Electrification of Non-Road Transportation
Non-Road Electrification Generally Offsets Petroleum Fuels
Forklifts
ITA’s Forklift Classes

- The Industrial Truck Association (ITA) has defined seven classes of lift trucks, or forklifts, which are defined by the type of engine, work environment, operator position and equipment characteristics.

- Forklift classes include:
  - Class 1: electric counter-balanced trucks
  - Class 2: electric narrow aisle trucks
  - Class 3: electric pallet trucks and tuggers under 999 lbs draw bar pull
  - Class 4: internal combustion sit down rider forklifts with cushion tires, suitable for indoor use on hard surfaces
  - Class 5: internal combustion sit down rider forklifts with pneumatic tires, suitable for outdoor use on rough surfaces
  - Class 6: electric or internal combustion powered, rider units with the ability to tow (rather than lift) at least 1,000 pounds
  - Class 7: almost exclusively powered by diesel engines with pneumatic tires, these units are suitable for rough terrain and used outdoors.

- Primarily classes one through five are used in materials handling applications.
Forklift Classes

**Electric Forklifts**

- **Class 1: Electric Counterbalanced**
  Warehousing, manufacturing

- **Class 2: Electric Narrow Aisle**
  High-density storage, narrow-aisle buildings

- **Class 3: Electric Hand Trucks**
  Moving pallets

**Fossil-Fueled Forklifts**

- **Class 4: Internal Combustion Engine Counterbalanced with Cushion Tires**
  Indoor warehousing and manufacturing, outdoor on smooth surfaces

- **Class 5: ICE Counterbalanced with Pneumatic Tires**
  Indoor and outdoor warehousing and manufacturing
Forklifts Applications

- Forklifts are applied primarily in material handling:
  - Commercial businesses
  - Warehouse facilities
  - Industrial facilities
  - Logistics

- As a rule of thumb, electric forklifts are economically competitive with ICE models if the annual forklift operating hours is more than 1,000 hours
Electric Forklift – Powering Options

- Flooded Lead Acid Batteries
  - Typically used in the industry
  - 8-8-8 rule: 8 hr charge, 8 hr rest, 8 hr run
  - Ideal for 1-shift operation; multi-shift requires more than 1 battery pack
  - Forklift truck design depends on the weight of a traditional battery to provide the counterbalance to loads
  - Cannot be used with fast chargers
  - Flooded lead acid batteries must be periodically topped off with distilled water.
  - Charge/discharge cycles: 300-500 based on depth of discharge

- Lithium Ion Batteries
  - Light weight design (weights 40-60% less than LA batteries)
  - Higher charge/charge cycle than lead acid batteries (2000 to 5000 cycles)
  - Can be used with fast chargers and opportunity chargers
  - Can operate in cold environment (better than lead acid batteries)
  - Less maintenance – no need to be topped off with water
  - Currently the cost is high (~4X) but expect it to come lower
Forklift Chargers

- Ferro-resonant Chargers (commonly used in the industry)
  - Uses three-winding transformers
  - Output voltage is independent of input voltage fluctuations
  - No electronic controls, sensitive to line frequency, low efficiency and more heat
  - Charging time: 8 hours typical
  - Limitation: potential for overcharging

- High Frequency Fast Chargers
  - Built with power electronic circuit (has MOSFET, IGBT etc.)
  - Operates at few to 100’s of kHz
  - Significant weight and size reduction
  - Fine control of output voltage
  - Electronic controls can limit overcharging, set kW threshold for demand response
  - High efficiency
  - Charging time: 3-4 hours typical

- Opportunity Chargers
  - Can charge the batteries during small breaks – interval charging
  - Typically charges the batteries for 10-15 min during breaks

Source: Enersys

Source: Fronius
Autonomous (Robotic) Forklifts

- Autonomous forklifts may help optimize work flow, provide flexibility and achieve cost savings.
- Cobotics: is the collaboration between people and robotic lift trucks allows both to work and interact in a reliable manner.
  - The forklifts are equipped with intelligent features allowing them to operate in the same environment alongside people and other vehicles without any additional infrastructure.
  - The units navigate with Lidar using existing structural features such as walls, racking or columns
    - a solution that is economical, easy and quick to install and can easily accommodate future changes to routes or activities.

