Plug-In-Hybrid Bus Propulsion Systems

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Presentation Outline

- Background
- What are the problems?
- Are Hybrid PHEV Transit Buses possible?
- Future developments for sustainable/clean transportation.

- Questions?
Background Problem # 1

- Current Status of Fossil Fuels in N.A.:
- Numbers are estimated years of supply at current consumption rates and best known ground reserves. New discovery rates are lower than population growth rates.

<table>
<thead>
<tr>
<th>Fossil Fuels</th>
<th>Canada</th>
<th>N.A.</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy Oil</td>
<td>15</td>
<td>12</td>
<td>40</td>
</tr>
<tr>
<td>Easy Oil+Tar Sands</td>
<td>150</td>
<td>33</td>
<td>46</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>9</td>
<td>10</td>
<td>67</td>
</tr>
</tbody>
</table>

- Canada and USA Transportation is 99% fossil fuel dependent. Thus, unsustainable.
Oil Consumption, CO2 Emissions

- Annual Oil Consumption Mm3
- Annual CO2 Emissions, MMT
- Oil Reserves, 10Mm3

Time, year

Oil Consumption Mm3, CO2 emissions MMT

-5000 0 5000 10000 15000 20000 25000 30000 35000

2000 2010 2020 2030 2040 2050 2060

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Background Problem # 2

Basic Thermodynamics

Fuel production

Fuel Energy

Energy Transformer

Oxygen/Air

Emissions, CO2, NOx, PM

Useful work 1/3

Waste heat 2/3
Vehicle use engine that transforms chemical energy in the fuel to mechanical energy, through combustion process.

Combustion process generates emissions:

- CO2, green house gas influencing atmospheric dynamic behavior, current transportation generates about 30% of NA(Canada, USA) emissions about 2.2 BMT.
- NOx, NO, NO2, affecting lungs efficiency, irritates bronchial tubes and reduces oxygenation capacity of the blood. Transportation generates about 50% of NOx.
- PM10, aggravate respiratory ailments.
Reduce Vehicle Emissions

See the Toronto CN Tower?
Reduce Vehicle Emissions

Now you don't, the CN Tower disappears in the smog.
Reduce Vehicle Emissions
Problem # 2 Re-defined

- Canada National Goal: reduce 50% of CO2 emissions by 2050.
- What does it mean?: By 2050 at least 60% of the primary energy must come from renewable sources, carbon neutral, and transportation must at least reduce its dependency on fossil fuels by about 50%.
- Increase investment on public transportation.
- Increase vehicle efficiencies to at least compensate for the natural fleet annual growth. NA vehicle fleet may increase by about 40% on 2050.
Buses are Cleaner than cars/SUV

Vehicles CO2 Emissions, g/km-person

CO2 Emissions, g/km-person

Diesel Bus, CNG Bus, Diesel HEV, Bus, SUV, gas, SUV, HEV, Compact Car, gas, Compact Car, diesel, Compact Car, HEV

Vehicles Type

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Viable options to change the fuel energy mix for transportation, with maximum impact in the shortest possible time:

- Biofuels, upper limit benefits about 30%, assuming cellulosic bio-fuel and minimum impact on food production.
- Maximize introduction of hybrids propulsion systems, benefits about 30%. At least 30 years to achieve. Vehicle change over every 15 years.
- Introduce electric fuel by tapping into electric grid for some classes of vehicles such as: commuter cars, school buses, electric trains, trolley buses. For Manitoba, benefits can be large in both reduction of CO2 and reduced fossil fuel consumption. Manitoba Hydro can fuel up some 300,000 cars without adding generating capacity.
Is PHEV Bus Feasible?

- City Bus Performance Requirements:
  - GVW: 19,000 kg
  - Duty Cycle: 50 cycles per hour, 200,000 cycles per year.
  - Top speed: 80 kph
  - Average working speed: 25 kph.
  - Acceleration: 0 to 30 kph in 10 sec.
  - Gradability: 16% at 12 kph.
  - Operating range: 500 km
  - Accessories load: 20 kW
  - Typical energy requirements: 3 kWh/km
  - Regen Power required: 240 kW during 10 sec.
  - Typical diesel fuel economy: 1.3 km/l (3.1 mpg)
Vehicle Mobility Demand

Bus Power Requirements, kW

- Mobility Power
- EngDrAcc
- ElectDrAcc
- PWREnDrAcc
- PWRELDrAcc
- MHDD Engine
- HHDD Engine

