NE 50th Anniversary Celebration
Georgia Tech
November 1, 2012

Ali Azad
SVP, Chief Development Officer
Babcock & Wilcox
Babcock & Wilcox Power Generation Group, Inc.
- Fuel-fired power generation
- Service, operation, and maintenance
- Construction and EPC
- Environmental emissions control systems (NO\textsubscript{x}, SO\textsubscript{2}, acid gas, carbon, particulate, and Hg)
- Renewables (biomass, solar, waste to energy)

Babcock & Wilcox Nuclear Energy, Inc.
- Component manufacturing and installation
- Field services
- Plant modifications
- Fuel design, enrichment and fabrication

Babcock & Wilcox mPower, Inc.
- Design, development and deployment of B&W mPower\textsuperscript{TM} small modular reactor technology

Babcock & Wilcox Nuclear Operations Group, Inc.
- Virginia-class submarine program
- Ford-class carrier program
- Refueling
- Fuel processing and fabrication

Babcock & Wilcox Technical Services Group, Inc.
- Nuclear material handling, storage and security
- Nuclear laboratories
- Weapons complex
- Decontamination and decommissioning
- Strategic petroleum reserve
Legacy of Innovation

1867... Building a power boiler reputation
- Original Babcock & Wilcox
- First water-tube power boiler
- Marine boilers for Teddy Roosevelt’s Great White Fleet

1947... Leading the development of nuclear power
- Nuclear components for the Manhattan Project
- Reactors for first nuclear-powered submarine, USS Nautilus
- First generation U.S. commercial nuclear power plants

1968 ... Addressing the environment
- Fossil fuel emission controls for particulate, SO\textsubscript{x}, NO\textsubscript{x}, Hg
- Development of supercritical coal plants
- Research in fuels, materials, combustion, and post-combustion systems

1994 ... Managing national security
- Prime contract for Y-12 and Pantex M&O
- Enriched uranium downblending
- Management of Los Alamos and Idaho National Laboratories

2005 ... Minimizing climate change
- Carbon capture and storage demonstration
- Biomass and solar thermal technologies
- Next-generation commercial nuclear power

Today... Technology leadership
- Small modular nuclear reactors
- Supercritical and ultra-supercritical boilers
- Providing navy nuclear products and services
Formal alliance between B&W and Bechtel

- Joint Venture agreement executed July 14, 2010
- Substantial investment commitments by B&W and Bechtel

Recognized and established energy industry leaders

- B&W:
  - 60+ years of nuclear engineering and manufacturing experience
  - Exclusive B&W mPower™ reactor technology
- Bechtel Power:
  - 60+ years of nuclear power industry experience
  - Integrated engineering and project management leadership

Alliance objectives

- Design, license and deploy first commercially viable Gen III++ SMR
- Improve cost and schedule certainty, with reasonable investment
- Increase accessibility to nuclear power across global energy industry

www.generationmpower.com

A “game changer” for the global energy industry
“Twin Pack” mPower Plant Site Layout

10 “Game-Changers”

1. 2 x 180 MWe units
2. Compact <40-acre site footprint*
3. Separated Nuclear & Conventional Islands
4. All safety-related systems underground
5. One-to-one reactor to T/G alignment
6. Optimized for minimum staff and O&M
7. Water- or air-cooled condenser option
8. Conventional steam cycle components
9. “Island Mode” & load following operation
10. Small EPZ radius, down to 1000 feet

*with water-cooled condenser

More Flexible, More Practical, More Affordable
Reducing Complexity
B&W mPower™ Reactor

Integral 530 MWt NSSS module
- Internal CRDMs, SG, Pressurizer and Coolant Pumps
- Lowest penetration 23 feet above top of active fuel
- 50-degree superheat in Secondary Loop
- 60-year design life, rail shippable

Next generation passive safety design philosophy
- Core remains covered during all Postulated Accidents
- Non-safety “defense-in-depth” systems used first
- Multiple defense-in-depth layers deliver ~$10^{-8}$

