

NS 999 Electric / Hybrid Locomotive Research

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Outline NS Low Emissions Locomotive Research

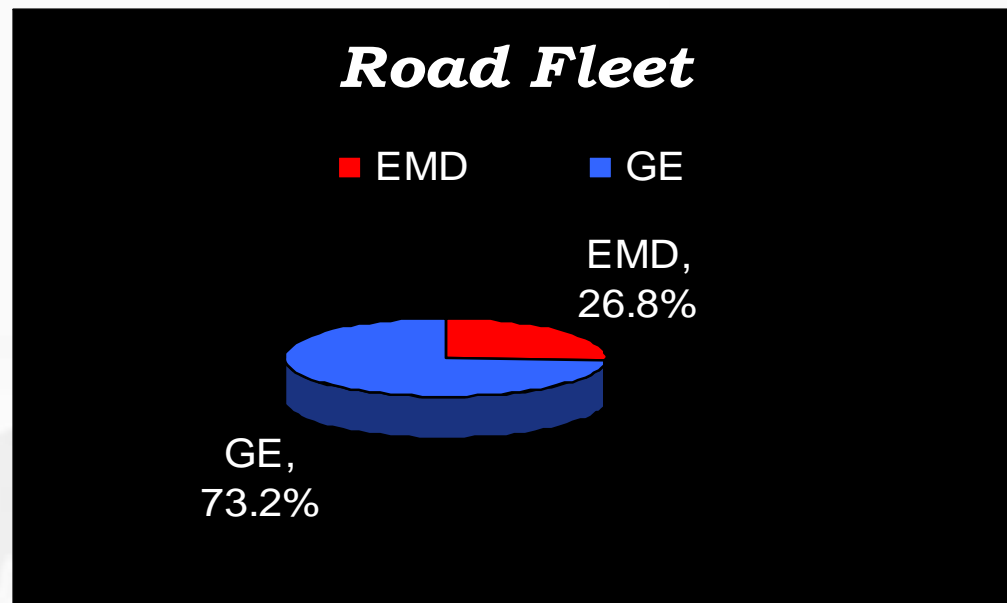
- NS Background / NS Locomotive Fleet
- Locomotive Emissions Federal Requirements
- Locomotive Basics – In Series Hybrid
 - NS 5052 – Compressed Natural Gas
 - NS 999, Battery Electric Design
 - NS 999, Initial 2009 Challenges, Improvements
 - NS 999 Battery Limits / Cycle Testing / Modeling

