

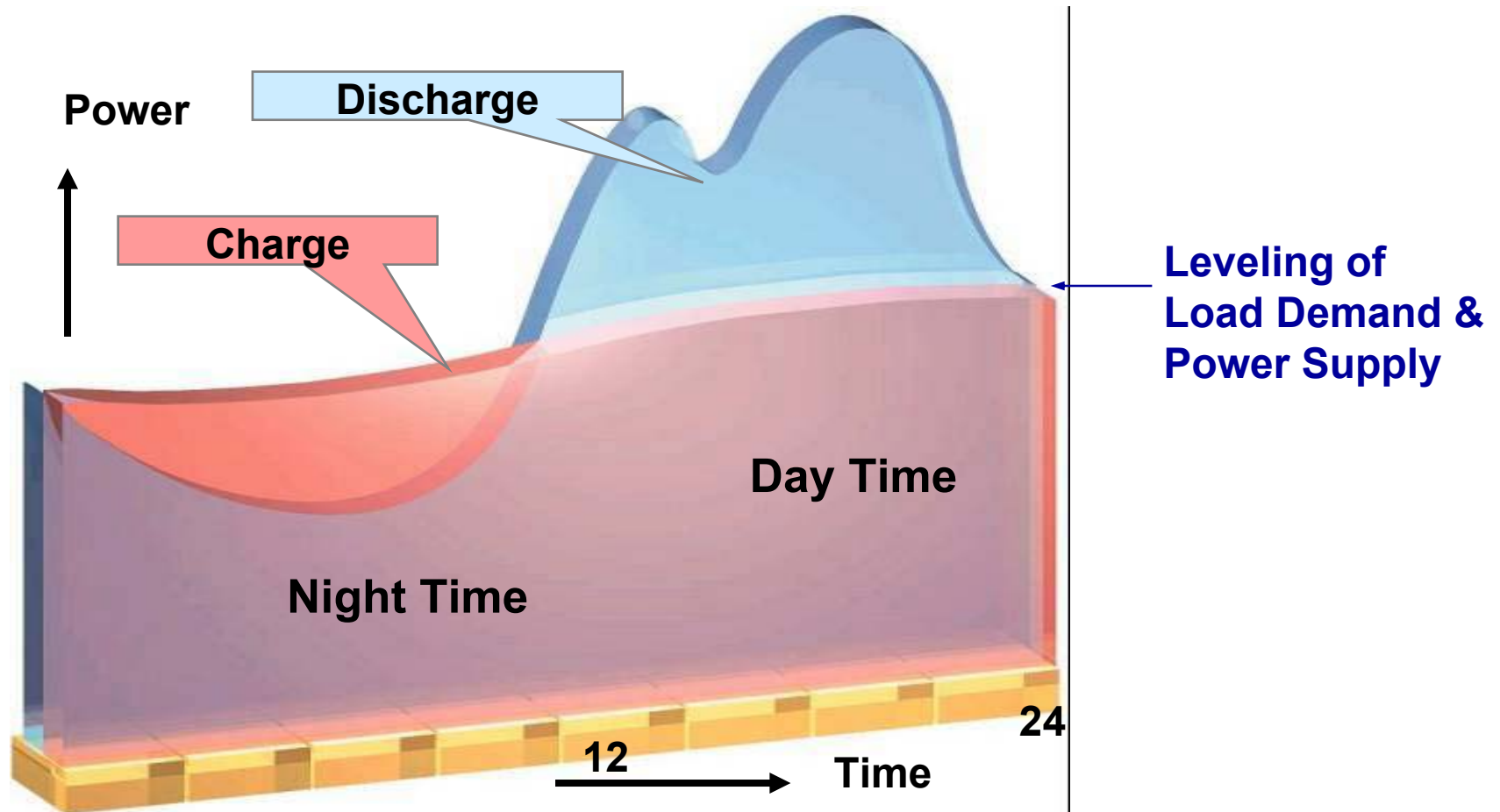
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## ***Overview of NAS Battery for Load Management***



**CEC Energy Storage Workshop  
February 2005**

# ***Load Management with Energy Storage***



# ***NAS Battery Highlights***

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- **Mid 1980s - TEPCO/NGK commence joint R&D**
- **Late 1980s – NGK/ABB commence cooperative exchange**
- **1992 – First demo project at TEPCO – still operating**
- **April 2002 – Over 50 demo projects later, NAS systems offered commercially in Japan**
  - **TEPCO offers commercial systems within its service area; since followed by other major utilities**
  - **NGK offers integrated commercial systems via teaming with Toshiba plus other PCS vendors**
- **September 2002 – AEP hosts first U.S. demonstration project**
  - **Power electronics/system integration provided by ABB**
  - **Other projects under development in U.S., Europe and SE Asia**
- **April 2003 – NGK initiates commercial scale NAS manufacturing**
  - **40 MW produced in 2003, ~65 MW in 2004**
  - **Space and plans for near-term expansion to ~140 MW/yr**
- **July 2004 – Operation of largest new NAS installation to date**
  - **9.6 MW/57.6 MWh project by TEPCO for Hitachi's auto systems factory**