4-Year fuel cycle with “standard” PWR fuel
- 69 fuel assemblies with <5% $^{235}$U enrichment
- ~40 GWD/T burn-up and no shuffling delivers economics
- Burnable poisons, no chemical boron shim in coolant
- Full reactivity control using 69 control rod assemblies

Modular ALWR with best of Generation III+ features ... low risk, low cost and passively safe
Primary and Secondary Loops

Primary Loop:
- 300°C @ 5.7 MPa (571°F @ 825 psia)
- 28°C (50°F) Super-heat (BOL)
- 163°C (325°F)
- 816 MT/hr (1.8 Mlbm/hr)
- 14.1 MPa (2050 psia)
- 320°C (608°F) Core outlet
- 13,607 MT/hr (30 Mlbm/hr)

Secondary Loop:
- Steam
- Feedwater
Control Rod Drive Mechanism

- Electro-Hydraulic Control Rod Drive Mechanism
  - 69 internal CRDMs
  - 244 cm (96 inches) of stroke
- Hydraulic latching mechanism
- High temperature motor
  - No cooling water required
  - Ceramic insulation
Fuel Assembly Attributes

- 17 x 17 Fuel Rod Array
- Remotely Removable End Fittings
- No Holddown Spring
- 24 Control Rod Guide Tubes
- 265 Fuel Rods and Burnable Poison Rods
- Lifted Fuel Rods
- 440 kg (970 lb) Weight
Passive Containment Cooling

CCW

Auxiliary Steam Condenser

CNX

RCI LP RHR

RCI HPI pump

LP Tank

Boron Tank

RCI HP DHR

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## Protection against “Fukushima-type” Events

<table>
<thead>
<tr>
<th>Events and Threats</th>
<th>mPower Design Features</th>
</tr>
</thead>
</table>
| **Earthquakes And Floods**               | • **Seismic attenuation**: Deeply embedded reactor building dissipates energy, limits motion  
• **“Water-tight”**: Separated, waterproof reactor compartments address unexpected events |
| **Loss of Offsite Power**                | • **Passively safe**: AC power, offsite or onsite, not required for design basis safety functions  
• **Defense-in-depth**: 2 back-up 2.50MWe diesel generators for grid-independent AC power |
| **Station Blackout**                     | • **3-day batteries**: Safety-related DC power supports all accident mitigation for 72 hours  
• **APU back-up**: Auxiliary Power Units inside reactor building recharge battery system  
• **Long-duration “station keeping”**: Space allocated for 7+-day battery supply for plant monitoring/control |
| **Emergency Core Cooling**              | • **Gravity, not pumps**: Natural circulation decay heat removal; water source in containment  
• **Robust margins**: Core heat rate (11.5kW/m) and small core (500MWth) limit energy  
• **Slow accidents**: Maximum break small compared to reactor inventory (4.7x10-5m²/m³) |
| **Containment Integrity and Ultimate Heat Sink** | • **Passive hydrogen recombiners**: Prevention of explosions without need for power supply  
• **Internal cooling source**: Ultimate heat sink inside underground shielded reactor building  
• **Extended performance window**: Up to 14 days without need for external intervention |
| **Spent Fuel Pool Integrity and Cooling** | • **Protected structure**: Underground, inside reactor service building, located on basemat  
• **Large heat sink**: 30+ days before boiling and uncovering of fuel with 20 years of spent fuel |

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**Multi-layer defense ... mitigates extreme beyond-design basis challenges**
Development Testing Programs

Component Tests
- Reactor Coolant Pump
- CRDM
- Fuel Mechanical Testing
- CRDM/Fuel Integrated Test
- Fuel Critical Heat Flux
- Emergency High Pressure Condenser

Integrated Systems Test (IST)
- Heat Transfer Phenomena
- Steam Generator Performance
- LOCA Response
- Pressurizer Performance
- Reactor Control

Greater than $100M Investment in Component Testing Program and IST Facility
First Deployment:
Clinch River Project
Planning for Initial Deployment

