

Norfolk Southern – Locomotive Hydrogen Fuel Perspective



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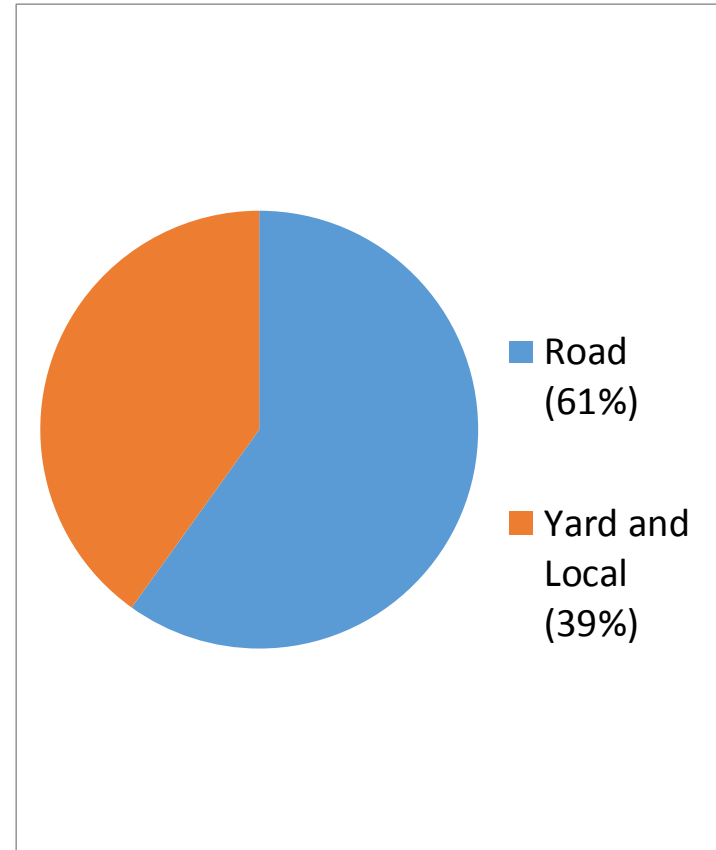
Norfolk Southern - Fast Facts

- 19,500 route miles in 22 states and District of Columbia
- 26,000 employees
- 7.9 Million cars and intermodal Units (2018)
- 61,000 Freight Cars
- 3,400 Locomotives



Locomotives

- Two Major Locomotives Types
 - Road – 2241 units
 - Yard and Local – 1171 units



Road Locomotives

- Used on intermodal trains, unit trains and major freight trains between terminals
- High Horsepower
 - 4000 to 4400
- Weigh 415,000 to 432,000 pounds
- Majority of fleet built since the year 2000
- Life expectancy 20 to 30 years



Yard and Local Locomotives

- Used in rail yards and on local trains to spot cars at industries
- Lower horsepower (2000-3000 hp)
- Lighter weight 250,000 – 390,000 lbs.
- Grouped into 4 and 6 axles
- Average age 29 years
- Low cost Maintenance
- **Very Reliable**



