Cargo Handling Equipment Technology Assessment

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Diamond Bar, California
Overview

- Background
- Technologies Evaluated
  - Applicable Equipment Type and Development Status
  - Benefits:
    - Fuel Economy
    - Emissions Reduction (Tail-pipe)
    - Operational Benefits
  - Costs
- Summary
- Contacts
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
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
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
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\textsubscript{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., CO₂)
    - CO₂ benefits consistent with fuel economy benefits
  - Criteria Pollutant Emissions (e.g., NOₓ, PM)
    - NOₓ – 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 order
    - Automated guided vehicles (AGV)
  - Under development for:
    - Yard trucks

- Grid-sourced
  - Commercially available for:
    - RTGs, RMGs, Automated Stacking Cranes
      - 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., CO₂)
    - Zero tailpipe
    - Power generation emission increase associated with increase electrical power use
  - Criteria Pollutant Emissions (e.g., NOₓ, 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
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
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

H₂ 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., CO₂)
    - NG – TBD
    - H₂ – zero tailpipe
  - Criteria Pollutant Emissions (e.g., NOₓ, PM)
    - NG
      - PM reduction
      - In-use NOₓ may be lower
    - H₂ fuel cell
      - Zero tailpipe

- Operational benefits
  - Eliminates diesel PM exposure
  - H₂ 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

- **H₂ 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
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
Emissions dependent on energy source selected

- Diesel GHG Emissions (e.g., CO₂)
  - ~95% reduction compared to diesel
- Diesel Criteria Pollutant Emissions (e.g., NOₓ, 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)
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
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
Emissions impacts dependent on engine technology and extent of engine maintenance program changes

GHG Emissions (e.g., CO\textsubscript{2})
- Improved engine performance/efficiency reduces:
  - CO\textsubscript{2}
  - Black carbon

Criteria Pollutant Emissions (e.g., NO\textsubscript{x}, PM)
- Reduced PM
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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