SPEAR POWER SYSTEMS

The Electric Tug: Battery Systems for Marine Applications
Prepared for the Membership of the American Waterways Operators

June 7, 2022 Revision B

The American Waterways Operators
The Tugboat, Towboat & Barge Industry Association

TRIDENT™

Agenda:

- Applications
- Terminology
- Safety
- Installation and regulation
- Sizing, aging, and end-of-life
- Future of in-vessel batteries
- Alternative strategies for inland waterways

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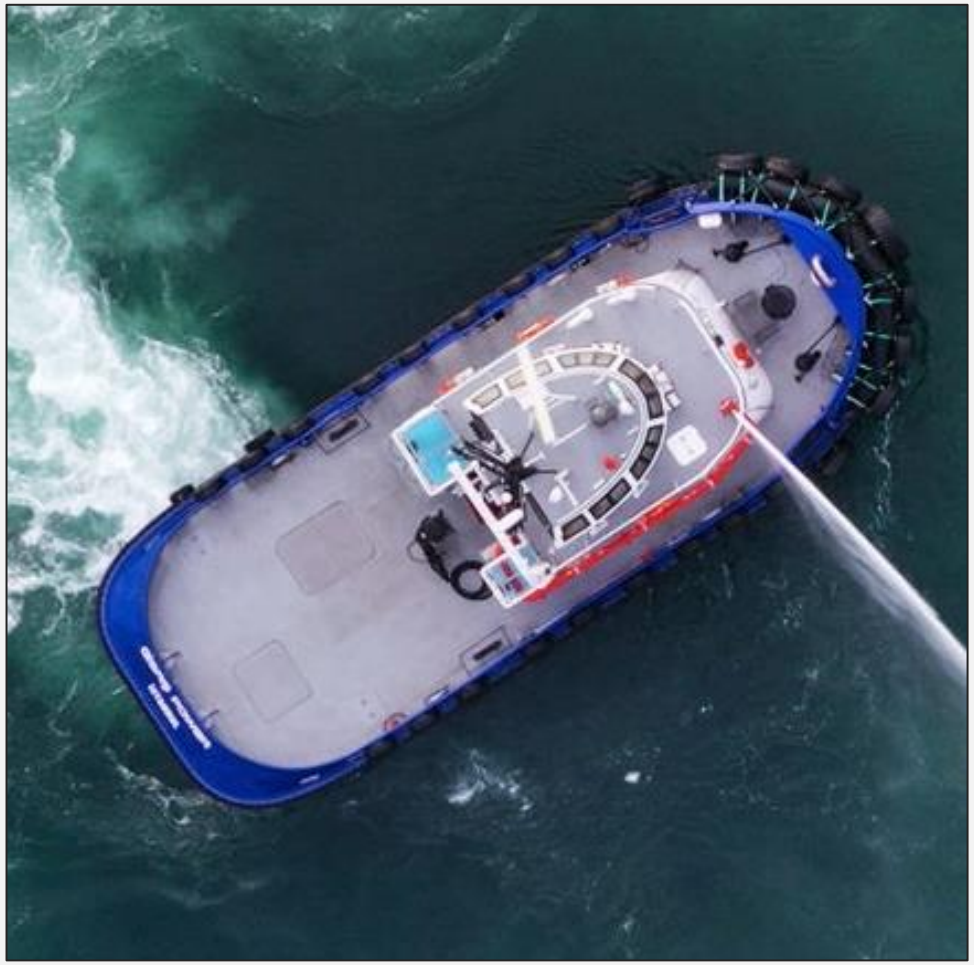
Applications



- **All Electric Propulsion**
  - Safe, simple, doable for select applications
  - Ferries have provided precedence
  - Harbor tugs in operation and construction
  - Big battery, big charging infrastructure
- **Diesel Hybrid**
  - More efficient and capable than diesel electric tugs
  - First US implementation of lithium ion
  - Benefits depend on application
  - Highly scalable
- **Alternative Fuel Hybrid**
  - Combination with LNG, hydrogen fuel cell, etc.
  - Battery supplies power ramp for maneuvering, bollard pull
  - Essential element of alternative fuel strategies

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Terminology

- **Cell**
  - Individual units of storage; LI typically 3.2 (LFP) or 3.6 (NMC) volts nominal (50% SOC)
  - Formats pouch, cylindrical, prismatic can
  - Capacity 5-200Ah (18-720Wh)
- **Module**
  - Base system unit, cells in series (V+V) and parallel (Ah+Ah)
  - Thermal management, battery management system (BMS) sensors, emergency control
- **String**
  - Modules in series to reach system voltage
  - BMS control elements
  - Housed in cabinet or rack
  - Base reliability unit
  - Banked in parallel to reach needed capacity

