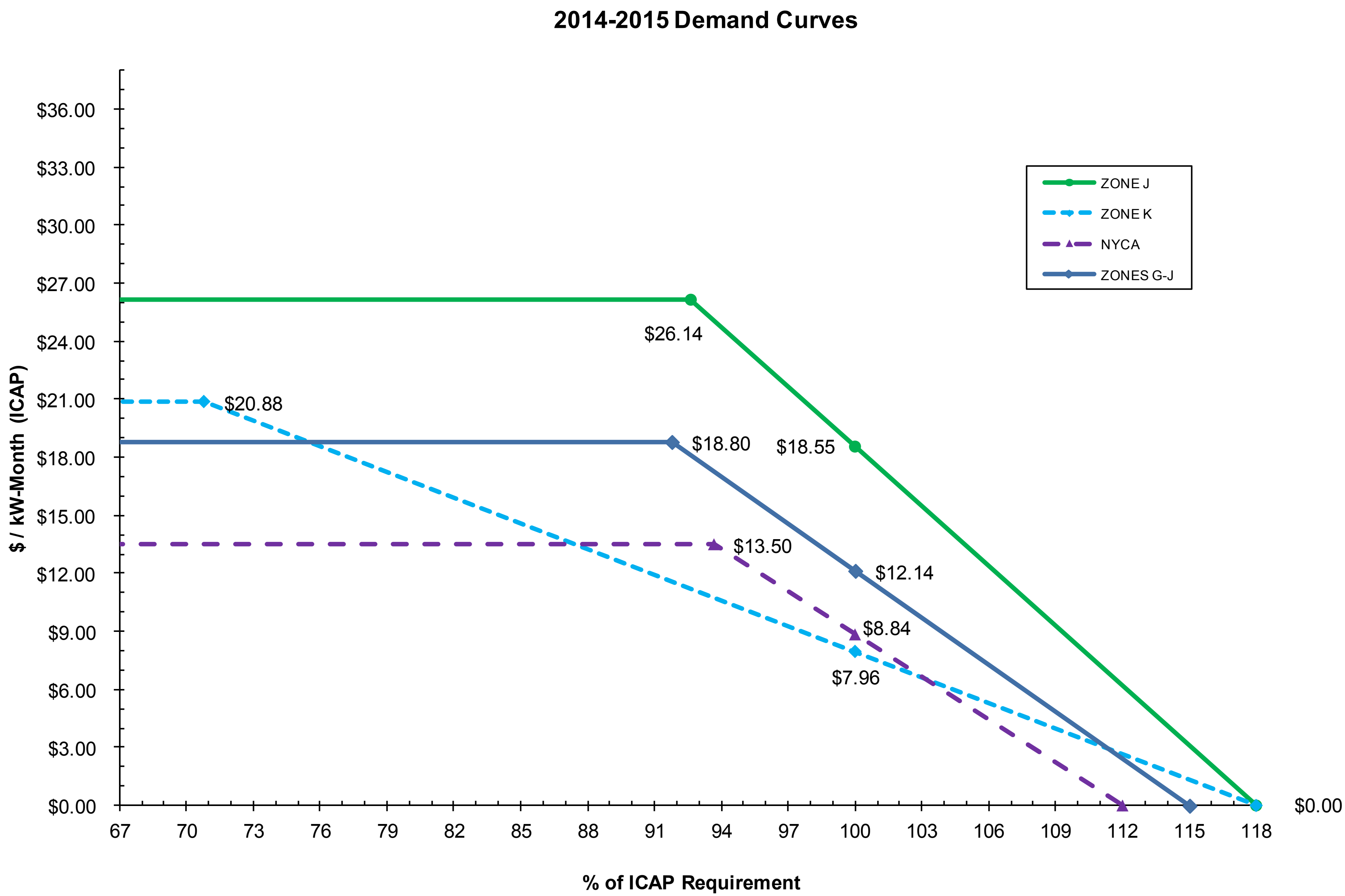


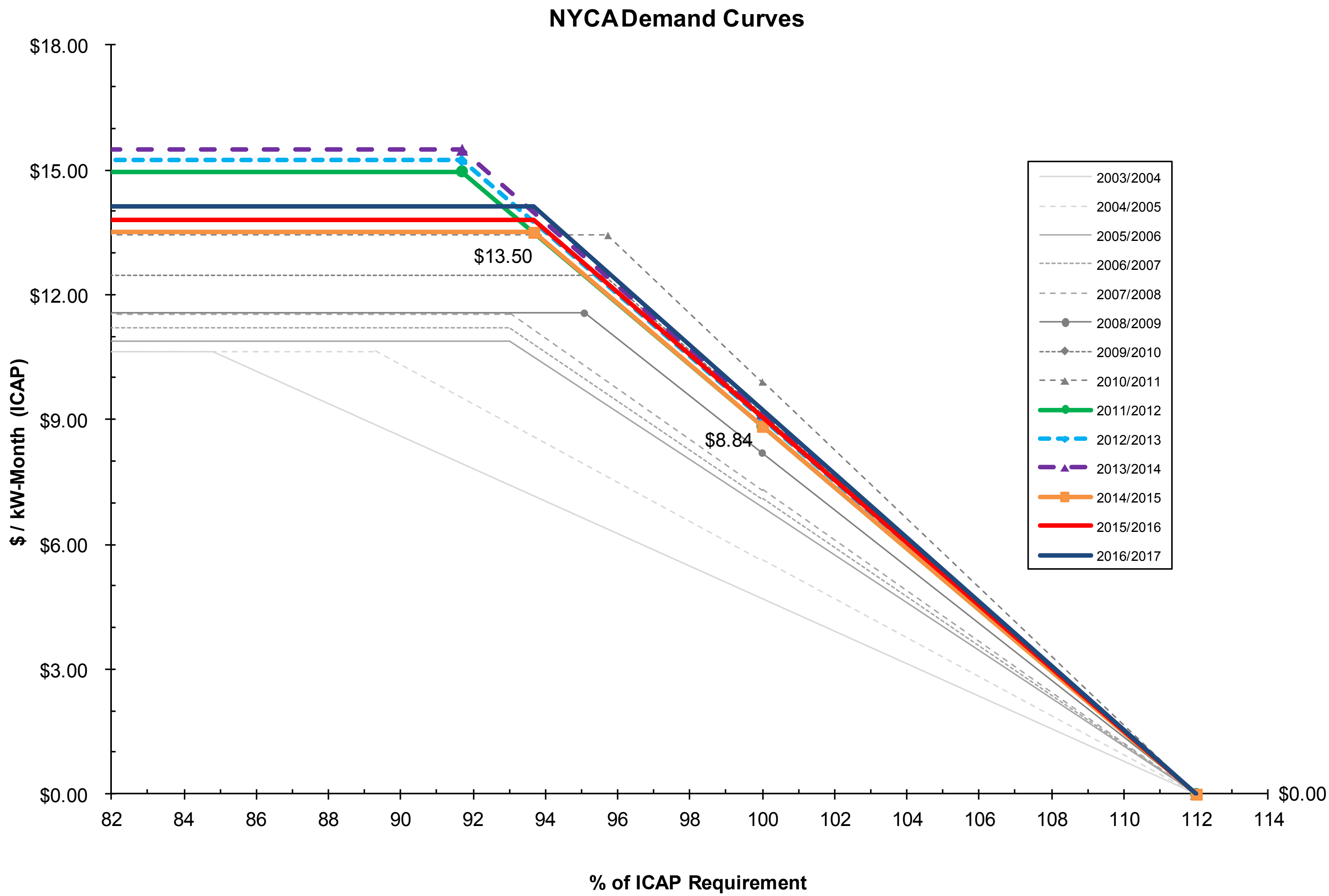
Appendix C: Demand Curve Parameters and Demand Curves

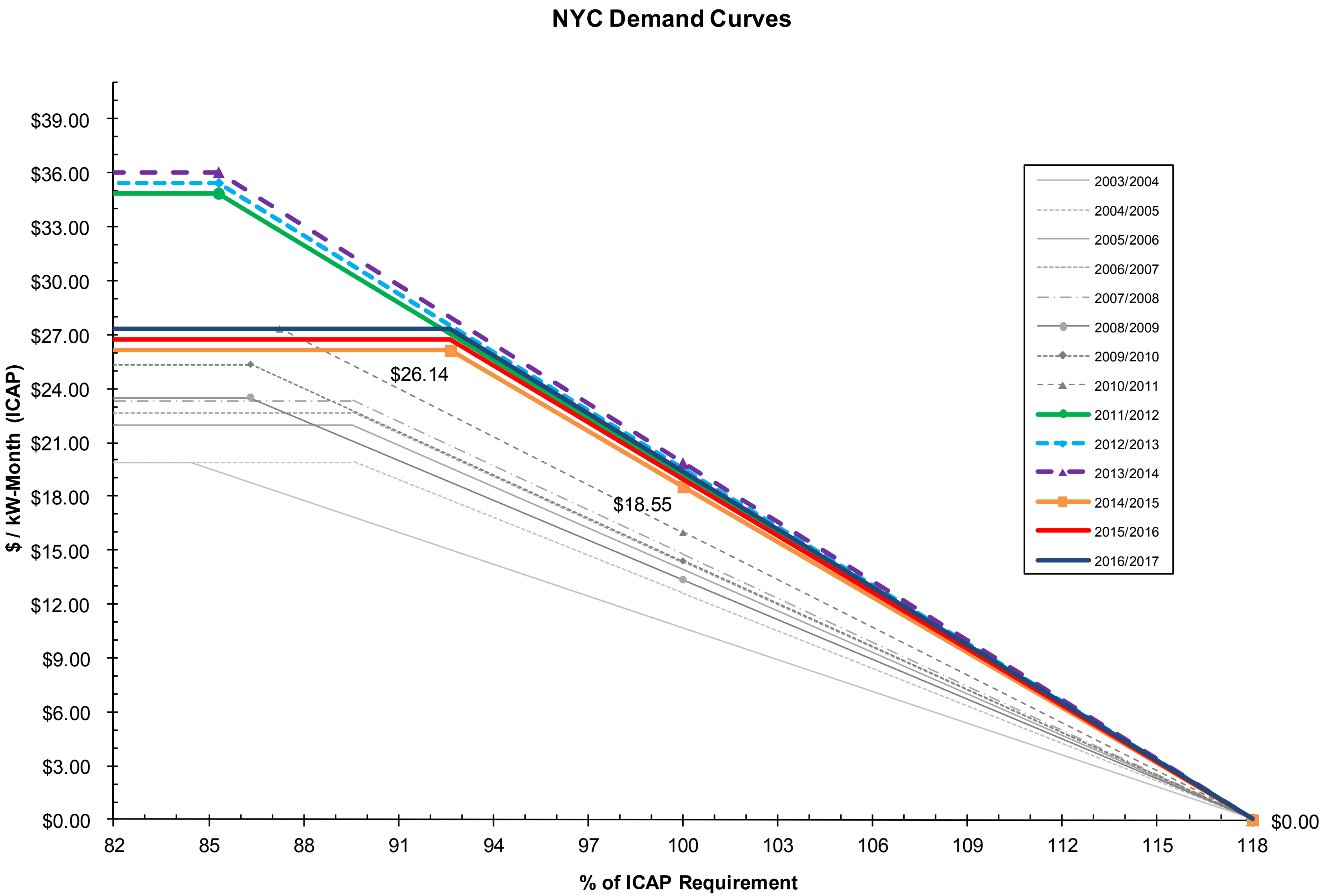
2014/2015					
	NYCA	NYC	LI	NCZ	
Annual Revenue Req. (per KW)	$107.98	$209.14	167.02	150.44	$/kW-Year (ICAP basis)
Net Revenue (per kW)	$18.48	$33.49	$86.67	$32.77	$/kW-Year (ICAP basis)
Annual ICAP Revenue Req. (per kW) =	$89.50	$175.65	$80.35	$117.67	$/kW-Year (ICAP basis)
Net Plant Capacity - ICAP (MW)	206.50	205.30	206.77	205.60	Average Degraded Capacity
Total Annual Revenue Req. =	$18,481,512	$36,060,780	$16,613,783	$24,193,149	
Ratio of Winter to Summer DMNCs	1.047	1.087	1.070	1.068	Adjusted from 2012 GB values
Summer DMNC	210.1	208.8	210.7	209.4	Net Summer Capacity (DMNC Rating Convention)
Winter DMNC	226.2	223.6	225.2	225.2	Net Winter Capacity (DMNC Rating Convention)
Summer Reference Point =	$8.84	$18.55	$7.96	$12.14	$/kW-Month (ICAP basis)
Winter Reference Point =	$5.41	$9.56	$4.85	$6.62	$/kW-Month (ICAP basis)