EMD SD40-2
A Typical 6 Axle Yard and Local Locomotive

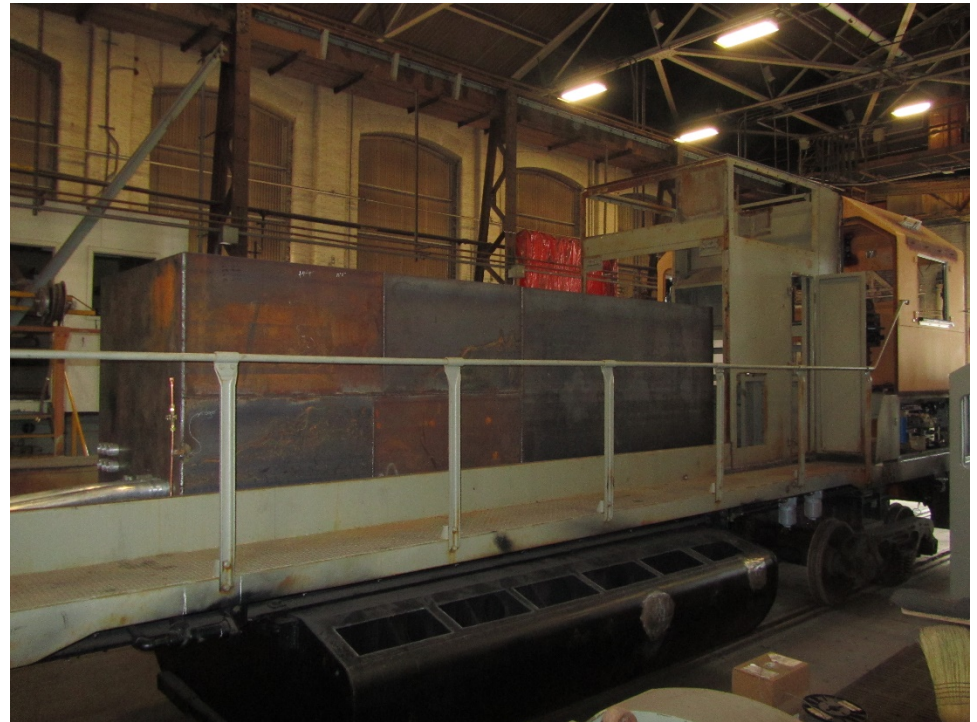
Norfolk Southern Repower Successes

- Georgia (GA EPD/GDOT –Grant)
 - Atlanta -
 - 10 GP33ECO Mother/Slug sets
 - 8 SD33ECO Mothers & 2 slugs
 - Rome
 - 1 GP33ECO Mother & Slug
 - Macon
 - 6 SD33ECO Mothers & 2 slugs
- Illinois (CMAP Grant)
 - Chicago
 - 15 GP33ECO Mothers & 3 Slugs
- Pennsylvania (SW PA Commission Grant)
 - Pittsburgh
 - 2 GP33ECO Mothers & Slug sets