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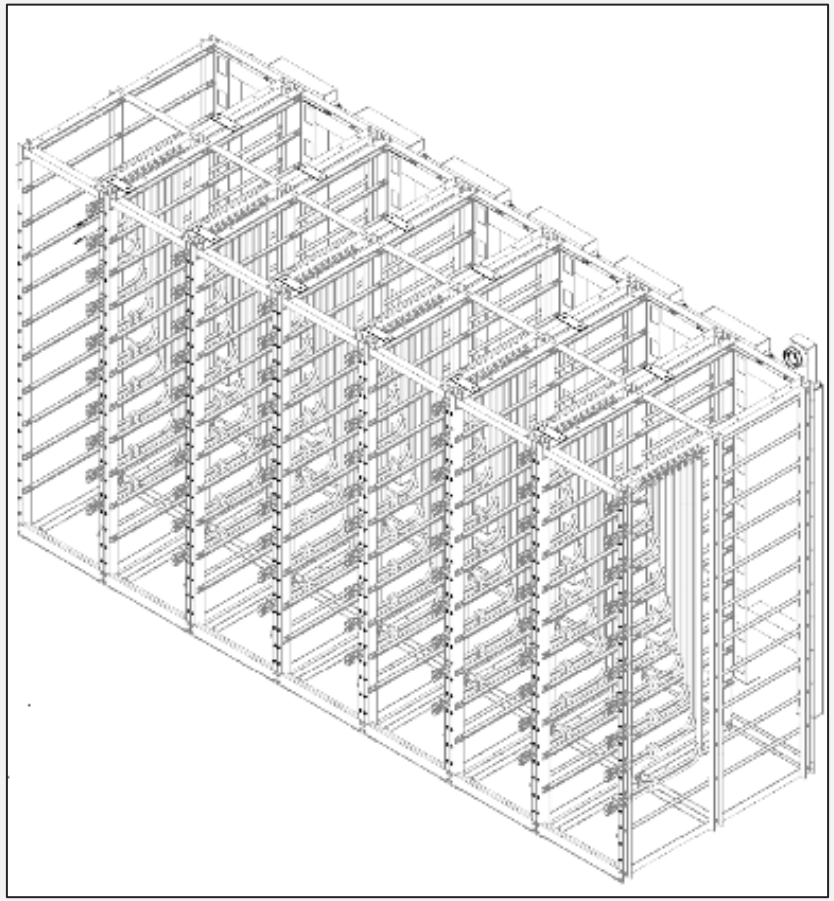
Safety



- **Battery Management System**
  - Monitors inputs and reaction and prevents abusive conditions, isolating string if necessary
  - High degree of redundancy required
  - Voltage monitoring best method of early detection
- **Thermal Runaway**
  - When abused or defect exposed
  - Electrolyte rapidly converts to gas, may ignite or explode in certain concentrations
  - Suffocation not possible, must lower temperature
  - Can cascade from cell to cell (propagation)
- **Mitigation**
  - Single cell propagation
  - Module venting
  - Fire suppression