Norfolk Southern System

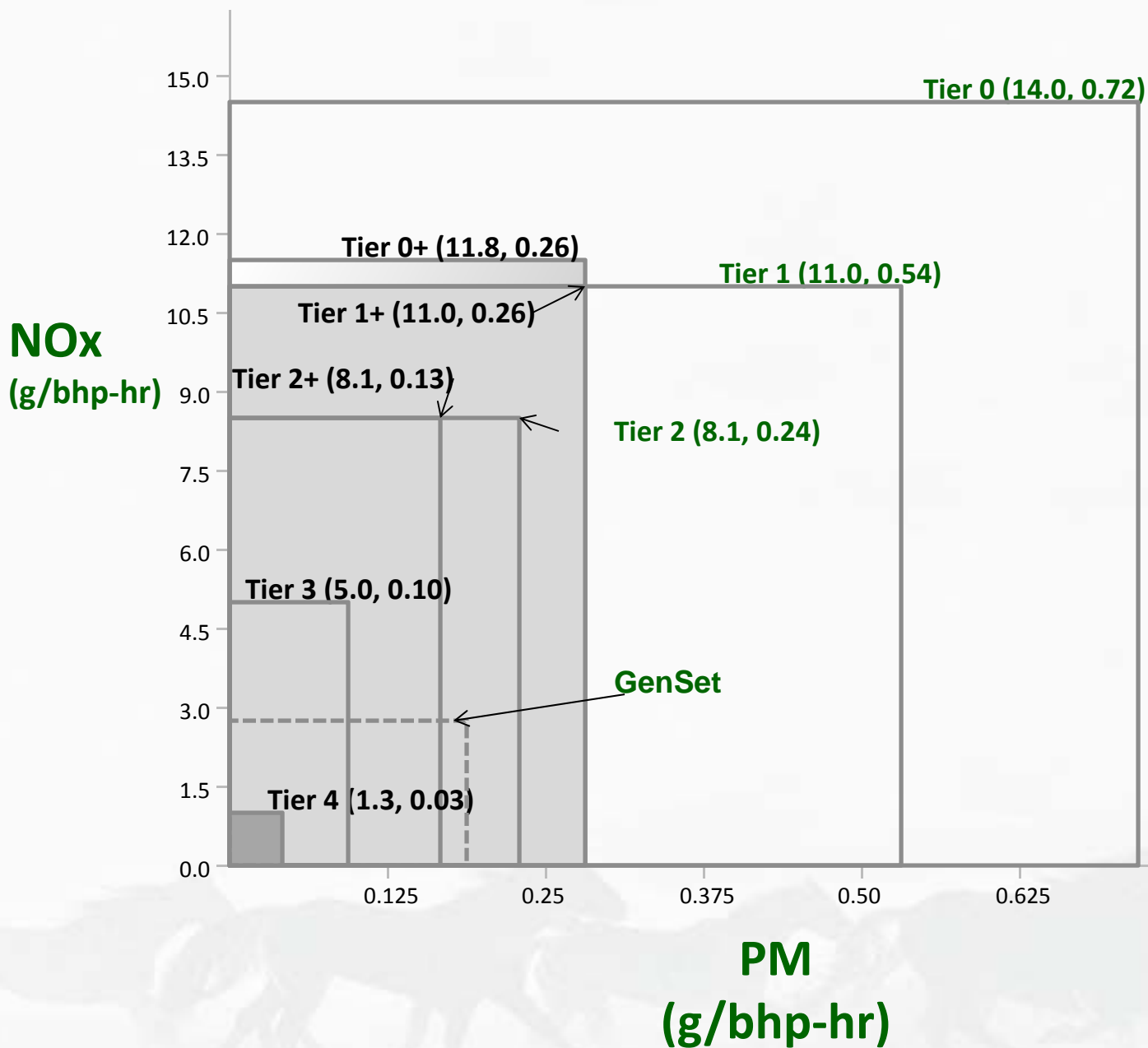


Locomotive Fleet

- 3700 Units
 - 2350 Road-Intercity Freight
 - 1350 Yard and Local Service
- Two Primary Builders GE and EMD