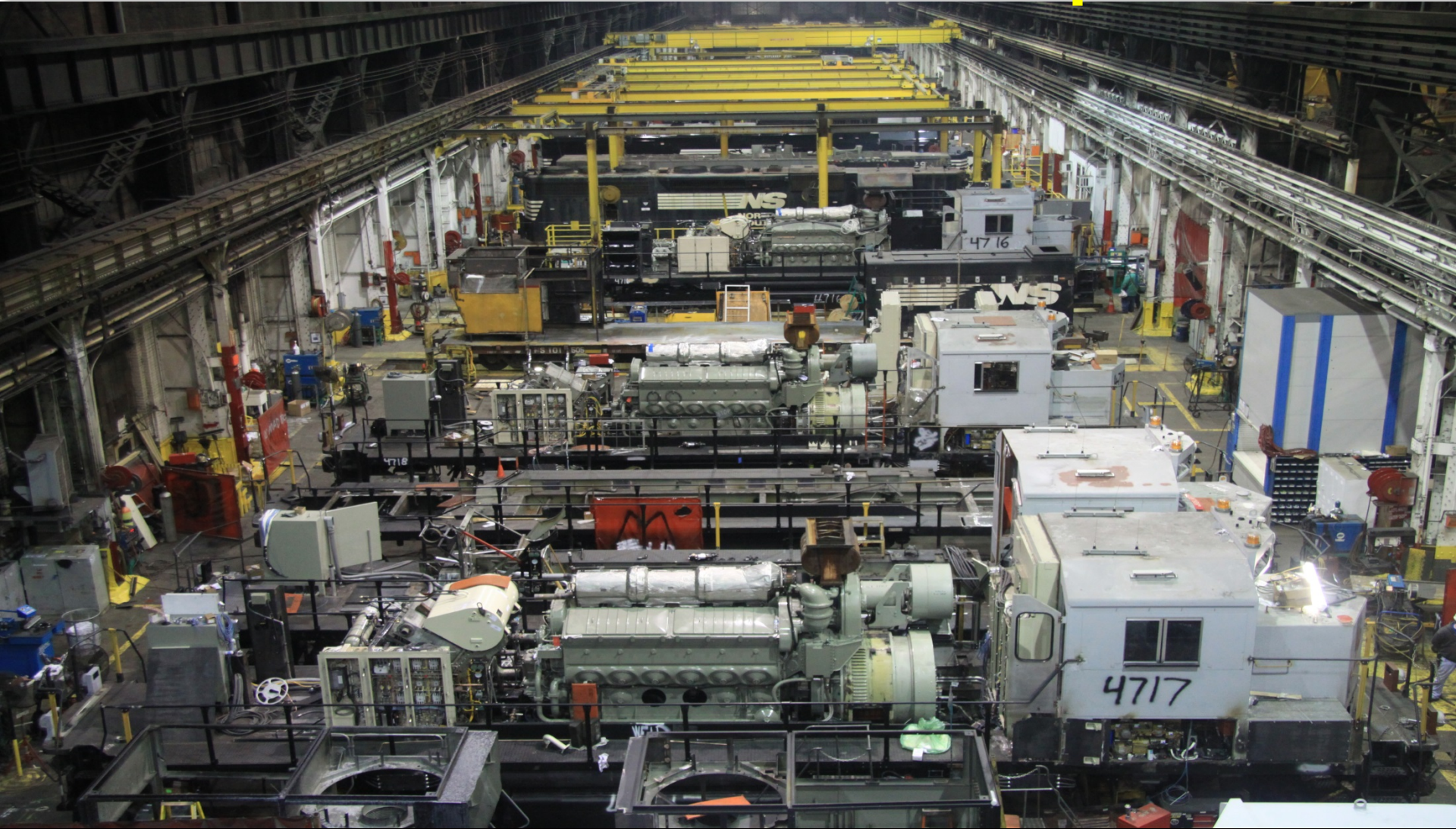
Locomotive Slug

- Slug - Engineless locomotive that gets power from a mother locomotive
- Provides extra tractive effort at low speeds
- Very suitable for switching service
- Reduces the need of powered locomotive where 2 locos are needed for switching



Slug under construction at NS Juniata Shops

ECO Locomotive Repower – Norfolk Southern – Juniata Shops

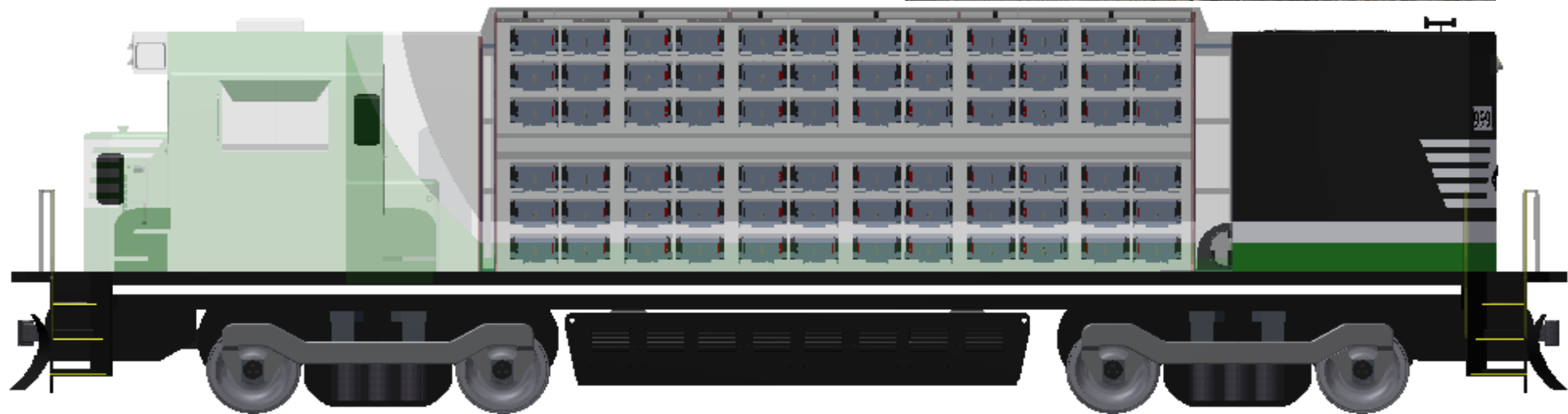


- Fuel Savings do NOT justify repowering – 75+ year payback
- Funding through Public/Private partnerships (70/30 split)
- Funding determined by \$/Ton of emissions savings



NS 999 Electric Switcher

- Battery Management System (TMV Gen 2)
- Individual Battery String Control (IGBTs)
- Advanced Lead Carbon Batteries (Axion PbC®)
- 144 Removable IntraPack Battery Trays
- OBN / DAQ / Dashboard (Remote Monitoring)
- 480VAC Wayside Charging Stations
- Cattron Remote Control Locomotive Kit



Natural Gas Mother/Slug

Reduced Particulate and NOx Emissions



CNG Fueled Locomotive

- Converted Rail Engine
- Spark ignited with Pre-Ignition Chamber



- CNG Storage in Slug
- Gas Compression is an Issue
 - Expensive Infrastructure
 - Fill Time can be lengthy