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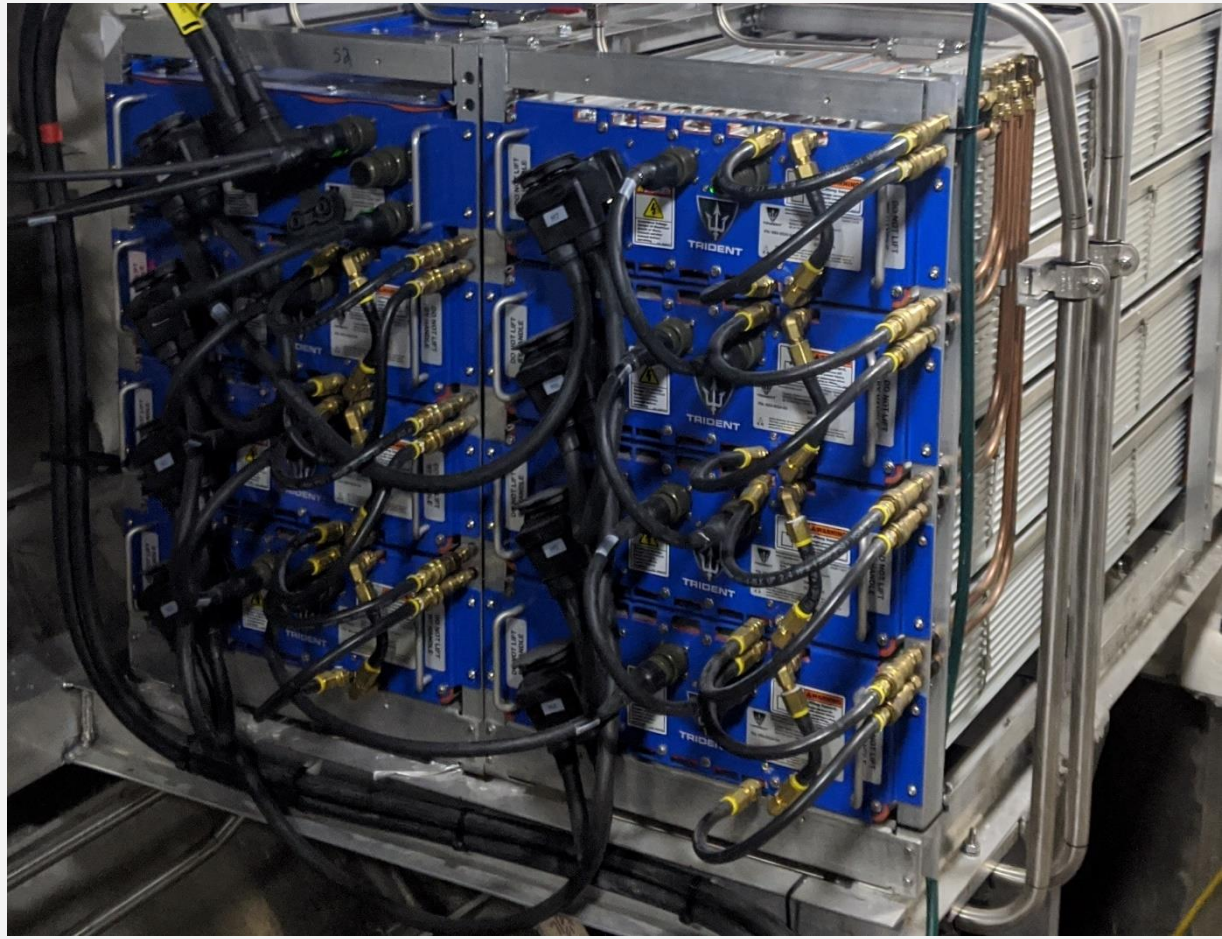
Installation and Regulation

- **Environment and space**
  - Typically dedicated battery room
  - Boundary requirements and fire suppression
  - Height, footprint, and service space limitations
- **Weight and balance**
  - 111 Wh/kg leads industry
  - 200 Wh/kg by end 2023
  - System can be distributed for balance
- **Regulation**
  - USCG CG-ENG Policy Letter No. 02-19 invoking ASTM F3353-19
  - DNV, then ABS, LR, BV, etc. have developed rules leading to type approval
  - Shore batteries unclear, regional, often local