Source: Baylo by Hyster
Non-energy Benefits

- Electric forklifts eliminate tailpipe emissions leading to:
  - Improved facility air quality and employee health
  - Reduced HVAC costs for indoor applications
  - Contribution to meeting compliance/corporate goals, and productivity improvements for the drivers due to less down time, quieter operation and increased comfort and safety
- Electric forklifts have lower maintenance cost than the ICE counterparts – e.g. no oil changes, filter changes.
- Electric forklifts offer operational and performance advantages:
  - More responsive and smoother to operate
  - Better ergonomics and quiet operation
Informational barriers are the primary barriers to increased adoption of electric forklifts where internal combustion units are currently being used are. There are several common misperceptions about electric units compared to internal combustion including:

- **Up front costs** – however with appropriate application (>1000 h/yr use) savings on maintenance and fuel costs will quickly make up for additional capital costs
- **Performance** – in general electric trucks can match or exceed performance of internal combustion units, due to technology advances
- **No space for spare batteries** – in most cases no battery swapping is needed depending on the type of charger/ battery installed
- **Battery maintenance** – weekly watering and equalization is required, however training or maintenance programs through the dealer are simple solutions.
- **Overcome with opportunity charging**
- **Batteries fail in colder environment**
  - Battery technology has improved and can work even in cold storage – internal resistance heating to keep the battery cells at optimum temperature
Airport Ground Support Equipment (GSE)
Airport Ground Support Equipment Overview

- **Baggage Tractor:**
  - With the capacity to tow between 15 and 17 tons, the baggage tractor is the most diverse piece of equipment used in an airport.
  - Primarily used to pull trains of baggage carts from the bag room to the aircraft and back to the bag room.
  - Online transfer: In some hub applications, the baggage tractor is utilized to move baggage from an arriving aircraft directly to a departing aircraft for passengers connecting to another flight on the same carrier.
  - Baggage tractors can also be used to stage other pieces of equipment around the aircraft, such as the air start unit and ground power unit (GPU).

- **Belt Loader:**
  - Belt loaders are mobile conveyors used to load baggage and bulk-load cargo into the belly of an aircraft.
  - Belt loader units are self-propelled and are able to lift up to 2,000 lbs of baggage and cargo from ramp level up to the lower door of the aircraft. Belt loaders can be powered by gas, diesel, electric or CNG.

- **Pushback Tractor:**
  - Primarily used to move aircraft when they are not under their own power. Aircraft tractors can be employed as gate tractors or maintenance tow tractors.
  - Gate tractors are used only in gate areas to bring planes into a gate and push them out once they are loaded. Maintenance tow tractors are used to position aircraft in remote parking areas and to move aircraft from maintenance hangars to the gate. Maintenance tow tractors are usually larger tractors and require significantly larger engines to move aircraft over long distances.
  - Two broad categories: conventional tractors and towbarless tractors.
    - Conventional aircraft tractors use a towbar to connect to the nose gear of an aircraft in order to move the plane around.
    - Towbarless tractors do not require the use of a towbar, as they grab the nose gear in a cradle and lift it off the ground to move the plane.
Airport Ground Support Equipment  

Benefits and Barriers

**Benefits of Adoption**

- Electric ground support equipment (GSE) offers the following cost benefits.
  1. **Maintenance:** Electric vehicles are much less expensive to maintain than their internal combustion (IC) counterparts. IC engines have several moving parts that need periodic maintenance, oil changes and lubrications.
  2. **Reliability:** Electric-powered vehicles have a great record for being reliable under a range of conditions. The reliability of an electric vehicle is twofold.
    - First, due to less maintenance, the vehicle operates for longer periods between scheduled maintenance visits.
    - Second, the electric vehicle is optimized to operate under various conditions. Electric vehicles have fewer limitations than IC vehicles in extreme cold and perform equally well in extreme heat.
  3. **Fuel:** The operating fuel cost for electric vehicles is much less than the fossil fuel over the life of the equipment use, typically.
  4. **Emissions:** The electric GSE have no on-site emissions compared to the IC engineer counterparts.