# ***July 2004 – Hitachinaka, Japan New NAS Battery Facility for Hitachi***

**The World's Largest Battery System for Energy Storage is now Operational  
at Hitachi's Automotive Systems Factory in Japan.**



# *April 2003 – Nagoya/Komaki, Japan*

## *New NAS Battery Manufacturing Plant*

### NAS Battery Goes Commercial in Japan

New Firing Kiln  
In Nagoya



Beta Alumina -  
Alpha Alumina Bonding



**Komaki Plant**

Production Capacity : 65MW/Yr.  
6000 sq.m Factory + 1000 sq.m Warehouse  
Land Space for 200MW is Available for  
Future Expansion



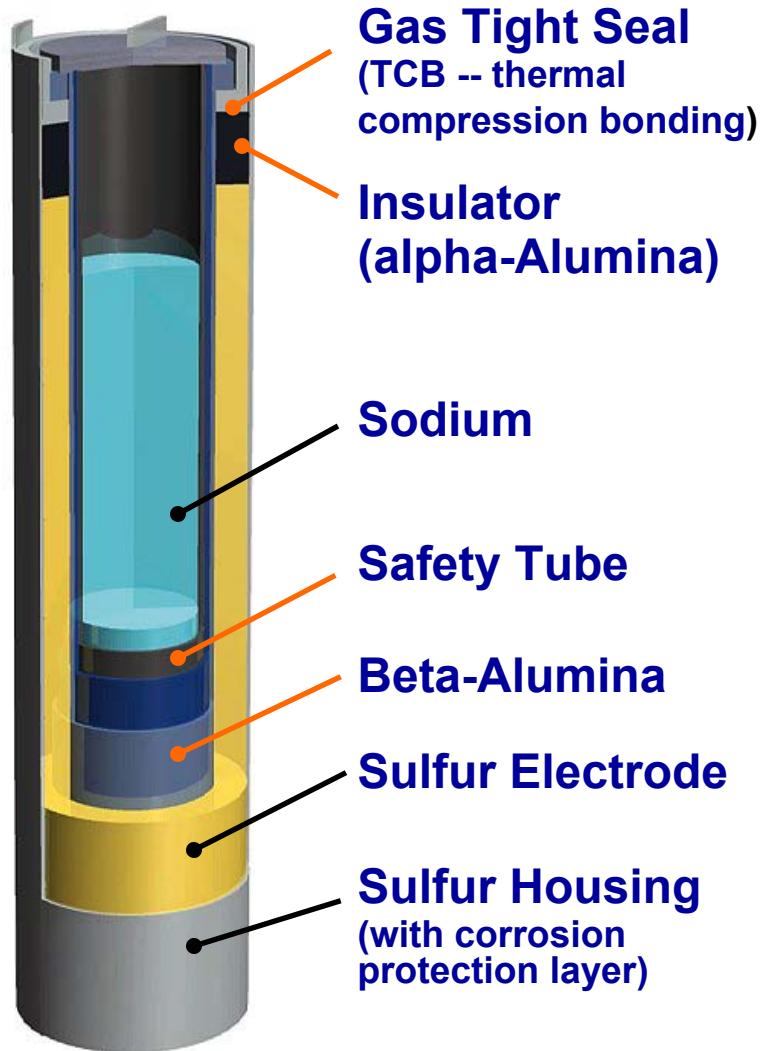
Robot Welding



500kW NAS



# Structure of NAS Battery Cell



- **Low resistance, high efficiency due to**
  - Beta Alumina tube
  - Sulfur electrode design

- **High durability due to**
  - Corrosion protection layer
  - Sulfur electrode design