Locomotive Emissions Standards – Switcher

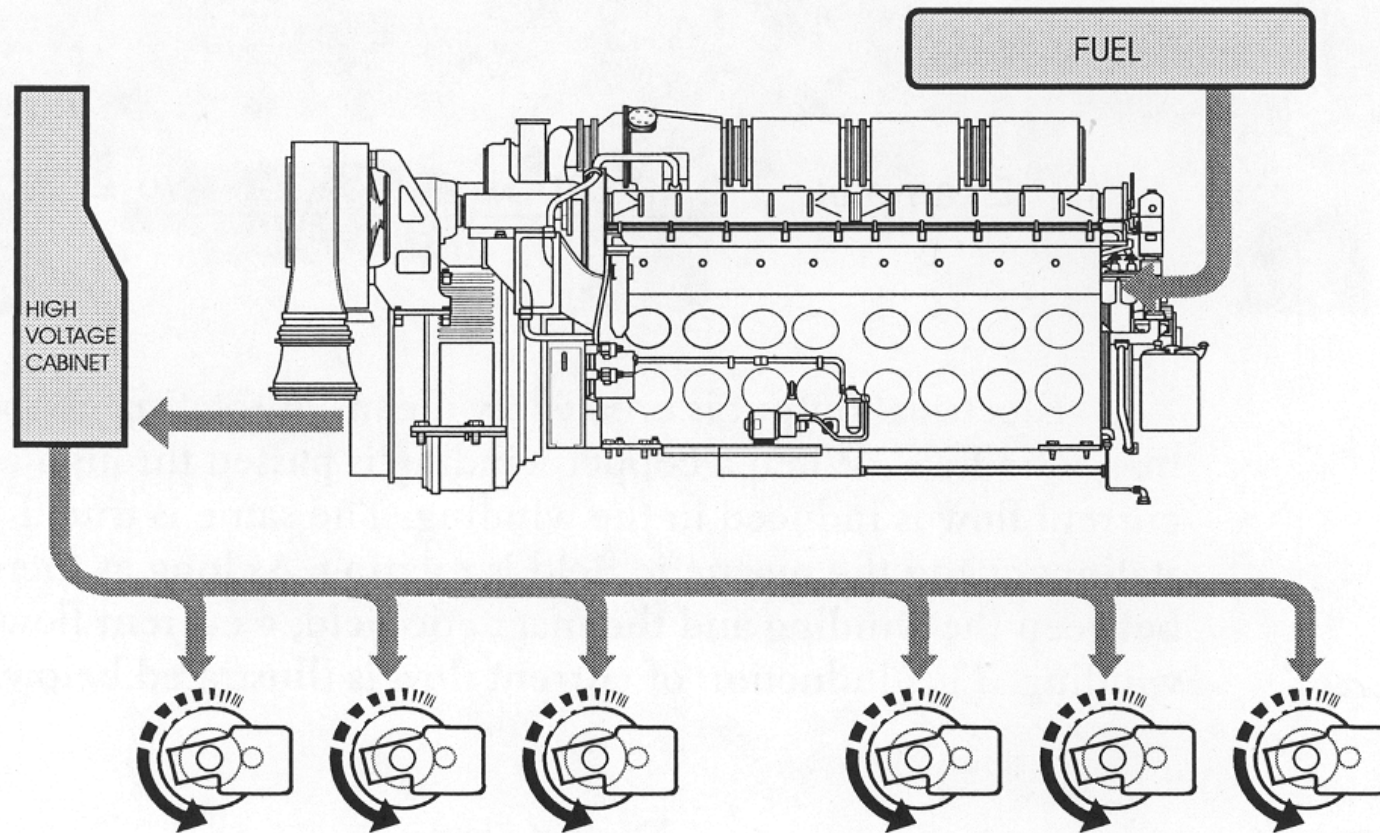


| EPA Standards (g/bhp-hr) | | |
|--------------------------------|------|-------|
| | NOx | P0.2M |
| Tier 0 (1973-2001) | 14.0 | 0.72 |
| Tier 0+ (1973-2001) | 11.8 | 0.26 |
| Tier 1 (2002-2004) | 11.0 | 0.54 |
| Tier 1+ (2002-2004) | 11.0 | 0.26 |
| Tier 2 (2005 and later) | 8.1 | 0.24 |
| Tier 2+ (2005-2010) | 8.1 | 0.13 |
| Tier 3 (2011-2014) | 5.0 | 0.10 |
| Tier 4 (2015 and later) | 1.3 | 0.03 |
| GenSet | 2.9 | 0.15 |