- **TVA Clinch River Project**
  - US regulation 10CFR Part 50 license approach
  - *Construction Permit (CP) by 2017; fuel load in 2021*
  - Initial pre-submittal planning work underway
  - Number of modules and configuration being evaluated

- **Design Certification Application (DCA)**
  - US regulation 10CFR Part 52 license approach
  - Benefit / Informed by TVA 10CFR Part 50 effort
  - Higher level of engineering completion
  - One design / review during parallel licensing process
  - *2014 submittal to NRC*
Manufacturing
B&W Manufacturing Facilities

Business Footprint

Total Employees = 449

<table>
<thead>
<tr>
<th>Location</th>
<th>FTEs</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charlotte</td>
<td>35</td>
<td>HQ</td>
</tr>
<tr>
<td>Charlotte</td>
<td>21</td>
<td>Generation mPower LLC</td>
</tr>
<tr>
<td>Cambridge</td>
<td>6*</td>
<td>Manufacturing and SG design</td>
</tr>
<tr>
<td>Rockville</td>
<td>3</td>
<td>Licensing</td>
</tr>
<tr>
<td>Ramsey</td>
<td>150</td>
<td>B&amp;W mPower™ design and testing</td>
</tr>
<tr>
<td>Barberton</td>
<td>30*</td>
<td>Thermal-hydraulics engineering</td>
</tr>
<tr>
<td>Euclid</td>
<td>40*</td>
<td>CRDM design and development</td>
</tr>
<tr>
<td>Frederick - BPC</td>
<td>160**</td>
<td>BOP design</td>
</tr>
<tr>
<td>Lynchburg - BPC</td>
<td>4**</td>
<td>Engineering interface &amp; licensing</td>
</tr>
</tbody>
</table>

* Dedicated FTEs from other B&W business groups
** Subcontracted/partner Bechtel workforce
Outstanding execution of SMR modularity is the technology “advantage”
Currently operating “N” stamp and fuel fabrication/manufacturing facilities for nuclear components:

• Heavy component fabrication – up to 1000 tons
  • Mt Vernon, Indiana
  • Barberton, Ohio
  • Cambridge, Ontario
• Control rod drive fabrication
  • Euclid, Ohio
• Fuel fabrication
  • Lynchburg, Virginia

Robust existing Approved Supplier List (ASL):

• Extensive experience with qualified vendors
• Regularly audited for compliance with relevant codes/standards
• Ongoing interface regarding required capacity & supply
Plant Economics
Minimize Overnight Cost

- Optimum power output (180 MWe)
- Simple standard plant layout and design
- Competitive global supply chain
- Innovative modularization
- Short construction schedule (3 years)
- $5000/kW for 360 MWe greenfield plant

Optimize Operating Costs

- “Plug and Play” design lever existing infrastructure
- 80% reduction in security staff with normal DBTs
- 3 licensed operators/shift for “two-pack”
- Fleet O&M support enabled by standardization
- DCWG approach with IAC for utility-centric design

Typical North American LCOE Comparison

Key Assumptions:
- Fuel range = $4.00 - $10.00/MMBtu (NG); $2.20/MMBtu (Coal)
- CO₂ price range = $0 - $30/ton
- Capacity factor = 92% (Large Nuclear and Coal); 95% (SMR);
  CCGT: 85% (Base Load); 40-60% (Intermediate Load)
- CAPEX range = $4600 - $6000/kW (Large Nuclear)

Competitive LCOE range: $82-97/MWh
## Estimated Annual Operating Costs

### Fixed O&M

<table>
<thead>
<tr>
<th></th>
<th>360 MWe</th>
<th>720 MWe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Staffing (# of personnel)</strong></td>
<td>298</td>
<td>427</td>
</tr>
<tr>
<td><strong>Labor Cost</strong></td>
<td>$35.4M</td>
<td>$51.3M</td>
</tr>
<tr>
<td><strong>Utilities, Supplies, Services</strong></td>
<td>$3.8M</td>
<td>$7.5M</td>
</tr>
<tr>
<td><strong>NRC Fees (est.)</strong></td>
<td>$2.9M</td>
<td>$5.8M</td>
</tr>
<tr>
<td><strong>Other Fees (INPO, NEI, EP, etc.)</strong></td>
<td>$2.8M</td>
<td>$3.9M</td>
</tr>
<tr>
<td><strong>Taxes, Insurance</strong></td>
<td>$1.5M</td>
<td>$3.0M</td>
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<tr>
<td><strong>Total Fixed O&amp;M</strong></td>
<td>$46.4M</td>
<td>$71.5M</td>
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### Variable O&M