- **High energy density due to**
  - Cell properties and design

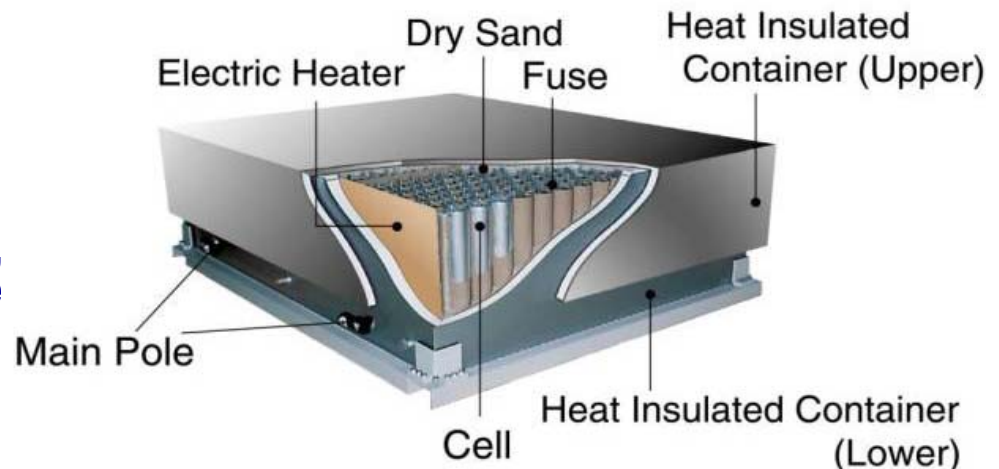
- **Intrinsic safety due to**
  - Incorporation of safety tube

# ***NAS Technology: Battery Module Overview***

- **Battery module: cells connected in series/parallel or series arrays within a thermally insulated enclosure**
  - Nominal AC capacity: 50 kW, 360 or 430 kWh (320 or 384 cells)
  - Operating temperature range: 290 and 360C
  - 3500 kg; L x W x H = 2.3 x 1.7 x 0.7 = 2.9 m<sup>3</sup>
  - Modules configured in series and/or parallel to support multi-megawatt loads

- **Protective measures:**

- Safety tube incorporated in cell design
- Hermetically sealed cells
- Double-layer stainless steel, vacuum insulated enclosure
- Sand filler packing between cells
- Fused electrical isolation



# ***NAS Product Lines***

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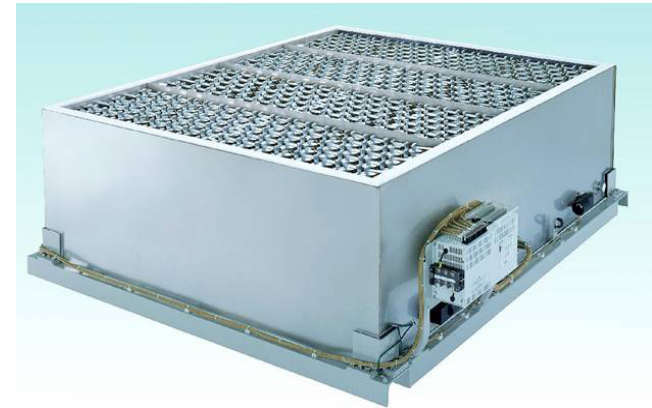
- **NGK offers NAS battery modules in two product lines:**
  - PS Modules: Best suited for long duration discharges typical of Peak Shaving applications
  - PQ Modules: Best suited for high power, short duration discharges typical of Power Quality applications
- **PS Modules are available in two configurations**
  - PS-E50 Modules nominally rated at 50 kW, 430 kWh
  - PS-G50 Modules nominally rated at 50 kW, 360 kWh
- **PQ Modules are available in one configuration**
  - PQ-50 Modules nominally rated at 50 kW, 360 kWh, or 150 kW for 30 seconds/hr plus 360 kWh, or up to 250 kW for 30 seconds/hr