**Barriers**

- Airline GSE turn over is not all at once, so replacing them could pose a challenge.
- GSE simple payback is farther out for some equipment than others due to lower utilization
  - Remedy: Allow phased approach so they can convert the most profitable items first, realize benefits and use the cost savings to fund the remainder
- Operating eGSE in cold weather regions is considered as a challenge citing battery issues
  - Remedy: This has been addressed by the battery manufacturers and newer technologies overcome this issue.
- The airline will have a reduction in diesel and jet fuel costs, while the airport will have an increase of electricity fuel costs; a partnership to share the burden and cost benefit should be discussed
  - Remedy: Agreement on how to track and bill electricity usage, or build a fixed cost into rent
- Driver ineffectiveness with electrics will have a few hurdles as the requirement of plugging them in is different than their current gas and diesel vehicles
  - Remedy: Employee charging may allow more employees to be familiar with the ease and benefits of plug in electric vehicles.
- Filing the grant applications on-time/logistical issues
Airport Electrification

- Ground support equipment
  - Bag tugs
  - Belt loaders
  - Container loaders
  - Aircraft tractors

- Ground power for planes
  - Ground power units – electric, diesel and use of jet engine
  - Cases with and without provision of pre-conditioned air are considered

- Landside vehicles
  - Shuttle buses, taxis, PEV parking
Airport Ground Support Equipment (GSE)

Drivers for Electrification:
- Air quality improvements
  - Benefits of emissions produced using electricity as a fuel versus diesel fuel or gasoline
- Economic benefits
  - Reduced fuel costs
  - Reduced maintenance costs
Electric GSE Equipment Options

Common GSE, all available in electric options

- Bag Tugs/Bag Tractor
- Belt loaders
- Pushback Tractor/Aircraft Tractor
Electric GSE Equipment Options

Not typical but all available in electric options

- Container/cargo loaders
- Passenger Stairs
- Lavatory Truck
- Catering Truck
- …golf carts
Other Electric Options

- **Auxiliary Power PC Air (PCA) Unit**
  - Pre-conditioned Air Units are used to cool the aircraft while it is parked at the gate.
  - Southwest Airlines project objective in 2002: Provide external pre-conditioned air (heat and cool) and 400 HZ power to the Aircraft to minimize the use of the Aircraft’s Auxiliary Power Units (APU) while the Aircraft is at the gate. Saving fuel and reducing emissions.
Southwest Airlines (SWA) “Gate Services” program has the potential to save*:
- $124,000 per day
- $40-45 million per year
- 20.5 M gallons per year

EPRI, with airlines and GSE industry, demonstrated ground power and its benefits in 2002

* Updated numbers from SWA Advisor in 2012
* Includes 423 gates in 64 cities with 3300 domestic flights per day operation
Ground Power Units

- Ground Power Units (GPUs) are ground support equipment which provides electricity for a parked aircraft.
- The power a jet uses is very different from standard grid power. Standard grid power is 60 Hz, while aircraft require electricity at 400 Hz.
- Airports are beginning to retrofit their gates to provide bridge mounted Electric GPU capability for their airline tenants (you may hear this as providing 400 hertz power)
  - The current option is for a plane to use its jet engine or portable diesel-powered generator (fuel usage in this scenario is estimated to be ~28 gallons per hour)
The following is an example of power usage:

- Baggage tugs with 1 battery each - ~20kWh/day (10-20 kW)
- Belt loaders with 1 battery each - ~10kWh/day (5-10 kW)
- Pushback tractor with 2 batteries - ~20kWh/day (10-20 kW)
- Container loaders with 2 batteries each - ~40kWh/day (20-40 kW)

If all the vehicles were plugged in at the same time, the gate would require a minimum of 45-90 kW.
Passenger loading bridges or jetways, at most airports already have dedicated electric infrastructures and due to the intermittent operation, this electrical infrastructure is available to support charging stations for eGSE.
Seaports and Intermodals
Seaports and Intermodals
Seaports And Intermodal Transfer Centers

- In seaports and intermodal transfer centers around the world, heavy equipment, historically powered only by diesel, can now be powered by electricity—either by being retrofit or as new equipment.
- Electricity offers a superior environmental choice and utilizes the newest technology that enables faster and more efficient goods movement, resulting in a swift return on investment.
Cranes

- **Application:** Ship-to-shore and gantry cranes are common in ports and intermodal centers. Some models of each crane type can be powered by electricity.