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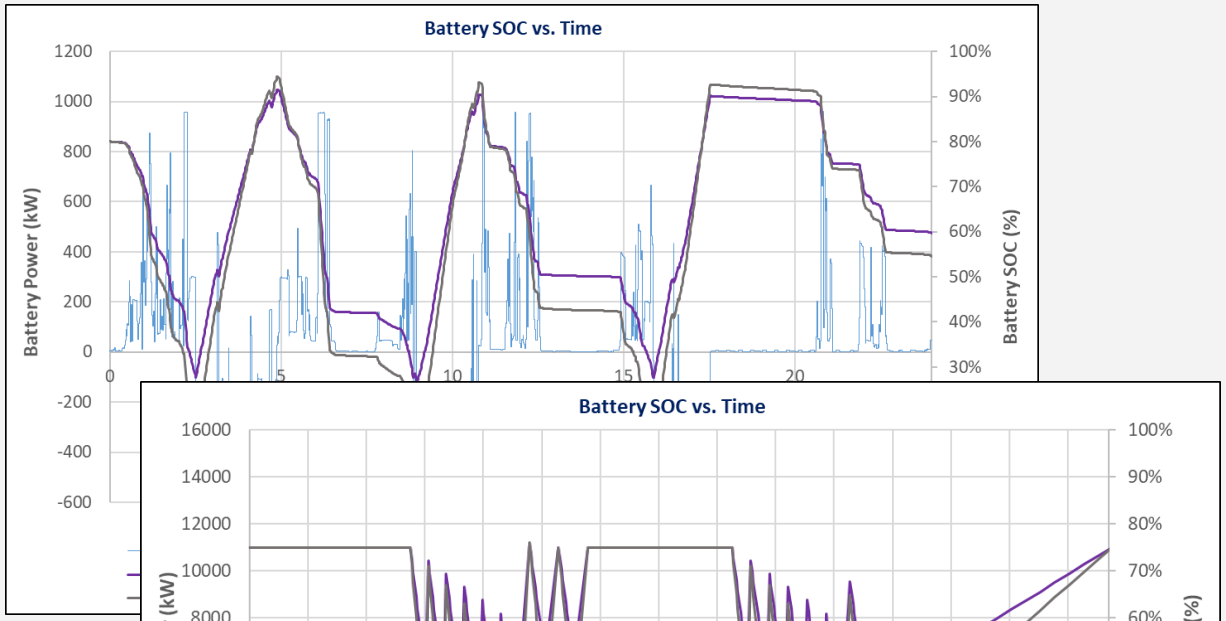
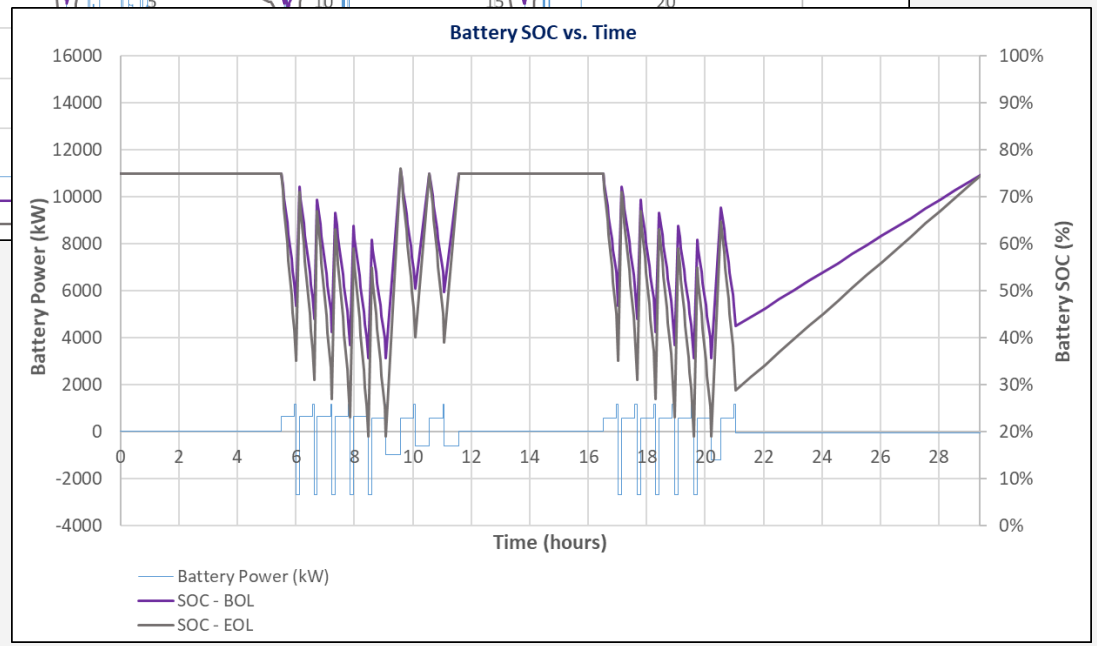
Sizing, Aging, End-of-Life





- **Aging concepts**
  - Batteries decrease in capacity over cycles (dynamic), modified by depth of discharge and rate
  - Calendar aging factors are static effects from temperature, average voltage,
  - Cells also increase in resistance over cycles, increasing voltage drop
- **End of Life (EOL)**
  - Capacity is too little to complete task (energy)
  - Voltage drop is too steep to complete task (power)
  - Capacity degradation no longer linear (reliability)
- **Sizing**
  - Battery vendor determines energy at BOL to produce desired service life
  - Competitive constraints