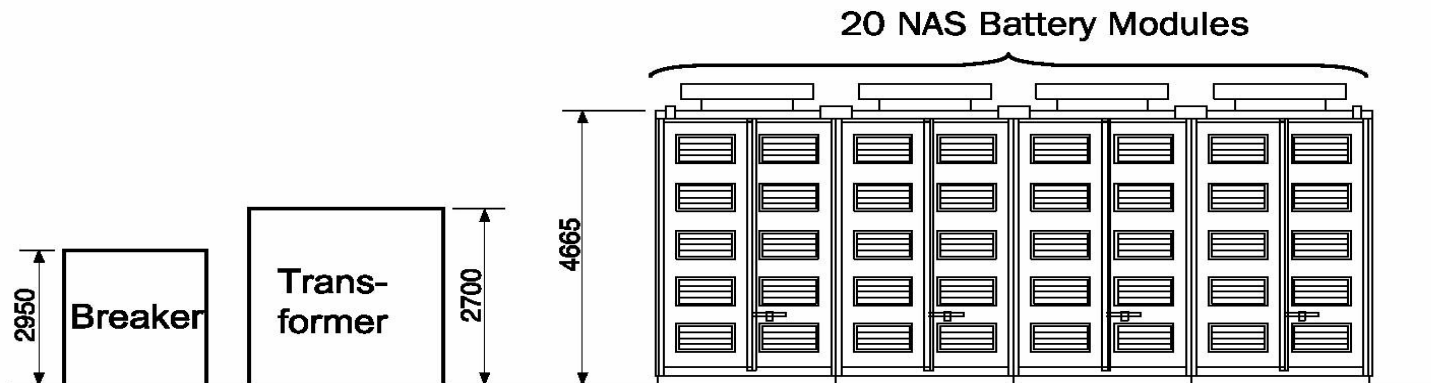
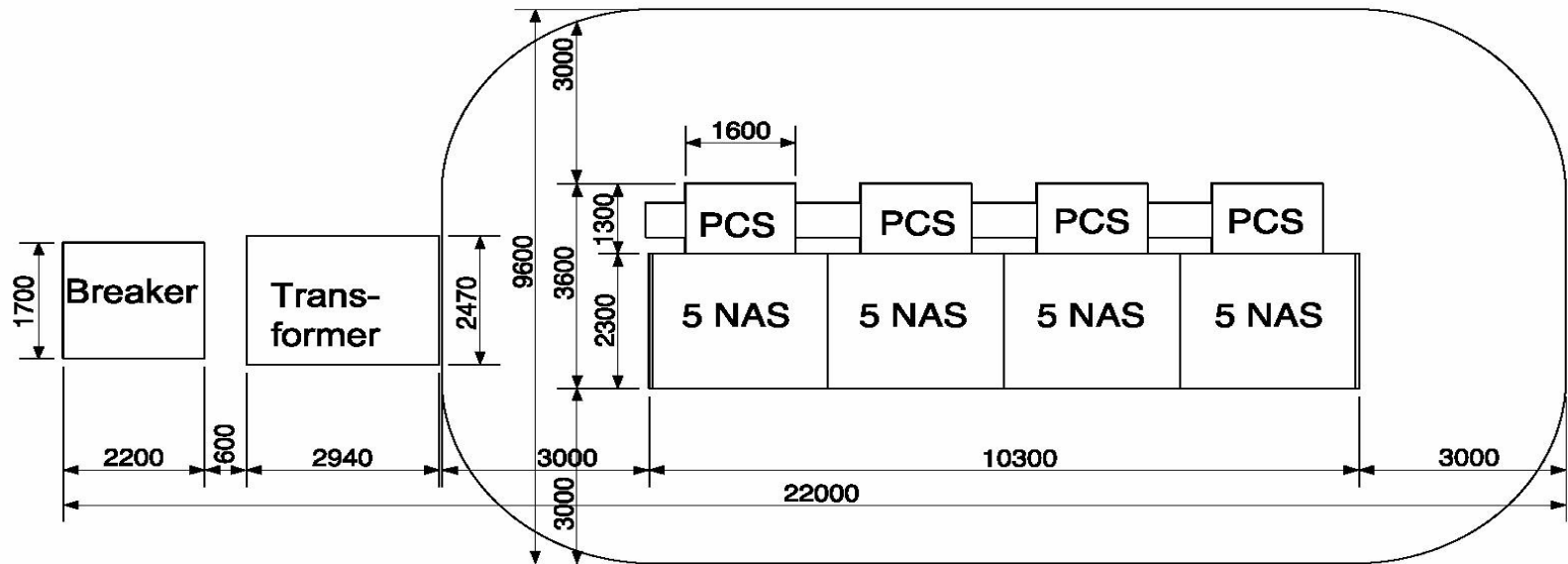
# NAS Product Line: Standard PS Modules

**For PS or Long Duration Standby in “Standard 5 Module Train”**

| NAS Module  | "PS-G50" Module                            | "PS-E50" Module                            |
|---|--|--|
| Module Energy Density & Avg DC Efficiency               | 151kWh/m <sup>3</sup><br>85% @ 100%DOD     | 181kWh/m <sup>3</sup><br>85% @ 100%DOD     |
| Rated Capacity & Power<br>(AC, based on 95% efficiency) | 360kWh @ 50kW<br>(60kW max)                | 430kWh @ 50kW<br>(60kW max)                |
| Cell Configuration & Module Voltage                     | (8Sx10P)x4S, 64V<br>or<br>(8Sx5P)x8S, 128V | (8Sx12P)x4S, 64V<br>or<br>(8Sx6P)x8S, 128V |
| Operating Temp & Standby Heat Loss                      | 290 to 360C<br>3.4kW                       |  |
| Dimensions (WxDxH) & Weight                             | 2224 x 1786 x 732 mm<br>3500kg             |  |
| Electrical Protection                                   | Internal fuses within each 8S string       |  |



# 20 PS Module Building Block (PCS Sized for 1 or 1.2 MW)



**20 Module Building Block PS Discharge Profiles**  
**for Rated 100% DOD per cycle**  
 (Alt PS Capable of 1.2 MW for up to 3hr with Full Discharge)