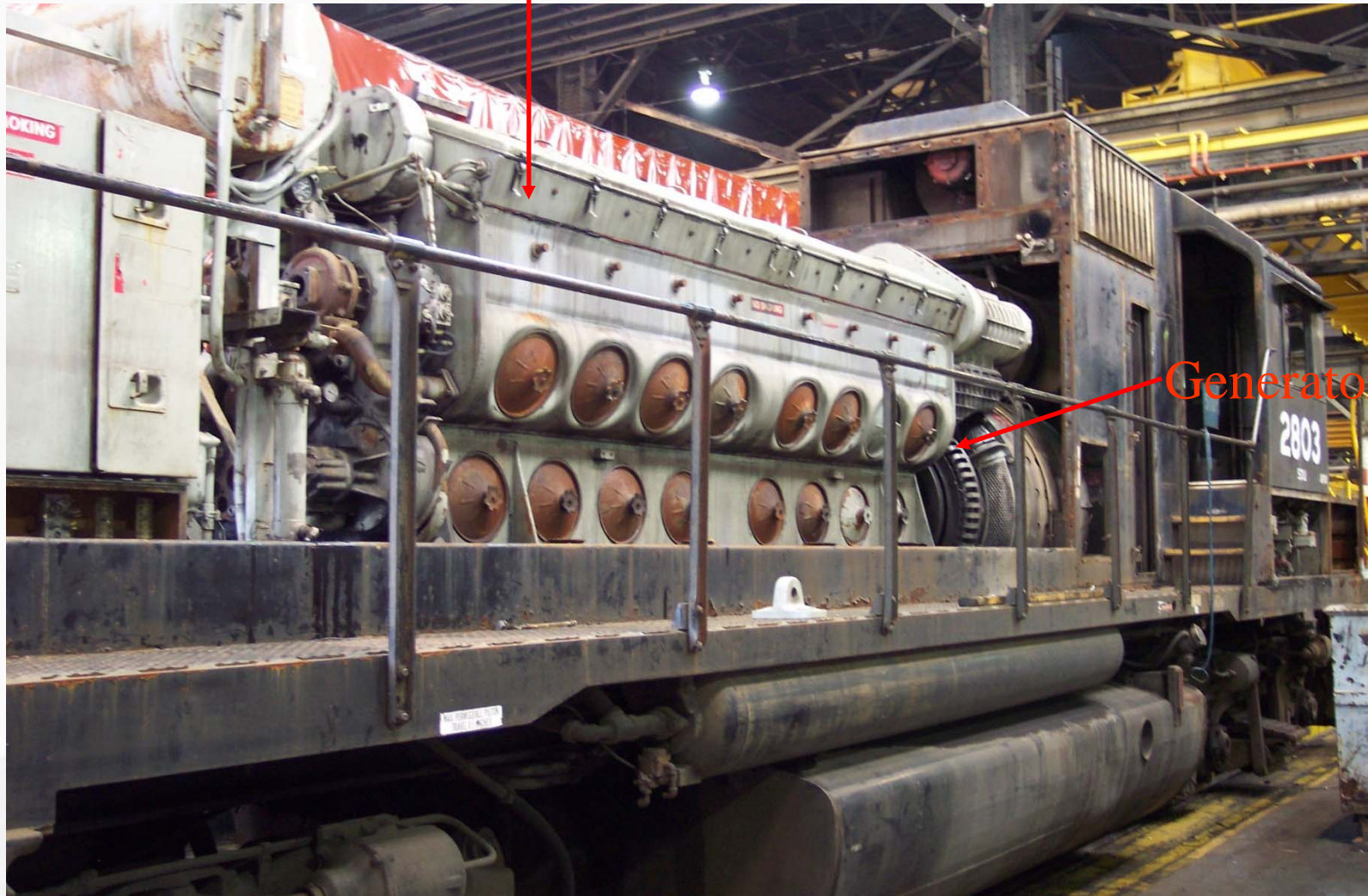
Diesel-Electric Locomotives

Diesel-Electric Power Generation



Engine Coupled to Generator

Engine

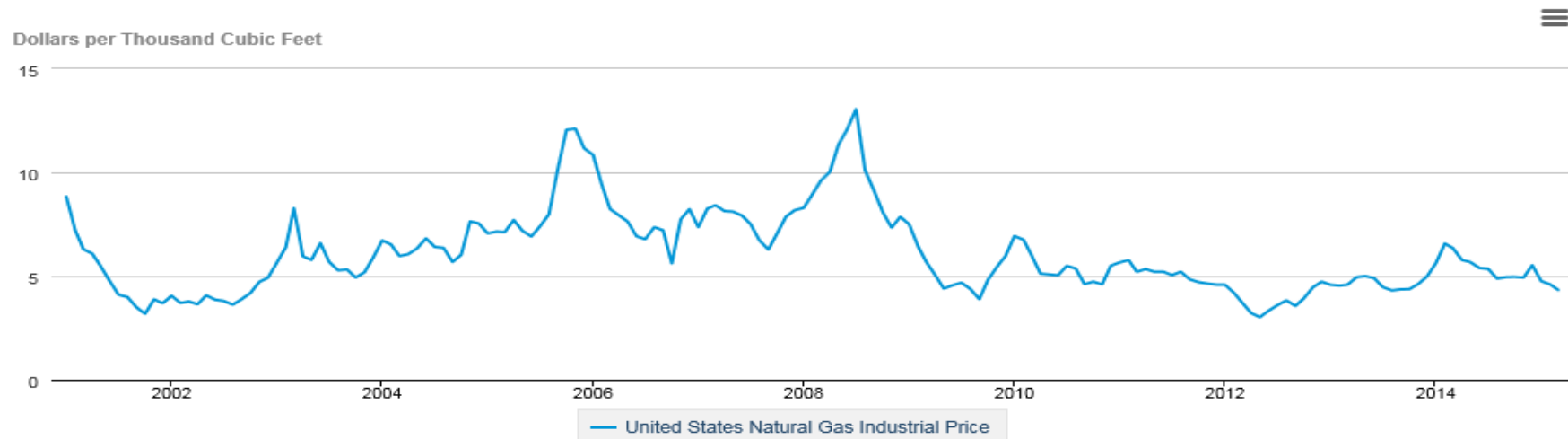


Generator

NS is Investigating Compressed Natural Gas

- North American Shale Gas
 - Cost Competitive, Reduced Emissions?
- Installing Energy Conversions Inc kit on an EMD GP 38-2, 645 Engine