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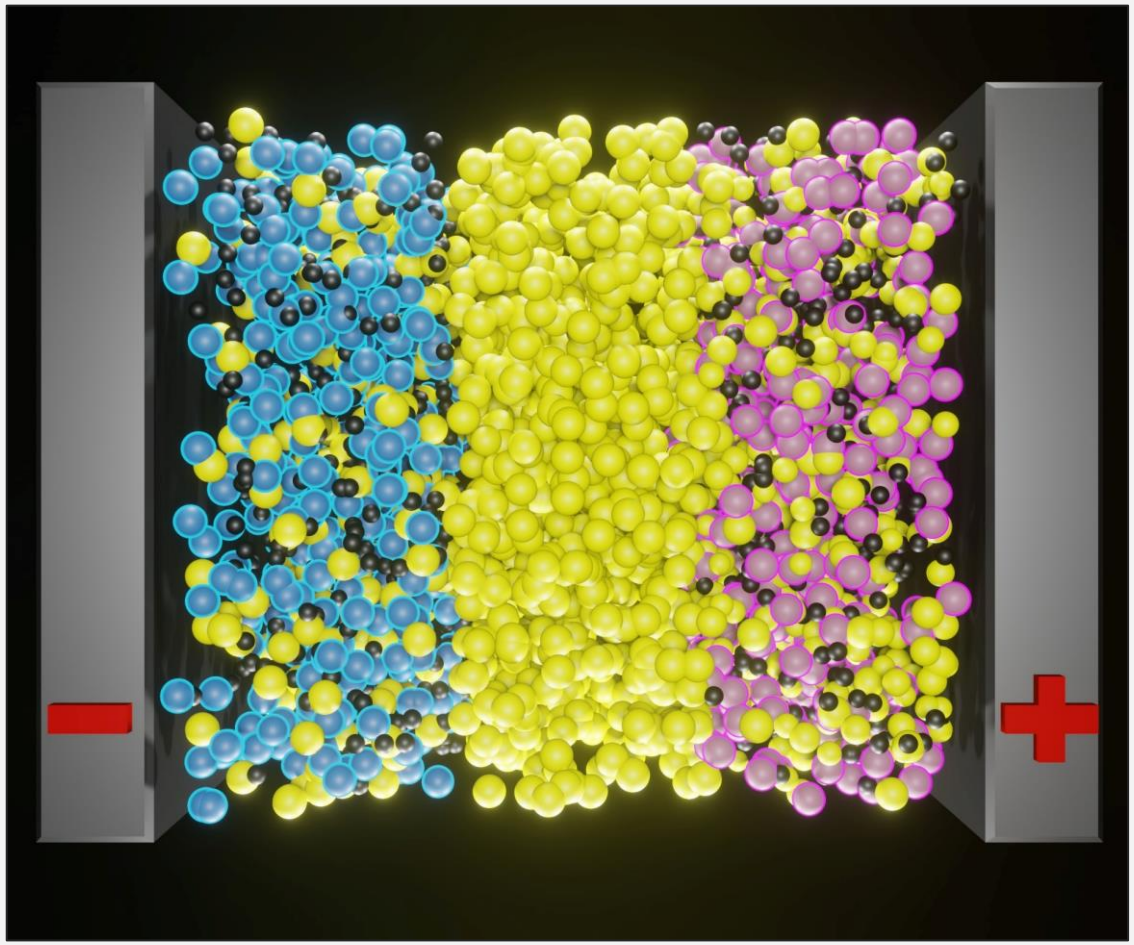
Future In-Vessel Batteries



- **Improved Energy Density**
  - Solid state, silicon anode next steps
  - Power and life limitations
  - 6-10 years from commercialization
- **Cost**
  - Marine ~$600/kWh historically, recent inflection
  - Automotive and stationary at 15%-30% $ marine
  - Significant safety, performance compromises
  - TWh automotive, GWh stationary
  - Marine currently 100 MWh, 1 GWh by 2026-7
- **Recycling and Second Life**
  - Scarcity of materials in NMC should yield cash positive recycling by EOL
  - LFP less certain
  - Strong second life potential, helped by provenance

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Alternatives for Inland Waterways

- **Containerization**
  - Can be swapped at beginning/end of route
  - Eases charging and peak costs
  - Current state of art ~1.5-2 MWh/20’
  - DC vs AC container, potential standardization of interface
  - Must maintain safety at all costs!
- **Storage as a Service (SaaS)**
  - Owner contract with storage provider for extended-life installation
  - Eases capital burden, lowers risk
  - Can be supported with service contracts to make truly turnkey
- **Energy as a Service (EaaS)**
  - Eases capital burden, accelerates second life
  - Adds stakeholders

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Current Direct

- **Collaborative**
  - EU Horizons 2020 funded 3-year project
  - 13 partners including Foreship, Lloyd's Register, Wartsila, Kotug, EDP, Port of Rotterdam
- **Radical**
  - EaaS model recruits most capable stakeholders, rewards all parties
    - Ports, utilities, investors
  - Advanced battery intelligence feeds asset and fleet management
  - >3MWh per 20' container (2x SoA)
- **Model for an American approach**
  - Benefits to port of high interest to ports, MARAD, DOE
  - Regional exploration faster than federal

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currentdirect.eu

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