- A ship-to-shore (STS) or quay crane is a rail-mounted dockside crane that transfers containers to and from ships at port.

- A gantry crane straddles stacks of shipping containers. It moves containers and consolidates stacks as containers are loaded onto trucks or railcars.
  - A rubber-tired gantry (RTG) crane typically runs on 8–16 wheels, directly on the pavement surface.
  - A rail-mounted gantry (RMG) crane runs on two rails.

- Wide-span cranes are typically used in new or redesigned intermodal centers. *They can increase throughput by up to 30%.*

- **Technology:** Electricity is supplied from the grid. Electric cranes typically are powered by an elevated busbar or a cable reel, which is mounted to the crane or stored in a trolley cart that follows the crane; the feed cable can be as long as 4,000 feet. Electric STS and RTG cranes operate at 4,160–13,800 VAC. One wide-span crane manufacturer specifies three-phase, 50/60 Hz, 10–15 kV. Power demand and energy use vary widely depending on hours of operation, number of lifts, container weight, weather, time of day, and use of regenerative braking.

- **Typical Input Demand:** 136 kW for STS; 330–420 kW for RTG; 540 kW for wide-span RMG

- **Typical Energy Usage per Lift Cycle:** 3.4–4.5 kWh for STS; 2.2–4.6 kWh for RTG; 2.2–3.4 kWh for wide-span RMG
Dredges

Application: A dredge uses scooping or suction devices to deepen harbors and waterways, restore beaches or wetlands, and dig in other underwater applications.

An electric dredge uses shore power delivered via a large cable, and can be beneficial for long-term projects.

Technology: Operating profiles, power demand, and energy use vary widely depending on the size and type of dredge, material being dredged, and hours of use. One estimate indicates 480 VAC, 80 amps.

- Typical Input Demand: 2.4–4.8 MW
- Typical Daily Energy Usage: 36,510–115,000 kWh
ShorePower or Shore-to-Ship Power or Cold Ironing

- Cold ironing is the process of providing shoreside electrical power to a ship at berth while its main and auxiliary engines are turned off.
- Cold ironing permits emergency equipment, refrigeration, cooling, heating, lighting and other equipment to receive continuous electrical power while the ship loads or unloads its cargo.
- Shorepower is a general term to describe supply of electric power to ships, small craft, aircraft and road vehicles while stationary.
- Other electric options for seaports include forklifts and automated guided vehicles (AGV).
- Short-distance electric yard hostlers at ports and distribution centers are also being demonstrated.

Refrigerated cargo containers can be plugged in or stacked in electric-powered “reefer” racks while awaiting ground transfer.
Electric Refrigeration Transport Units (eTRU)
Electric Truck Refrigeration Units  *Overview and Applications*

- **eTRU:**
  - TRUs are mobile refrigeration systems for use on truck, trailers, shipping containers and rail cars that provide cooling powered by an integral diesel IC engine. The eTRUs are hybrid electric TRUs equipped to shut down integral diesel IC engines on the TRU and instead use an electric motor for temperature control when stationary and plugged into electric grid power.

- **Applications:**
  - Food (produce, frozen food, meat, dairy, beverages, etc.)
  - Food Distribution
  - Food Manufacturing
  - Refrigerated trucking and cold storage
  - Others: Pharmaceutical, Cosmetics, Furniture etc.

