Cargo Handling Equipment

Technology Assessment

September 9, 2014

Diamond Bar, California

California Environmental Protection Agency

Air Resources Board

Overview

- Background
- Technologies Evaluated
  - Applicable Equipment Type and Development Status
  - Benefits:
    - Fuel Economy
    - Emissions Reduction (Tail-pipe)
    - Operational Benefits
  - Costs
- Summary
- Contacts

Background – What are CHE?

- Cargo Handling Equipment (CHE) operate primarily at:
  - Ports
  - Rail yards
  - Goods distribution centers
- Includes diverse types of equipment:
  - Yard trucks, automated guided vehicles (AGV)
  - Container handling equipment (including cranes)
  - Bulk handling equipment

Yard Truck

Loader

RTG Crane

Top Handler

Forklift

Reach Stacker

Port/Rail CHE Primarily Diesel But Alternative Technologies In-Use

- Yard trucks
  - LNG
  - Propane
  - Gasoline
  - Electric (demonstration)
- RTG and RMG cranes
  - All-electric
  - Diesel-electric hybrid
- Forklifts
  - Propane
  - Electric
  - Gasoline

Distribution Center CHE Primarily Low Emission Technology

- Electric, propane, or H_2 fuel cell:
  - Forklifts
  - Pallet jacks, walkies
  - Other lifts (man, scissors, other)
  - Sweepers
- Diesel
  - Limited yard trucks

Background – Regulatory Environment: Port/Intermodal Rail

- CHE Regulation:
  - Requires PM emissions equivalent to on-road 2007 or later, Tier 4 off-road, or DPF-equipped
  - All in-use equipment, as of 1/1/2007, either retired, replaced, or retrofitted
  - New CHE must meet current emission standards and be DPF-equipped if not Tier 4
- ~4,600 CHE engines at ports and intermodal rail yards
  - >75 percent of in-use CHE in compliance – 100% by 2017
  - Equipment useful life:
    - Yard trucks: 7 years
    - Container handling equipment: 11-12 years
    - Bulk handling equipment and forklifts: 20 years

Background – Regulatory Environment: Non-intermodal Rail/Distribution Centers

- In-Use Off-Road Equipment Regulation:
  - Applicable to diesel-fueled off-road equipment
  - Fleet rule: requires reductions in PM and NOx fleet emissions
  - Requires equipment registration, labeling, reporting
  - Restricts addition of older equipment to fleets
- LSI Fleet Regulation:
  - Applicable to:
    - Gasoline-, propane-, and CNG-fueled engines (>1 liter and >25 hp)
    - Forklifts, industrial tow tractors, airport ground support equipment, and sweeper/scrubbers
  - Fleet rule: requires reductions in NOx + HC fleet emissions with stricter requirements for forklifts
  - Electric equipment included in fleet size determinations and fleet average calculations
  - Requires recordkeeping

Background – Technology Performance Requirements

- Demonstrate operational performance:
  - Durability and reliability comparable to diesel
  - Operate for full 8 to 10 hour shift without down time
  - Quick shift to shift turn around with short refueling/recharging/battery exchange time
  - Equipment operator acceptance

Technologies Evaluated

- Hybrid (electric and hydraulic)
- All-electric (battery and grid source)
- Alternative fuels (H_2, natural gas (LNG/CNG))
- Maglev
- Lower emissions diesel engine
- System efficiency improvements
- Maintenance/reduced deterioration

Hybrids: Equipment powered by two or more energy sources

- Diesel-electric hybrid:
  - Energy sources:
    - Diesel engine
    - Electric storage device (i.e. battery or capacitor)
- Diesel-hydraulic hybrid:
  - Energy sources:
    - Diesel engine
    - Pressure storage device (i.e. hydraulic fluid accumulator)
- Diesel-Electric Plug-in Hybrid
  - Energy sources:
    - Diesel engine
    - Electric storage device (i.e. battery or capacitor)
    - Electricity from grid
- Fuel Cell-Electric Hybrid
  - Energy sources:
    - Fuel cell
    - Electric storage device (i.e. battery or capacitor)

Hybrid Technologies – Development Status and Application

- Diesel-Electric Hybrid
  - Commercially available for:
    - Cranes: RTG, shuttle carrier, straddle carrier
    - Bulk handling: excavator, dozer, loader
    - Container handling: reach stacker
- Diesel-Hydraulic Hybrid
  - Commercially available for:
    - Bulk handling: excavator
- Diesel-Electric Plug-in Hybrid
  - Yard truck under development
- Fuel Cell-Electric Plug-in Hybrid
  - Yard truck under development