Monthly Revenue (Summer) =	$1,857,284	$3,872,498	$1,677,514	$2,541,837	
Monthly Revenue (Winter) =	$1,223,742	$2,137,463	$1,092,346	$1,491,109	
Seasonal Revenue (Summer) =	$11,143,704	$23,234,988	$10,065,086	$15,251,021	
Seasonal Revenue (Winter) =	$7,342,452	$12,824,778	$6,554,077	$8,946,652	
Total Annual Revenue =	$18,486,156	$36,059,766	$16,619,162	$24,197,673	validates "Total Annual Revenue Req." is met
Demand Curve Parameters					
ICAP Monthly Reference Point =	$8.84	$18.55	$7.96	$12.14	$/kW-Month (ICAP basis)
ICAP Max. Clearing Price =	$13.50	$26.14	$20.88	$18.80	$/kW-Month (ICAP basis)
Demand Curve Length=	112.0%	118.0%	118.0%	115.0%	

2015/2016					Escalation Factor = 2.2%
	NYCA	NYC	LI	NCZ	
Annual Revenue Req. (per KW)	$110.35	$213.75	$170.70	$153.75	$/kW-Year (ICAP basis) - (LMS-100 updated)
Net Revenue (per kW)	$18.88	$34.23	$88.58	$33.49	$/kW-Year (ICAP basis)
Annual ICAP Revenue Req. (per kW) =	$91.47	$179.52	$82.12	$120.26	$/kW-Year (ICAP basis)
Net Plant Capacity - ICAP (MW)	206.5	205.3	206.8	205.6	Average Degraded Capacity