United States Natural Gas Industrial Price



NS 5053 Assembly



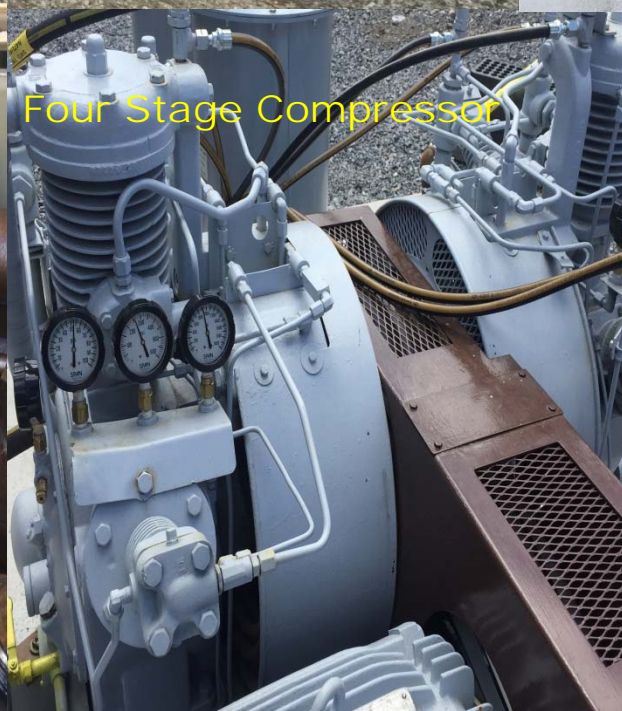
April 27, 2015 NS 5053 Initial Startup



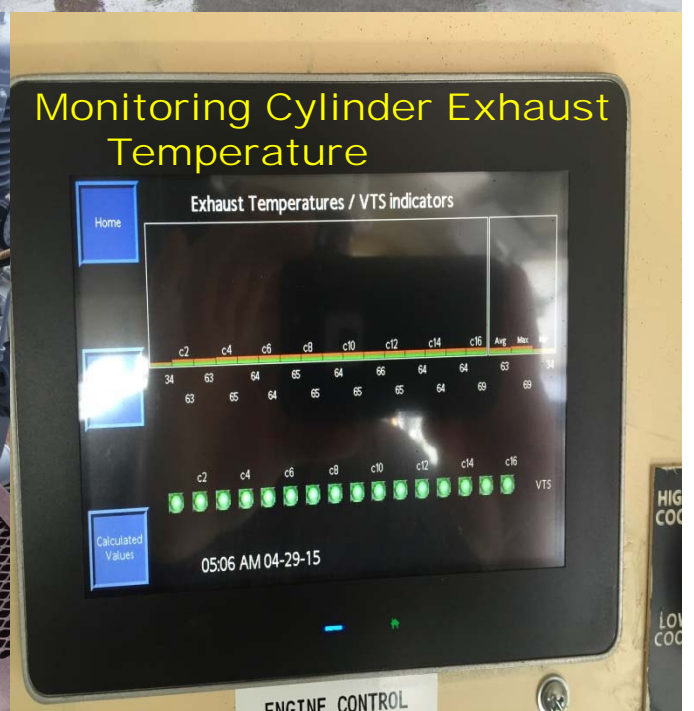
799 CNG Storage Slug



Gas Injection to Cylinder



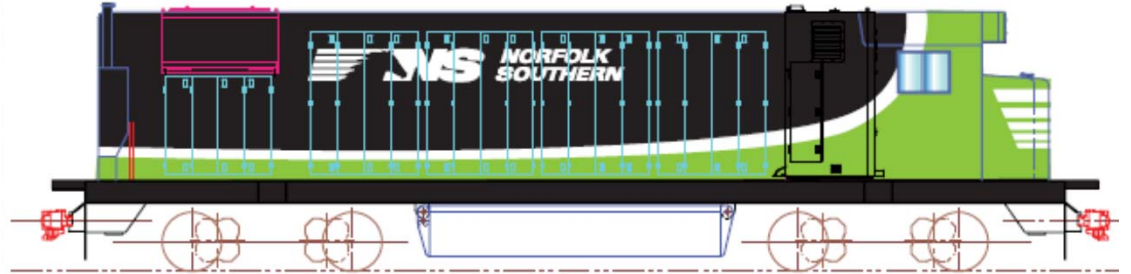
Four Stage Compressor