Hybrid Performance–Fuel Economy

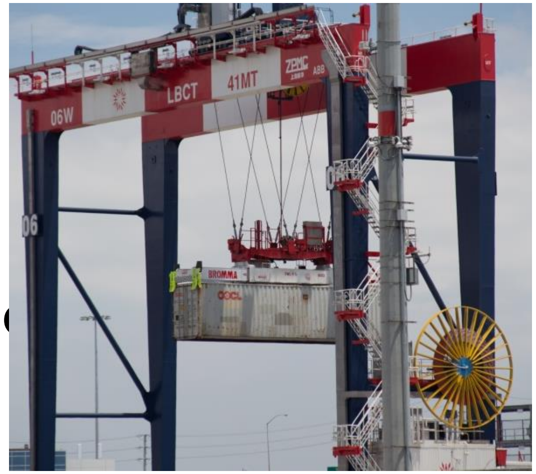
- Duty-cycle dependent
- Favors high energy intensity activities
  - Lifting and lowering containers
  - Acceleration and braking
- Fuel economy improvement ranges
  - Yard trucks: 15 to 20%
  - Cranes: 40 to 60%
  - Container handling equipment: 30%
  - Bulk handling equipment: 15–40%

Hybrid – Benefits

- Emissions benefits dependent on engine duty cycle
  - GHG Emissions (e.g., CO_2)
    - CO_2 benefits consistent with fuel economy benefits
  - Criteria Pollutant Emissions (e.g., NO_x, PM)
    - NO_x – variable
    - PM – up to 60% reduction – difficult to measure due to high DPF effectiveness
- Operational benefits
  - Reduced engine noise
  - Can operate for full shifts with quick shift to shift turn around
- Capital costs ~10 to 20 percent higher for most

All-Electric Technologies – Development Status and Application

- Rechargeable battery
  - Commercially available for:
    - Forklifts
      - Lift capacity up to 40k lbs
      - Larger capacities available as special o
    - Automated guided vehicles (AGV)
  - Under development for:
    - Yard trucks
- Grid-sourced
  - Commercially available for:
    - RTGs, RMGs, Automated Stacking Cran
      - Using bus bar and power reel technology



All-Electric Infrastructure Requirements

- Electrical supply infrastructure (i.e., substations, transformers, underground conduit, etc.)
  - Redundant pathways to substation
  - Emergency power source
- Rechargeable battery specific
  - Recharging stations
  - Battery exchange accommodations
- Grid-sourced specific
  - Busbar, or
  - Channel for power reel cable

All-Electric – Benefits

- Emissions
  - GHG Emissions (e.g., CO_2)
    - Zero tailpipe
    - Power generation emission increase associated with increase electrical power use
  - Criteria Pollutant Emissions (e.g., NO_x, PM)
    - Zero tailpipe
    - Power generation emission increase associated with increased electrical power use
- Operational benefits
  - Facilitates automation
  - Increased durability and reduced maintenance
  - Eliminates diesel exhaust exposure

Costs: All-Electric vs. Conventional

- Incremental capital costs:
  - Rechargeable battery:
    - Fork lift –
      - Lower lift capacities – comparable to propane
      - High lift capacities – ~40% higher than diesel
  - Grid-sourced:
    - Crane ~ 10% higher than diesel

Alternative Fuels – Development Status and Application

- Natural gas (LNG/CNG)
  - Commercially available for:
    - Yard trucks
      - Currently equipped with larger ISL G engine
      - Release of ISB G engine anticipated in 2016
    - Fork lifts
- H_2 fuel cell
  - Commercially available for:
    - Fork lifts
      - Commercially deployed in US since 2007
      - Approximately 8,000 in use in US with approximately 800 deployed in CA

Alternative Fuel Infrastructure Requirements

- Refueling station:
  - Fuel supply
  - Fuel dispensing
  - Fuel storage
  - Fire suppression
- Costs vary depending on facility size

Alternative Fuel –Benefits

- Emissions
  - GHG Emissions (e.g., CO_2)
    - NG – TBD
    - H_2 – zero tailpipe
  - Criteria Pollutant Emissions (e.g., NO_x, PM)
    - NG
      - PM reduction
      - In-use NO_x may be lower
    - H_2 fuel cell
      - Zero tailpipe
- Operational benefits
  - Eliminates diesel PM exposure
  - H_2 fuel cell – eliminates multiple battery storage, charging, and exchange

Costs: Alternative-fueled vs. Conventional

- Natural Gas
  - Yard trucks
    - CNG ~$125K
    - LNG ~$135K
    - Diesel ~$95K (On-road or Tier 4f)
    - Introduction of smaller ISB G engine will result in improved fuel efficiency and possible fuel cost benefit
- H_2 fuel cell
  - Forklifts
    - Incremental cost of ownership varies with facility operation:
      - Cost savings for fairly intensive warehouse and distribution operation
    - Capital equipment costs and fuel costs significantly higher than battery electric
    - Quick refueling provides economic savings in labor and facility space compared to battery exchange and charging
      - Estimated 10% cost saving for 60 units deployed in facility with 2-3 shifts per day for 6-7 days per week