<table>
<thead>
<tr>
<th></th>
<th>Twin Pack</th>
<th>Four Pack</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital Improvements</strong></td>
<td>$3.5M</td>
<td>$7M</td>
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<tr>
<td><strong>Outage Cost</strong></td>
<td>$4M</td>
<td>$8M</td>
</tr>
<tr>
<td><strong>Fuel Cost</strong></td>
<td>$30M</td>
<td>$60M</td>
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<tr>
<td><strong>Total Variable O&amp;M</strong></td>
<td>$37.5M</td>
<td>$75M</td>
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</table>

### Total O&M

<table>
<thead>
<tr>
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<th>Four Pack</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Annualized O&amp;M</strong></td>
<td>$83.9M</td>
<td>$146.5M</td>
</tr>
<tr>
<td><strong>Cost per MWh</strong></td>
<td>$28.0</td>
<td>$24.5</td>
</tr>
<tr>
<td><strong>Cost per MWh (excluding fuel)</strong></td>
<td>$18.0</td>
<td>$14.4</td>
</tr>
</tbody>
</table>

### Key Assumptions:

- Based on 2004 DOE/Dominion study
  - Reflects greater simplicity/automation
- Greenfield, water-cooled plant
- 95% capacity factor
- 48-month fuel cycle / 15-day refueling
- Centralized O&M support / remote M&D

**Simple design and regulatory optimization delivers efficient O&M**

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Early Generation Capability Allows for 18 million MWh of Saleable Electricity Prior to Final COD

$90MM in Net Profit Generated
Before COD of 4th Twin-Pack or Large Gigawatt Plant

Flexibility Increases ROI
**B&W mPower™ Additional Applications**

**Tar Sands & Mining**
- 2/3 of world’s “liquid” hydrocarbons
- Largest deposits in Canada & Venezuela
- 12 GW by 2015 in Alberta to meet growth

**Aluminum Refining**
- Electric-intensive process
- 15 MWh to produce 1 ton AL
- 50 GW required globally (30 MT/yr)

**PetroChem**
- Largest energy user in industry
- Process heat = 90% of (non-elec.) energy use
- 115 GW current global electrical demand

**Desalination**
- 85,000 MGD added by ‘33
- 327,000 GWh/yr
- 10-15% nuclear

**Practical carbon-free solution for energy intensive industries**
mPower Value Proposition

- Near-term (2020) regulatory response option
  - Addresses tightening environmental constraints (CSAPR, MACT)
  - Hedges against mid-term GHG “carbon tax” uncertainty
- Portfolio “balancing” opposite natural gas build-out
  - Environmentally clean, stable fuel cost, dispatchable generation
- Competitive “utility scale” power plant economics
  - $5000/kW ONC equivalent or better than GW-class options
  - Acceptable $82-97/MWh LCOE from low security and plant staffing
- Reasonable ($1.8B) investment and project risk
  - Incremental investment for incremental generation (360 MWe)
  - ~70% factory and off-site construction supporting 3-year schedule
- Low-risk technology and infrastructure for ~2020 COD
  - NSSS 50% complete, DCA pre-application licensing underway
  - Existing North American reactor manufacturing capability
### The Babcock & Wilcox Company

|------------------------------------|------------------------------------|-----------------------------------|--------------------------|------------------|

#### Key Areas of Expertise

- **Clean Energy Technology**
- **High-Consequence Operations**
- **Advanced Engineering and Manufacturing**