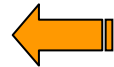


# ***LL and PS + EPS Applications***



## **Load Leveling Application**

**NAS Installation No. 18: 6MW / 48MWh  
at TEPCO's Ohito Substation**



## **PS + EPS Application**

**NAS Installation No. 49: 1.2MW / 7.2MWh  
at Kasai's Sewage Disposal Plant**



# ***NAS Product Line: Standard PQ Module***

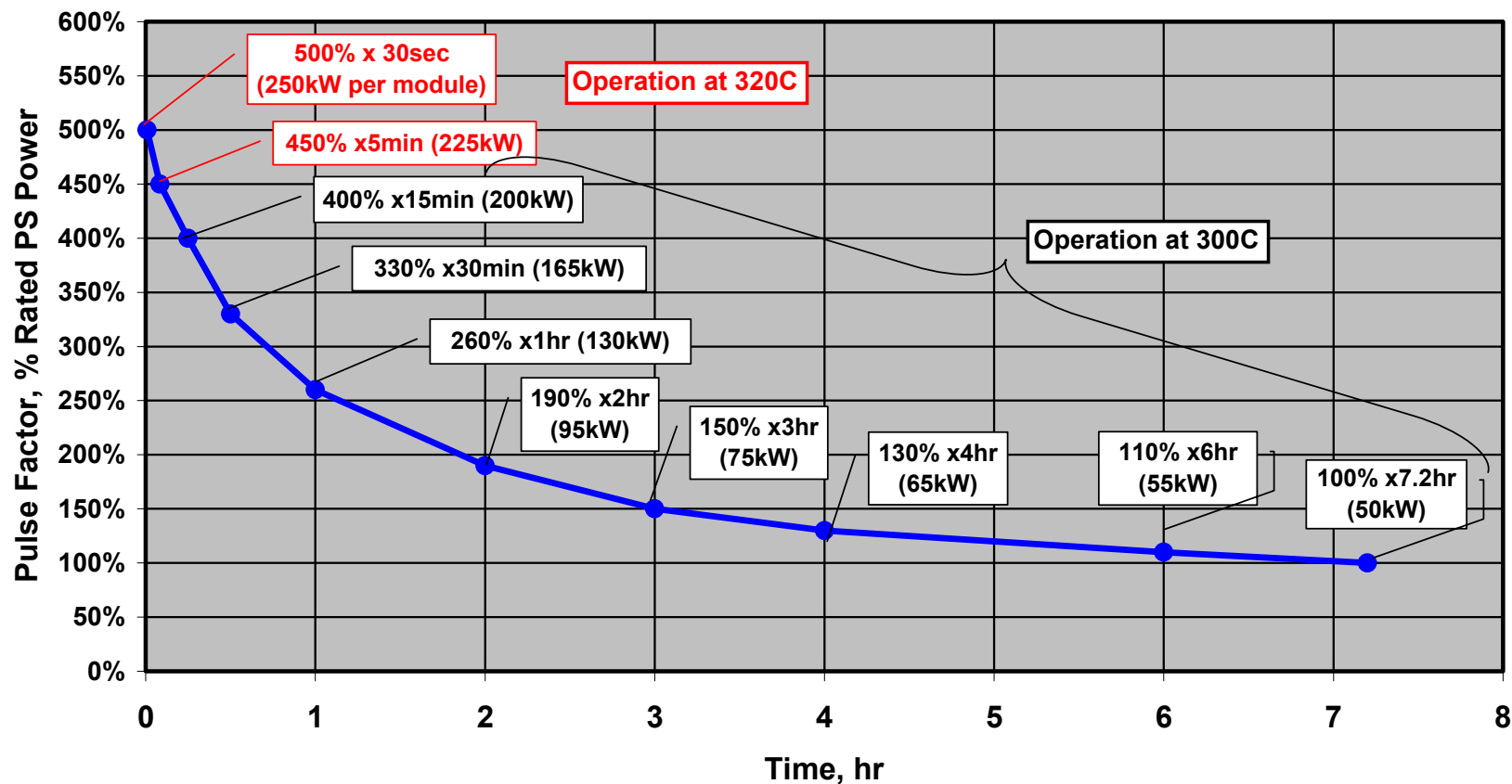
**For PQ and Combined PQ & PS Applications**

|  |  |
|--|--|
| <b>NAS Module</b>  | <b>"PQ-50" Module</b>  |
| <b>Module Energy Density &amp; Avg DC Efficiency</b>               | <b>151kWh/m<sup>3</sup><br/>85% @ 100%DOD<br/>90% @ 40%DOD</b> |
| <b>Rated Capacity &amp; Power</b><br>(AC, based on 95% efficiency) | <b>360kWh @ 50kW<br/>(250kW max)</b>                           |
| <b>Cell Configuration &amp; Module Voltage</b>                     | <b>320S, 640V</b>  |
| <b>Operating Temp &amp; Standby Heat Loss</b>                      | <b>290 to 360C<br/>2.2kW (PQ)<br/>3.4kW (PQ &amp; PS)</b>      |
| <b>Dimensions (WxDxH) &amp; Weight</b>                             | <b>2224 x 1786 x 732 mm<br/>3500kg</b>                         |
| <b>Electrical Protection</b>                                       | <b>External DC breaker,<br/>external fuse at terminal</b>      |