Monitoring Cylinder Exhaust Temperature

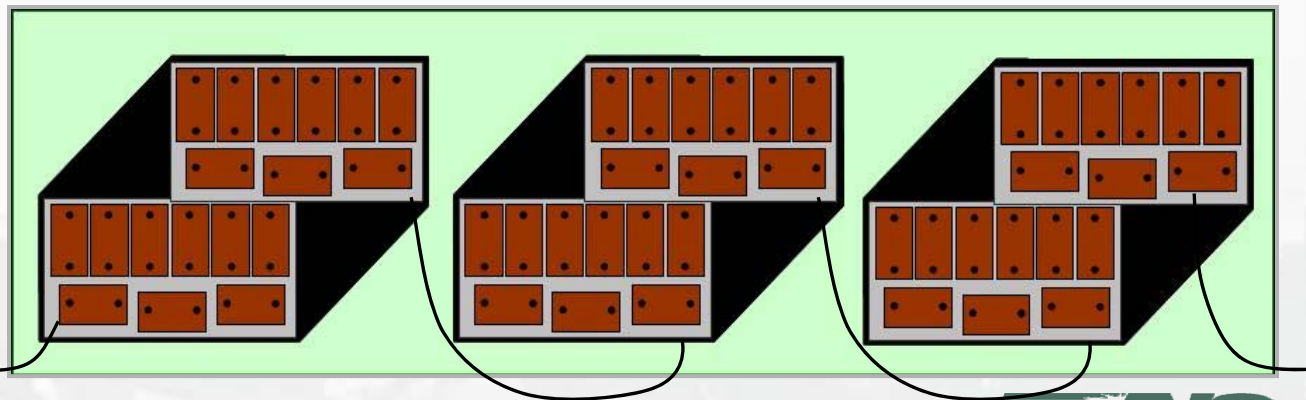
Electric Locomotive Research

- Multiengine Configurations
- BMEX 259 - Brookville Regenerative Braking
- NS 999, Hydrogen Fuel Cell



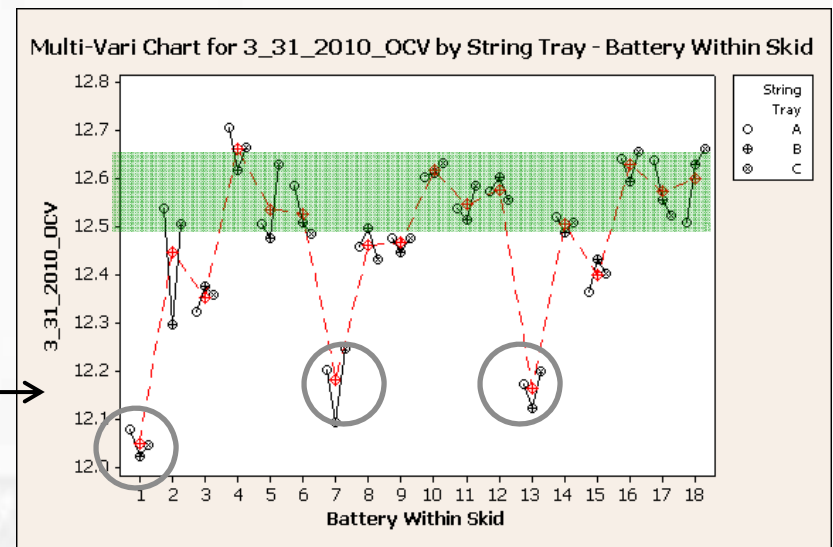
NS 999 Zero Point Source Emission Locomotive