Maglev – Development Status and Application

- Shanghai maglev train in commercial passenger operation since 2004
  - 19 miles
  - $1.2B capital cost
- Maglev traditionally uses electromagnets for operation
- Maglev using permanent magnets and diesel engine propulsion has completed small-scale demonstration
- Two US projects planned
  - South Carolina airport and inland port
  - Washington multi-modal transportation

Maglev Infrastructure Requirements

- Fixed rails
  - Permanent magnet
  - Electromagnet – requires electric power source
- Port Angeles, Washington permanent magnet demonstration infrastructure built for ~$5M/linear lane-mile

Maglev – Fuel Economy

- Permanent magnet rails eliminate energy for electromagnetic rails
- Vehicles propelled using forces generated from rotating magnetic discs on vehicle
- Energy source for spinning discs discretionary:
  - Diesel
  - All electric with on board energy storage
  - Micro-turbine
  - Fuel cell
- Forces required for propulsion low because wheel/rail friction losses eliminated with rail/wheel air gap
- ~95% reduction in diesel fuel use
- <1kWh power required per container-mile

Maglev – Benefits

- Emissions dependent on energy source selected
  - Diesel GHG Emissions (e.g., CO_2)
    - ~95% reduction compared to diesel
  - Diesel Criteria Pollutant Emissions (e.g., NO_x, PM)
    - ~95% reduction in PM and NOx compared to conventional diesel

Lower Emissions Diesel Engine – Development Status

- ARB working with SouthWest Institute to test diesel engine efficiency strategies for on-road applications.
- Anticipate transfer to off-road diesel engines to follow on-road adoption by 3 to 5 years

Lower Emissions Diesel Engines – Emissions

- Benefits dependent on equipment duty cycle
- GHG Emissions (e.g., CO_2)
  - Reduced CO_2 consistent with fuel economy benefit realized
- Criteria Pollutant Emissions (e.g., NO_x , PM)
  - NO_x emission level targets: 0.02 g/bhp-hr

Automation – Development Status and Application

- Five automated container terminals in Asia and Australia, and five in Europe
- Two semi-automated ports in US (Virginia and New York)
- Two CA container terminals in process of automating
  - LBCT's Middle Harbor to include all electric automated container handling from ship to drayage truck
  - TraPac to include diesel-hybrid and electric equipment with semi-automated container handling

Automation Infrastructure Requirements

- Varies with automation system chosen
  - Automation software
  - Sensing device matrix embedded in yard
  - Electrical power infrastructure (i.e., substations, transformers, underground conduit, etc.)
  - Busbar or channel for power reel cable
  - Fiber optic cable
- Infrastructure costs on order of $0.5B to $1B depending on facility size and degree of automation

Automation – Benefits

- Facilitates equipment electrification
  - Zero tailpipe emissions
  - Reduced equipment maintenance costs
- Increased safety
  - Separates workers from moving equipment
  - Reduces opportunity for human error
- Expedited container loading and unloading
  - Shorter dock times for mega-container ships
  - Incentive for increased ship visits
- ~ 30 to 40% operational cost savings ($/TEU)

Maintenance/Reduced Deterioration – Development Status

- Effective engine maintenance programs
  - Emissions deterioration factors assume engines receive OEM specified maintenance
  - SAE and mining industry studies demonstrate emissions degradation due to inadequate maintenance
- CHE Regulation requires annual CHE opacity monitoring at California ports and intermodal rail yards
  - Similar to on-road truck Periodic Smoke Inspection Program
  - Requires engines be serviced or repaired if fail opacity limits
  - Monitoring technology is proven and available

Maintenance/Reduced Deterioration–Fuel Economy

- Good vehicle maintenance practices provide performance benefits
  - Engine maintenance and repair
  - Maintaining recommended tire pressure, etc.
- DoE estimates up to 20% fuel efficiency benefit with a regular engine maintenance
  - Minimizes degradation of original vehicle performance

Maintenance/Reduced Deterioration –Emissions

- Emissions impacts dependent on engine technology and extent of engine maintenance program changes
- GHG Emissions (e.g., CO_2)
  - Improved engine performance/efficiency reduces:
    - CO_2
    - Black carbon
- Criteria Pollutant Emissions (e.g., NO_x, PM)
  - Reduced PM

Costs: Implementing Opacity monitoring Program

- Facility one-time costs for self-testing
  - Opacity monitoring equipment: $5,500 - $9,000
  - Training: ~$1,800/employee (class fee and labor)
- On-going costs
  - Testing: ~$50/engine

Summary

- CHE new technology deployment dependent on:
  - Technology providing economic/competitive advantage
  - Successful technology demonstrations require:
    - Reliability/durability comparable to diesel
    - Operate for entire shift without down time
    - Quick shift to shift recharge/refuel/battery exchange
  - Incentive funding
  - Infrastructure availability
- Container terminals – support implementation of automated systems using all-electric CHE
- Bulk terminals – support development and use of hybrid and electric bulk-handling equipment

Team Contacts

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