# NAS Product Line: Standard PQ Module

## NAS Pulse (or “PQ Factor”) vs Discharge Duration





# ***Combined PQ & PS Applications***



## **Large Scale PQ Application**

**NAS Installation No. 57: PQ3MW / PS1MW  
at Fujitsu's Akiruno Technology Center**

## **1st Demonstration in the USA**

**NAS Installation No. 59: PQ500kW / PS100kW  
at AEP's Gahanna, Ohio, Office**



# Summary of Deployed NAS Projects

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- Total NAS projects deployed since 1992 through December 2004:
  - Over 100 projects and 100 MW to date, including demonstrations
  - 59 projects >500kW have cumulative capacity of ~88MW and 680MWh (accounting for the relocation of some projects)
  - 2 projects rated at 9.6 MW and ~60 MWh – the largest battery energy storage projects in the world
- Breakdown by market:
  - Commercial (Comml), e.g., data handling: 29%
  - Industrial (Indl), e.g., manufacturing: 22%
  - Electric power companies (EPC), e.g., substation support: 26%
  - Water treatment plants (WTP), e.g., sewage handling: 23%
- Breakdown by application:
  - Load Leveling (LL): 63%
  - LL + Emergency Power Supply (EPS): 24%
    - *EPS for multi-hours of backup power*
  - LL + Uninterruptible Power Supply (UPS): 13%
    - *UPS for short-term PQ protection*
    - *~3% are equipped with PQ module with PQ  $\geq 3$*

# NAS Projects $\geq 500\text{kW}$ Through March 2002

| No. | Customers  | Site              | Market   | NAS<br>kW/kWh | Application | Start of<br>Operation |
|-----|--|-------------------|----------|---------------|-------------|-----------------------|
| 2   | TEPCO  | Kawasaki SS       | EPC      | 500/4000      | LL          | Jun-95                |
| 10  | TEPCO  | Tsunashima        | EPC      | 6000/48000    | LL          | Mar-97                |
|     | (2000kW relocated to Project 19)                               |                   |          |               |             |                       |
| 14  | NGK  | Head Office       | Comm'l   | 500/4000      | LL          | Jun-98                |
| 18  | TEPCO  | Ohito SS          | EPC      | 6000/48000    | LL          | Mar/Oct 99            |
|     | (1000kW relocated to Projects 58 and 62, 4000kW to Project 86) |                   |          |               |             |                       |
| 19  | Toko Electric  | Saitama           | EPC      | 2000/16000    | LL          | Jun-99                |
| 22  | Chubu EPC  | Odaka SS          | EPC      | 1000/8000     | LL          | Mar-00                |
| 28  | TEPCO  | Tsunashima SS     | EPC      | 2000/14400    | LL          | Nov-00                |
|     | (2000kW relocated to Project 86)                               |                   |          |               |             |                       |
| 33  | TEPCO  | Shinagawa SS      | EPC      | 2000/14400    | LL          | Mar-01                |
|     | (2000kW relocated to Project 86)                               |                   |          |               |             |                       |
| 46  | TEPCO  | Asahi Brewery     | Indl     | 1000/7200     | LL+EPS      | Oct-01                |
| 47  | TEPCO  | Takaoka           | Indl     | 600/3600      | LL          | Oct-01                |
| 49  | City of Tokyo  | Kasai Water No.1  | WTP      | 1200/7200     | LL+EPS      | Dec-01                |
|     |  | Kasai Water No.2  | WTP      | 1200/7200     | LL+EPS      | Aug-03                |
|     |  | Kasai Water No.3* | WTP      | 480/2880      | LL          | Jan-04                |
|     | (*480kW relocation from Hachijo Island)                        |                   |          |               |             |                       |
| 51  | TEPCO  | Fuji/Zerox        | Indl     | 1200/7200     | LL          | Mar-02                |
| 52  | TEPCO  | Takaoka           | Indl     | 800/5760      | LL          | Mar-02                |
| 55  | TEPCO  | Pacifico          | Special* | 2000/14400    | UPS         | Mar-02                |
|     | (*2002 World Soccer Cup. Subsequently relocated to Project 78) |                   |          |               |             |                       |

|              |                |
|--------------|----------------|
| Demo Project | Comm'l Project |
|--------------|----------------|