<table>
<thead>
<tr>
<th>Power Type</th>
<th>Refrigeration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>240 Vac &amp; 480 Vac</td>
</tr>
<tr>
<td>Fleet Type</td>
<td>Return-to-base</td>
</tr>
<tr>
<td>Use Profile</td>
<td>Normal Operations (Load/unload, pre-cool, staging)</td>
</tr>
<tr>
<td>User</td>
<td>Private fleets</td>
</tr>
<tr>
<td>Typical Locations</td>
<td>Distribution Centers, Food MFGs, Cold Storage, etc.</td>
</tr>
</tbody>
</table>
Electric Truck Refrigeration Units  

**Benefits and Barriers**

### Benefits of Adoption
- Low to no emissions on site
- Fuel cost savings
- Increased benefits to environmental justice communities

### Barriers

**Behavioral barriers:**
- Refrigeration units are equipped with diesel generation sets by default. In order to power these units with electricity, plug-in capability is necessary at any point where the unit is not in transit.
  - This includes truck stops, warehouses, intermodal stations or ports and the final point-of-sale for the goods. This requires that these start, intermediate, or end points for delivery of goods would need to provide electric service for the refrigeration units to plug in.
- Once plug-in capability is available, behavior change campaigns will be needed to ensure that eTRUs are plugged in whenever possible.

**Informational barriers:**
- Businesses operating TRUs underestimate the time spent idling, associated costs, and environmental impacts, and they are unaware of alternatives.
- Private fleets with return-to-base operations can accumulate substantial time idling in their facility (for example, 1–1.5 hours to pre-cool a trailer, 1–2 hours loading while the TRU may be running, and 1–2+ hours staged for delivery).
- It is not uncommon for fleets to load during the evening before and park loaded trailers with TRUs operating to maintain temperature for several hours of TRU run time overnight. An operating practice in a certain distribution segment often involves loading trailers on the day ahead and parking them for 14–18 hours.
Agriculture
Agriculture Opportunities

• Electric/Robotic Cultivation and Harvesting
• Robotic Livestock Tending
Yard Hustlers
Yard Hustlers Overview and Applications

- **Yard Hustlers:**
  - Also known as: hostlers, spotters, yard trucks, yard dogs, shunt trucks, tractors, etc.
  - Class 8, GCWR 81,000 lbs. Up to 25 mph.
  - A semi-tractor intended to move semi trailers within a cargo yard, warehouse facility, or intermodal facility, much like a switcher locomotive is used to position railcars.
  - Battery: Standard: 80 kWh; Extended: 160 kWh
  - Charging: Standard: 10-20 kW; Fast: 80 kW

- **Applications:**
  - Distribution Centers, e.g. CVS, Amazon, Walmart etc.
  - Container/trailer facilities: Rail, manufacturing, distribution, etc.
  - Managed by hours, not miles
  - Example fleets: Distribution centers (Amazon), Parcel (UPS), Rail Intermodal (BNSF or a contractor like RMS that may do the container handling), large 24x7 manufacturers (e.g. FritoLay chip plants), the large LTL Freight sites (like YRC Freight).

- **Savings and payback:**
  - Typical savings could be in the range of $40-60k per truck annually (fuel, maintenance, emission control).
  - Payback can be < 3 years without incentives. Payback is quicker when adding the many other benefits (e.g. workman’s comp, process improvement, etc.)
Yard Hustlers  

Benefits of Adoption

- **Emission-free with lower noise, heat, and vibration**: The electric power train eliminates the hazards of inhaled diesel emissions. Much lower truck vibration, heat, and noise reduce driver fatigue, health costs, safety incidents and driver turnover.

- **Eliminates injury and fines**: With no diesel fuel, motor oil, or glycol, the common sources of slips and injury as well as the cost of spill readiness, cleanup, and fines are eliminated.

- **Better truck control**: Regenerative braking provides finer, single-foot vehicle control with smooth, no-shift deceleration for shorter stopping distance and stopping time.

- **Lower voltage**: Trucks run on voltages < 120V DC (like voltages in residential homes) much lower and safer than 350V DC to 450V DC used by other manufacturers.

- **Seatbelt interlock**: Optional ignition lock prompts drivers to engage the seatbelt.

- **Saves money**: On fuel, maintenance as well as emission control equipment.

Barriers

- Higher capital cost to deploy
- Ability to legally replace current diesel with older, refurbished unit
- Electrical Infrastructure availability (only an issue at some sites)
- Fear and lack of familiarity
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