- Battery Configuration (54 Batteries in Series 'Strings', 16 Multiple Strings in Parallel)
- Initial NS 999 - Several Design Issues
 - Poor Battery Management
 - Difficult to Maintain Packaging
- NS 999 Data – Battery Management Challenges
 - Capacity
 - Heating



2009 Battery Management System

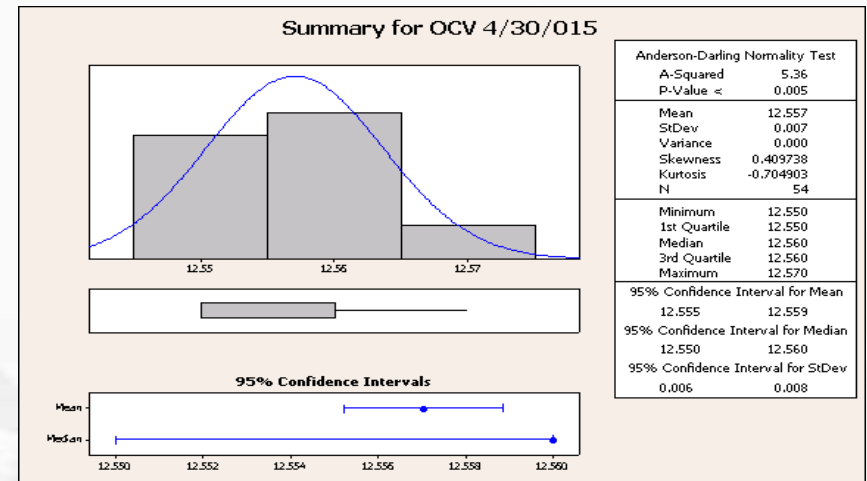
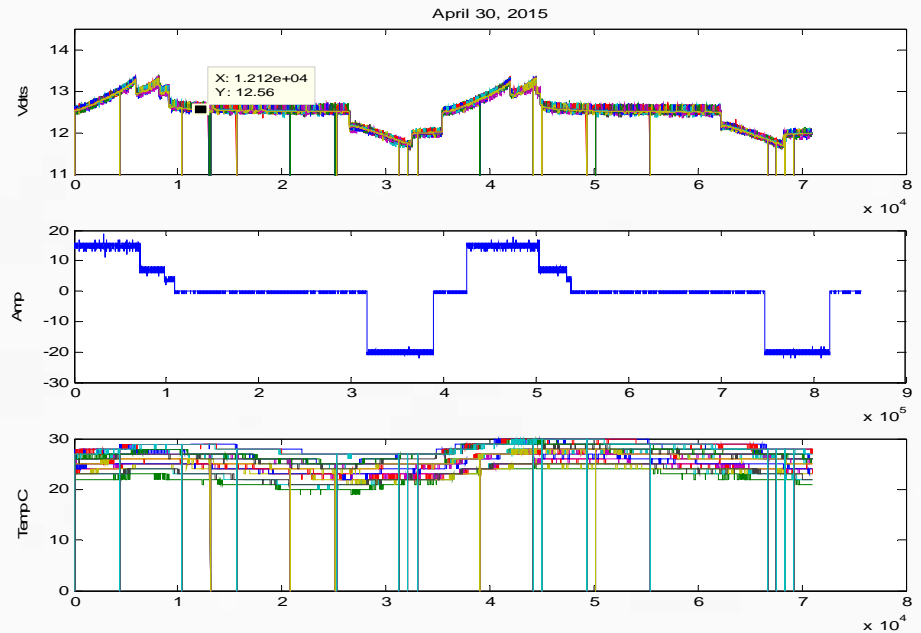
- **Desired BMS Functionality**
 - Equalize Long Strings of Batteries
 - Like State of Charge (SOC)
 - Monitor for Fault Conditions
 - Isolate Battery Strings (If needed)
- **Failure to Maintain Uniform State of Charge (SOC) =**
 - Reduced Power Output
 - Shortened Battery Life
 - Potential Risk of Fire (Overcharging)



BMS not adequately charging batteries 1, 7, or 13 location (Unequal load on strings).