Total Annual Revenue Req. =	$18,888,106	$36,854,117	$16,979,286	$24,725,398	
Ratio of Winter to Summer DMNCs	1.047	1.087	1.070	1.068	Adjusted from 2012 GB values
Summer DMNC	210.1	208.8	210.7	209.4	Net Summer Capacity (DMNC Rating Convention)
Winter DMNC	226.2	223.6	225.2	225.2	Net Winter Capacity (DMNC Rating Convention)
Summer Reference Point =	$9.03	$18.95	$8.12	$12.41	$/kW-Month (ICAP basis)
Winter Reference Point =	$5.53	$9.77	$4.97	$6.76	$/kW-Month (ICAP basis)
Monthly Revenue (Summer) =	$1,897,203	$3,956,002	$1,711,233	$2,598,369	
Monthly Revenue (Winter) =	$1,250,886	$2,184,416	$1,119,373	$1,522,643	
Seasonal Revenue (Summer) =	$11,383,218	$23,736,012	$10,267,399	$15,590,211	
Seasonal Revenue (Winter) =	$7,505,316	$13,106,494	$6,716,239	$9,135,856	
Total Annual Revenue =	$18,888,534	$36,842,506	$16,983,638	$24,726,068	validates "Total Annual Revenue Req." is met
Demand Curve Parameters					
ICAP Monthly Reference Point =	$9.03	$18.95	$8.12	$12.41	$/kW-Month (ICAP basis)
ICAP Max. Clearing Price =	$13.79	$26.72	$21.34	$19.22	$/kW-Month (ICAP basis)