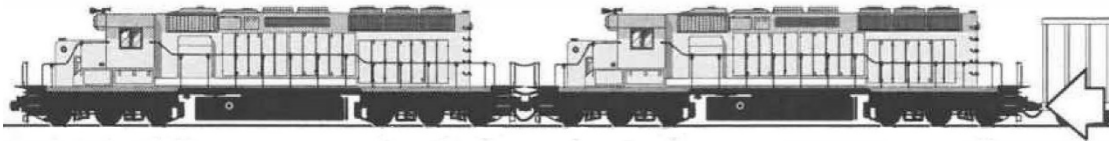
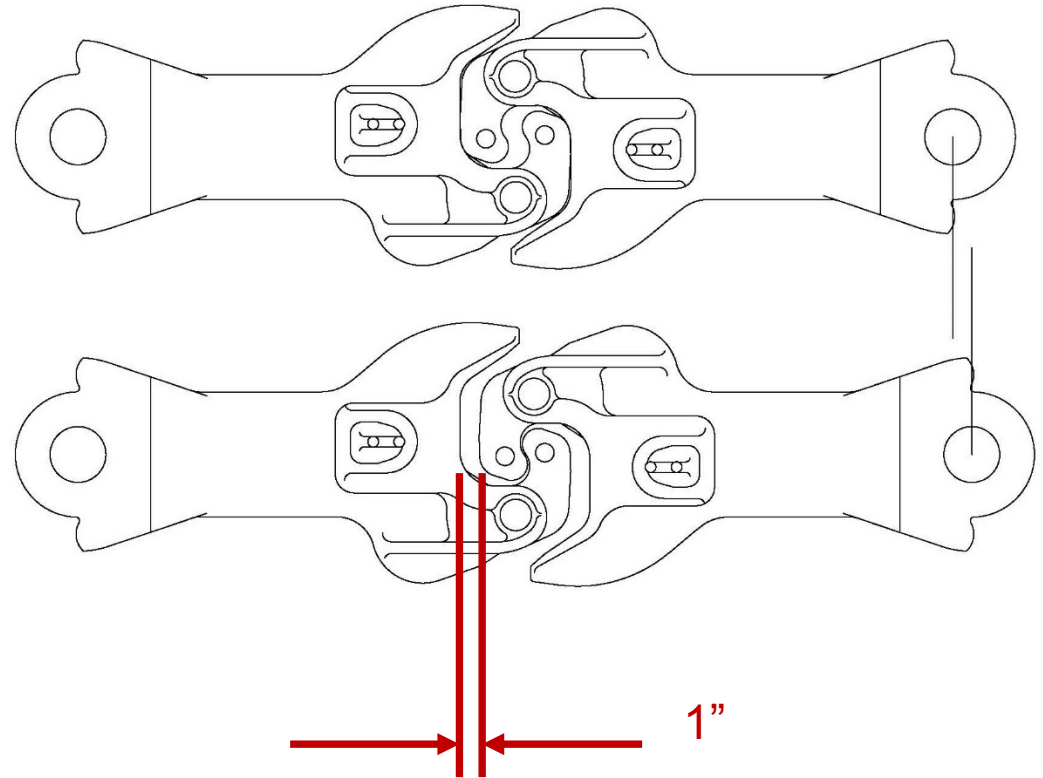
New Technology – Lessons Learned from Gensets

- Made from proven industrial products – engines, alternators, electrical choppers etc.
- Lessons Learned
 - Parts availability issues
 - Training Issues
 - Dealer vs. Railroad Maintenance
 - Not Railroad Rugged



Locomotive Equipment must be Designed for Coupler Slack & Hard Couplings

- Coupler movement
1" between pairs
- Slack can run in at any time
 - Abrupt force on locomotive(s)
- **Potential to cause damage to the propulsion system**
- **Radio Controlled Switchers see hard couplings at 5 mph**



Entire train couple slack reacts against the locomotives

Locomotive Idle Reduction – Shore Power – Electric Engine Coolant Heater

Advantages

- Zero Point Emissions
- Better emissions savings than Auto Engine Start/Stop
- Better Energy Savings – Up to 400 kW on a winter day
- Reduces Starting Battery issues