# ***NAS Projects $\geq 500\text{kW}$***

## ***(June 2002 thru March 2004)***

| No. | Customers       | Site                 | Market | NAS<br>kW/kWh | Application  | Start of<br>Operation |
|-----|-----------------|----------------------|--------|---------------|--------------|-----------------------|
| 56  | TEPCO           | Chichibu SS          | EPC    | 1000/7200     | LL           | Jun-02                |
| 57  | TEPCO           | Fujitsu              | Indl   | 3000/7200     | LL+UPS(PQ=3) | Jun-02                |
| 58  | TEPCO           | Super Market         | Comml  | 1000/8000     | LL           | Aug-02                |
| 59  | AEP             | Office Building      | Comml  | 500/720       | LL+UPS(PQ=5) | Sep-02                |
| 60  | TEPCO           | Honda/Tochigi        | Indl   | 1800/10800    | LL           | Dec-02                |
| 62  | TEPCO           | Super Market         | Comml  | 1200/8000     | LL           | Feb-03                |
| 64  | City of Tokyo   | Shinmachi            | Comml  | 500/2160      | LL+UPS       | Mar-03                |
| 67  | TEPCO           | Tokyo Dome           | Comml  | 1000/7200     | LL+EPS       | Apr-03                |
| 68  | TEPCO           | Mitsui Norin         | Comml  | 1500/3600     | LL+UPS(PQ=3) | May-03                |
| 69  | TEPCO           | Pharmacy Plant       | Indl   | 600/1800      | LL+UPS       | May-03                |
| 70  | NGK             | Komaki               | Indl   | 600/3600      | LL+UPS       | May-03                |
| 71  | TEPCO           | University           | Comml  | 1200/8000     | LL+EPS       | Jul-03                |
| 72  | TEPCO           | Hospital             | Comml  | 600/2000      | LL+UPS       | Jul-03                |
| 73  | TEPCO           | Super Market         | Comml  | 900/6000      | LL           | Aug-03                |
| 74  | TEPCO           | Department Store     | Comml  | 1200/8000     | LL           | Aug-03                |
| 76  | TEPCO           | Chemical Plant       | Indl   | 2400/16000    | LL+EPS       | Sep-03                |
| 77  | TEPCO           | Government Office    | Comml  | 1200/8000     | LL+EPS       | Dec-03                |
| 78  | TEPCO           | Video Manufacturer   | Indl   | 2400/16000    | LL+EPS       | Feb-04                |
| 79  | TEPCO           | Matuso SS            | EPC    | 2000/14400    | LL           | Feb-04                |
| 89  | TEPCO           | Perfume Factory      | Indl   | 1200/8000     | LL+EPS       | Mar-04                |
| 84  | City of Saga    | City Hall            | Comml  | 600/3600      | LL+EPS       | Mar-04                |
| 85  | Kyushu          | Boat Racing          | Comml  | 2400/14400    | LL+EPS       | Mar-04                |
| 86  | Yamagata Pref.  | Murayama Sewage      | WTP    | 600/3600      | LL           | Mar-04                |
| 81  | TEPCO           | Kamiyama SS          | EPC    | 2000/14400    | LL           | Mar-04                |
| 82  | City of Fukuoka | Subway Office No.1&2 | Comml  | 1200/7200     | LL           | Mar-04                |

|              |                |
|--------------|----------------|
| Demo Project | Comm'l Project |
|--------------|----------------|