Demand Curve Length =	112.0%	118.0%	118.0%	115.0%	

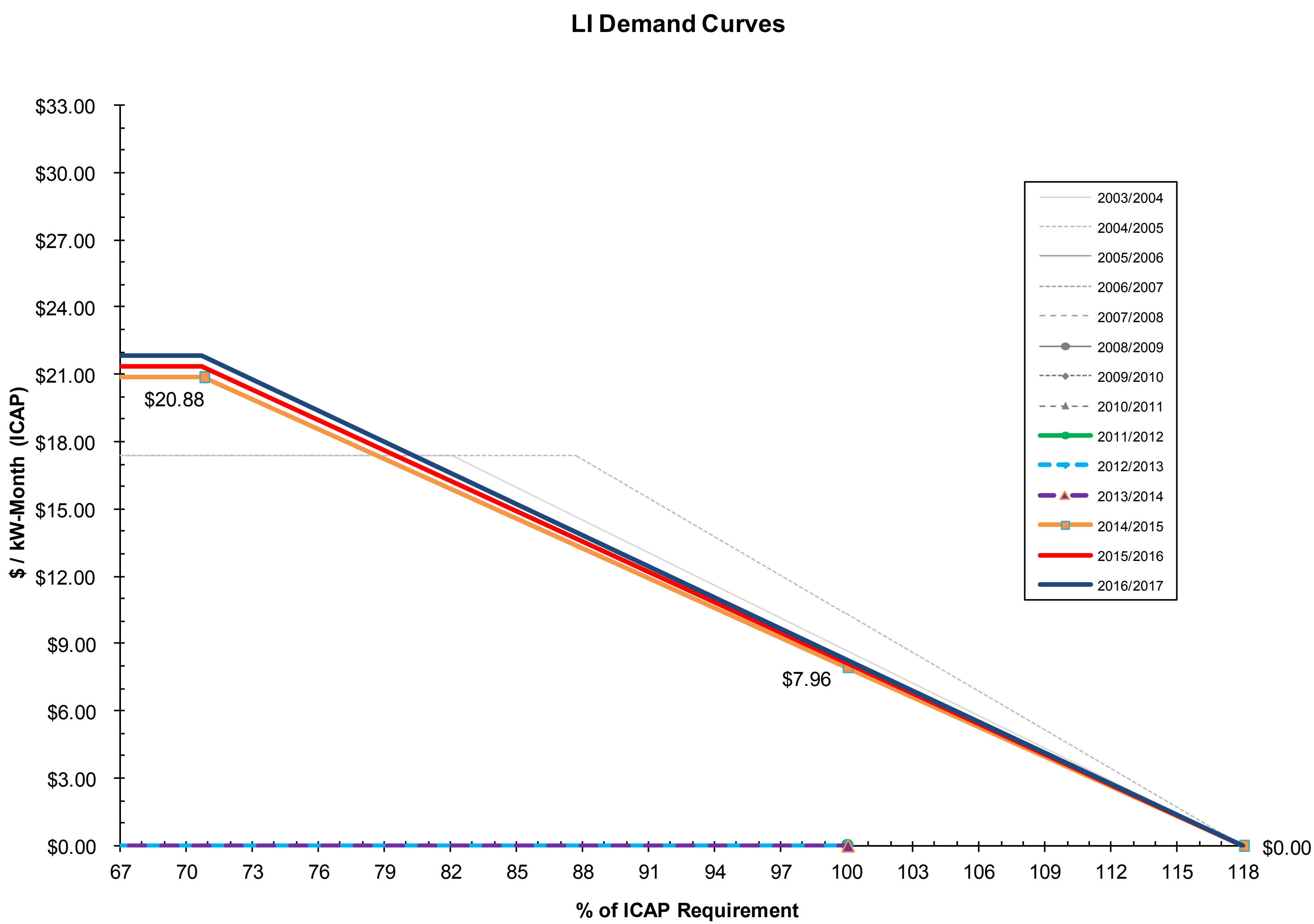
2016/2017					Escalation Factor = 2.2%
	NYCA	NYC	LI	NCZ	
Annual Revenue Req. (per KW)	$112.78	$218.45	$174.45	$157.13	$/kW-Year (ICAP basis) - (LMS-100 updated)
Net Revenue (per kW)	$19.30	$34.98	$90.53	$34.22	$/kW-Year (ICAP basis)
Annual ICAP Revenue Req. (per kW) =	$93.48	$183.47	$83.92	$122.91	$/kW-Year (ICAP basis)
Net Plant Capacity - ICAP (MW)	206.5	205.3	206.8	205.6	Average Degraded Capacity
Total Annual Revenue Req. =	$19,303,644	$37,664,908	$17,352,831	$25,269,357	
Ratio of Winter to Summer DMNCs	1.047	1.087	1.070	1.068	Adjusted from 2012 GB values
Summer DMNC	210.1	208.8	210.7	209.4	Net Summer Capacity (DMNC Rating Convention)
Winter DMNC	226.2	223.6	225.2	225.2	Net Winter Capacity (DMNC Rating Convention)
Summer Reference Point =	$9.23	$19.37	$8.30	$12.68	$/kW-Month (ICAP basis)
Winter Reference Point =	$5.65	$9.99	$5.08	$6.91	$/kW-Month (ICAP basis)
Monthly Revenue (Summer) =	$1,939,223	$4,043,681	$1,749,167	$2,654,900	