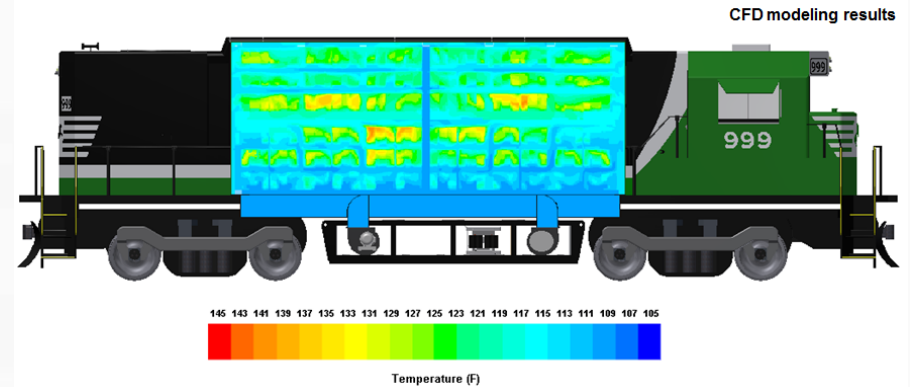
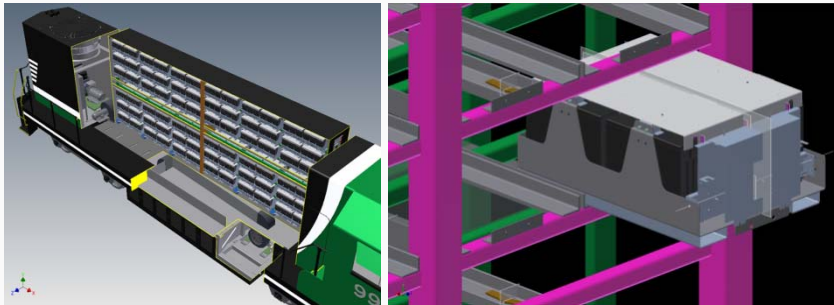
Gen 2.0 Battery Management System

- Simple Charge Discharge Profile
- Channels:
 - 54 Terminal Voltages
 - 18 Temperature Channels
 - Current
- Very Low Variation 0.03V Range, Minimal Temperature Change



NS 999 All Electric Switcher Locomotive

Gen 2.0 - Juniata Locomotive Shop

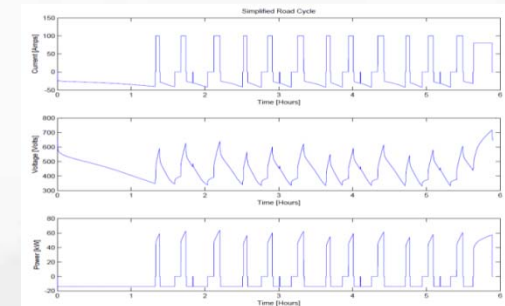
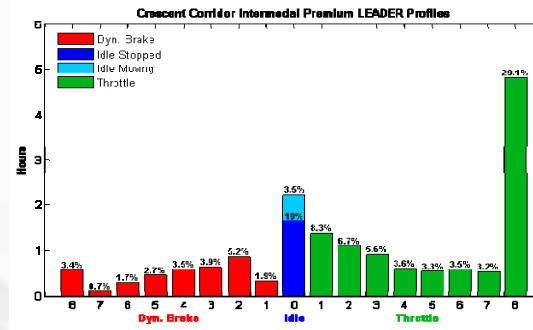


- Battery Management System (TMV Gen 2)
- Customized ISO Container (Battery Storage)
- Advanced Lead Carbon Batteries (Axion PbC®)
- Removable IntraPack Battery Trays
- Individual Battery String Control (IGBTs)
- RCL / OBN / Dashboard (Remote Monitoring)
- 480VAC Wayside Charging Station(s)

Battery Testing & Modeling



- Battery Test Program
 - HLS (Roanoke, VA)
 - Penn State University (PTI Labs)
- Evaluating Alt. Battery Technologies
 - Charge Acceptance
 - Thermal Characteristics
 - Cycle Life
- MATLAB Energy Modeling
 - Over-the-Road Load Profiles
 - Evaluate Hybrid Locomotive Configuration(s)
 - Hardware-in-the-Loop (HIL) Testing





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Questions?