# ***NAS Projects $\geq$ 500kW (April to December 2004)***

| No. | Customers        | Site                  | Market | NAS<br>kW/kWh | Application | Start of<br>Operation |
|-----|------------------|-----------------------|--------|---------------|-------------|-----------------------|
| 86  | TEPCO            | Morigasaki PFI        | WTP    | 9600/64000    | LL          | Apr-04                |
| 95  | City of Fukuoka  | Subway Office No.3    | Comml  | 2400/14400    | LL+EPS      | Apr-04                |
| 90  | TEPCO            | Super Market          | Comml  | 1200/8000     | LL          | Jun-04                |
| 91  | TEPCO            | Camera Mfr.           | Indl   | 1800/12000    | LL+EPS      | Jun-04                |
| 92  | TEPCO            | Nippon Tobacco        | Indl   | 4800/28800    | LL          | Jun-04                |
| 93  | TEPCO            | Hitachi Automotive    | Indl   | 9600/64000    | LL          | Jul-04                |
| 94  | TAIYO Pharmacy   | Takayama              | Comml  | 1200/8000     | LL+EPS      | Jul-04                |
| 96  | TEPCO            | Hospital              | Comml  | 600/4000      | LL+EPS      | Aug-04                |
| 97  | TEPCO            | Department Store      | Comml  | 2400/16000    | LL          | Aug-04                |
| 98  | TEPCO            | Milk Distribution     | Indl   | 1200/8000     | LL          | Aug-04                |
| 99  | TEPCO            | Super Market          | Comml  | 1200/8000     | LL+EPS      | Sep-04                |
| 100 | TEPCO            | University            | Indl   | 2400/16000    | LL          | Oct-04                |
| 101 | TEPCO            | Aircraft Mfr.         | Indl   | 4800/32000    | LL          | Oct-04                |
| 103 | TEPCO            | Nonferrous Metal Mfr. | Indl   | 2400/16000    | LL+EPS      | Nov-04                |
| 104 | TEPCO            | Nonferrous Metal Mfr. | Indl   | 3600/24000    | LL          | Nov-04                |
| 102 | TEPCO            | Government Office     | Comml  | 2400/14400    | LL+EPS      | Dec-04                |
| 105 | TEPCO            | Camera Mfr.           | Indl   | 1200/8000     | LL+EPS      | Dec-04                |
| 106 | Yamagata Pref.   | Pkitama Water Treatme | WTP    | 600/3600      | LL+EPS      | Dec-04                |
| 107 | World Exposition | Nagoya                | Indl   | 600/4000      | LL+EPS      | Dec-04                |
| 108 | TEPCO            | University            | Indl   | 1200/8000     | LL          | Dec-04                |

# ***NAS Battery Attributes***

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- **Commercial reality in Japan – ready for global market**
- **No barriers to high volume, low cost production – abundant materials, ceramics mfg and automated production verified**
- **Superior energy density – small footprint**
- **Superior pulse power capability – seconds to 10s of minutes**
- **Easily sited outdoors and indoors; no emissions, noise or vibrations; relocatable if mission changes**
- **15 year life and high cycle life: 2500 cycles for 100% DOD, 4500 for ~90% DOD, 6500 for ~65% DOD, etc**
- **High DC efficiency, insensitive to ambient temperature, no self discharge, no memory effect**
- **Prompt response – full power charge to discharge in 1 msec**
- **Remote operation and minimal planned maintenance, i.e., periodic inspection – no pumps, valves, heat xchgrs, etc**
- **Safety and high reliability confirmed via extensive testing and demonstrations**



# ***NAS Value Components Within Target Markets***

- **High value NAS projects for market entry adapt combinations of the following applications**
  - **Peak Shaving or Load Leveling, e.g., 3 to 10 hours daily of shifting off-peak energy to offset peak energy demands**
  - **Power Quality support, e.g., seconds to minutes for voltage sag and outage mitigation, plus bridge to generation**
  - **Standby Power, e.g. hours for backup power – prompt to delayed**
  - **“Prompt” spinning reserve, e.g., 15 minutes for grid frequency support and contingency optimization,**
  - **Ancillary Services, e.g., regulation control – up and down, conventional spinning reserves, black start, reactive power support**
  - **Renewables Optimization, e.g. seconds to minutes for stabilization of wind fluctuations; hours for curtailment or spillage mitigation, or forecasting hedge to minimize imbalance payments, or bulk time-shift of generation**
  - **Improved utility asset utilization and reliability via distributed and relocatable energy storage that avoids or defers system upgrades to serve peak and/or premium load requirements**

# Examples for High Value Combined Applications

## Distribution Utility (DU)

- Load Leveling: 6 MW, 38 MWh Weekday Load Shifting
  - Distribution System Upgrade Deferral/Avoidance
  - Reduced T Demand and Energy Charges(\*\*)
- Plus 5 MW, 5 MWh for Voltage Sag and Outage Protection
  - Premium PQ Customer Service
- Plus 5 MW, 1.25 MWh for as Available Regulation Control (\*\*)
  - Added Revenue per Market Rates

## Energy Services Based Utility or Provider

- 3 MW, 30 seconds for Voltage Sag and Outage Protection
  - Premium PQ Customer Service
- Plus 1 MW, 7 MWh for Daily Peak Shaving
  - Reduced Energy and T & D Demand Costs for Customer
  - As Available from DU, Demand Response/Reduction Payments

## Transmission and Generation Based Utility or Wind Generator

- Prompt Spinning Reserve: 20 MW, 7.5 MWh for Bridge to Generation
  - Avoided Alternative Solution, including Load Interruption(\*\*)
- Plus 10 MW, 35 MWh for Daily Shift of Off-Peak Load to Peak Source
  - Higher Value for Firm, Peak Generation
  - Stabilize Wind Fluctuations – Reduce Regulation Impact Cost
- Plus 10 MW, 2.5 MWh for as Available Regulation Control
  - Revenue per Market Rates

(\*\*) : Value accrual uncertainties