Monthly Revenue (Winter) =	$1,278,030	$2,233,604	$1,144,148	$1,556,429	
Seasonal Revenue (Summer) =	$11,635,338	$24,262,087	$10,495,001	$15,929,402	
Seasonal Revenue (Winter) =	$7,668,180	$13,401,625	$6,864,888	$9,338,575	
Total Annual Revenue =	$19,303,518	$37,663,712	$17,359,890	$25,267,977	validates "Total Annual Revenue Req." is met
Demand Curve Parameters					
ICAP Monthly Reference Point =	$9.23	$19.37	$8.30	$12.68	$/kW-Month (ICAP basis)
ICAP Max. Clearing Price =	$14.10	$27.31	$21.81	$19.64	$/kW-Month (ICAP basis)
Demand Curve Length =	112.0%	118.0%	118.0%	115.0%	


2014-2015 Demand Curves
ZONE J
ZONE K
NYCA
ZONES G-J
$26.14
$20.88
$18.80
$18.55
$13.50
$12.14
$8.84
$7.96
$0.00
$ / kW-Month (ICAP)
$36.00
$33.00
$30.00
$27.00
$24.00
$21.00
$18.00
$15.00
$12.00
$9.00
$6.00
$3.00
$0.00
67
70
73
76
79
82
85
88
91
94
97
100
103
106
109
112
115
118
% of ICAP Requirement


NYCA Demand Curves
$18.00
$15.00
$12.00
$9.00
$6.00
$3.00
$0.00
$ / kW-Month (ICAP)
$13.50
$8.84
$0.00
82
84
86
88