Disadvantages

- 3 Phase 480 Volt Electrical Connection



Locomotive Idle Reduction – Shore Power Wayside Station



Safety

- Ground Fault Detection
- Loop Complete Detection
- Phase Imbalance Detection

Ergonomic

- Less than 18 pound force to manipulate

Disadvantage

- 9 Feet Rail Clearance

NS – Hydrogen Perspective - Safety

- Fuel Handling
 - Flammability



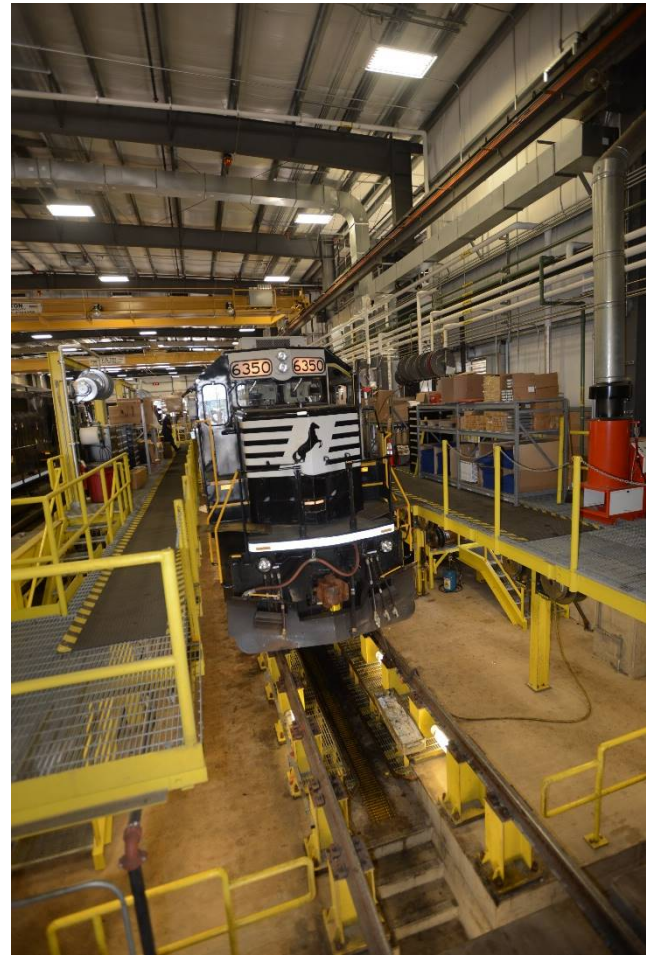
- Maintenance Shops Sources of Ignition
 - Open Flame heaters
 - Welders

Hydrogen Performance Issues

- **Economics**
 - Benchmark against diesel fuel cost
 - Trucking Competition
- **Power and Tractive Effort**
 - 4300 Traction HP per loco (3168 kW to traction motors)
 - 200,000 pound starting tractive effort
- **Fuel Range**
 - At least 1000 miles between fuel fills Newark, NJ to Chicago for NS
 - Tenders increase cost
- **Proven Reliability – Extremely important!**

Maintenance Considerations for Hydrogen

- 184 Day Maintenance Intervals
- Long Term equipment overhauls
 - 34,000 MW hours between overhauls
- Parts Availability
- Training of Shop crews



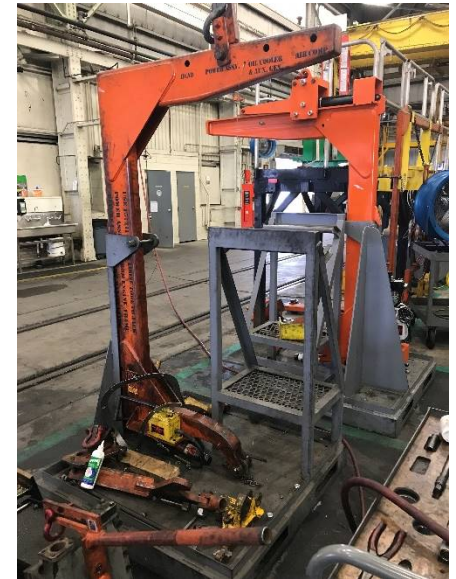
Infrastructure

- Shops
 - Gas detection
 - Heating Systems
 - Ventilation



- Servicing Facilities

- Tooling
 - Lifting fixtures etc



Summary

- Meet or Exceed Safety of current locomotives
- Meet Economic expectations
 - Cost of fuel, infrastructure and maintenance
- Performance equivalent to today's locomotives
 - 4300 Traction/ 200,000 lb starting TE
 - Equivalent Fuel Range
- Durable, Reliable and Rugged for Railroad Use
- Maintenance
 - By railroad employees
 - Time intervals equivalent or better than existing locos