90
92
94
96
98
100
102
104
106
108
110
112
114
% of ICAP Requirement
2003/2004
2004/2005
2005/2006
2006/2007
2007/2008
2008/2009
2009/2010
2010/2011
2011/2012
2012/2013
2013/2014
2014/2015
2015/2016
2016/2017



NYC Demand Curves
$ / kW-Month (ICAP)
$39.00
$36.00
$33.00
$30.00
$27.00
$24.00
$21.00
$18.00
$15.00
$12.00
$9.00
$6.00
$3.00
$0.00
82
85
88
91
94
97
100
103
106
109
112
115
118
% of ICAP Requirement
$26.14
$18.55
$0.00
2003/2004
2004/2005
2005/2006
2006/2007
2007/2008
2008/2009
2009/2010
2010/2011
2011/2012
2012/2013
2013/2014
2014/2015
2015/2016
2016/2017


LI Demand Curves
$33.00
$30.00
$27.00
$24.00
$21.00
$18.00
$15.00
$12.00
$9.00
$6.00
$3.00
$0.00
$ / kW-Month (ICAP)
$20.88
$7.96
$0.00
67
70
73
76
79
82
85
88
91
94
97
100
103
106
109
112
115
118
% of ICAP Requirement
2003/2004
2004/2005
2005/2006
2006/2007
2007/2008
2008/2009
2009/2010
2010/2011
2011/2012
2012/2013
2013/2014
2014/2015
2015/2016
2016/2017

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WASHINGTON
LONDON
MADRID
ROME

THE Brattle GROUP