Bus Speed, kph
Vehicle Energy Cycle demand

50 kph, Bus Cycle Power Profile, kW

- Cycle Total Power, kW
- Accessories Power, kW

Cycle Time, sec

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ENERGY FLOW

Engine

Gasoline

Inverter 1

Generator

400VAC

Motor 1

Zebra Battery and/or UltraCap

367-667VDC

Motor 2

Auxiliary

Braking Resistors

ACCESSORIES

SIEMENS ELFA SYSTEM

Motor

Air Conditioning

Power Steering

Air Compressor

AC/DC

MOT1

MOT2

AUX

400VAC

230VAC

Inverter 2

AC

M

PS

AIR
### Vehicle sources of energy

<table>
<thead>
<tr>
<th>Fuel:</th>
<th>Wh/kg</th>
<th>Wh/L</th>
<th>W/kg</th>
<th>Life-cycle-cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead-Acid</td>
<td>30</td>
<td>75</td>
<td>250</td>
<td>1.5</td>
</tr>
<tr>
<td>Ni-MH</td>
<td>65</td>
<td>150</td>
<td>200</td>
<td>1.5</td>
</tr>
<tr>
<td>Ni-Zn</td>
<td>65</td>
<td>130</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Li-NanoPH</td>
<td>90</td>
<td>150</td>
<td>300</td>
<td>1.8</td>
</tr>
<tr>
<td>Zn-Air</td>
<td>250</td>
<td></td>
<td>250</td>
<td>??</td>
</tr>
<tr>
<td>Ultra-C</td>
<td>10</td>
<td></td>
<td>1000</td>
<td>1.5</td>
</tr>
<tr>
<td>FTPHEV</td>
<td>3,333</td>
<td></td>
<td>140</td>
<td>2.0</td>
</tr>
<tr>
<td>Diesel</td>
<td>4,100</td>
<td></td>
<td>480</td>
<td>0.65</td>
</tr>
<tr>
<td>Bio-Diesel</td>
<td>4,100</td>
<td></td>
<td>480</td>
<td>0.65</td>
</tr>
<tr>
<td>FCH2</td>
<td>1,100</td>
<td></td>
<td>370</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Energy Storage Selection

- For PHEV, like HEV, Energy Store Capacity Selection is Critical:
- Operating range determine the energy storage capacity.
- Acceleration and regeneration determine the power requirements.
- For vehicle the energy storage mass should be below 10% of CVW.
- Battery mass, largest of range or acceleration/regen and < 0.1 CVW.
Energy Storage Selection

- Wh/kg
- W/kg

- Needed
- Li-
- Ni-MH
- Ni-Zn
- Lead-Acid

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ENERGY STORAGE SELECTION

- Batteries:
  - REGEN ENERGY available,
  - BATTERY LIFE: Bat. Life ~((1/Temp.), (1/DSOC)). Temperature must be kept below 40 C. Each charge and discharge heat up the battery.
  - Current practices: DSOC ~0.05 of nominal capacity, for regen.
  - For HEV good practice battery design charge to below its nominal capacity, technology dependent.
  - Regen battery capacity: 22 kWhr
  - For Ni-MH, mass 340 kgs but for max. regen 1200 kgs
  - Li-NanoPh, mass 244 kgs but for max. regen 800 kgs
ENERGY STORAGE SELECTION

Energy Storage maximum mass about 10% of CVW. Or 1,500 kgs.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Wh/kg</th>
<th>range, km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-MH</td>
<td>65</td>
<td>45/500</td>
</tr>
<tr>
<td>Li-NanoPh</td>
<td>90</td>
<td>60/500</td>
</tr>
<tr>
<td>Zn-Air</td>
<td>250</td>
<td>160/500</td>
</tr>
<tr>
<td>FTPHEV</td>
<td>3,333</td>
<td>888. at 37 kph continuous</td>
</tr>
<tr>
<td>Diesel</td>
<td>4,100</td>
<td>500 with 450 l of fuel</td>
</tr>
</tbody>
</table>
Yes, PHEV Bus is feasible

- PHEV transit bus is possible but will require operational compromises and deployment in specific routes, i.e. downtown corridors, University Campus routes, School buses, etc.
- PHEV transit bus with bio-fuel range extender engine is very feasible and it can be done by building on the current available hybrid buses through down sizing the engine and upsizing the batteries by about a factor of 3X. The estimated benefits can be about 50% CO2 emission reductions and about 40% fossil fuel savings.
- Yes, some cities in NA are testing PHEV buses.
- FTPHEV already exists and cities with infrastructure are cashing in the benefits.
Yes, PHEV bus is feasible

- Obstacles to overcome:
  - Higher specific energy batteries, 500 Wh/kg.
  - Rapid charging capable batteries. To at least 90% in 5 minutes.
  - Development of fast charging induction charger to facilitate opportunity charging at route turn around idle time.
Future Developments for heavy vehicles

- Diesel engines efficiency are scheduled to increase from 0.45 to 0.55 by 2012. Reduces emissions and save fuel.
- Next generation Bio-fuels are being developed, such as: bio-butanol, bio-octanol and others. Benefits reduce use of fossil fuel and reduce emissions.
- Hybrids system are expanding fast, from buses into heavy trucks. Benefits, 25 % fuel saving, reduce emissions.
- Work continues in evaluating the use of hydrogen fuel cells for niche applications. Reduce use of fossil fuel and emissions.
- Some cities are evaluating the merits of using PHEV buses, with engine range extender. Reduce use of fossil fuel and emissions.
References:

- Environment Canada-Canada’s 2005 GHG Inventory.
- The USA GHG Inventory 2005, EPA, USA.
- King County Metro Transit Hybrid Articulated Buses: Final Evaluation Results, NREL Technical Report, December 2006.
Clean Buses-Trolleys early 2000’s
Clean Buses-Trolleys early 2000’s

- 40LF Trolley: CVW, 32,000 Lbs comparable to CNG.
- All electric power system including accessories drive. Main power from overhead wires.
- Battery aux.. energy source for about 1 km off wires operation. Ni-Cd batteries.
- Power supply : 600V
- Traction Pulse Mod. Inverters, IGBT: 3PH, 250KVA
- Traction Motor: 3PH, 420V, 210 kW , 1287 lbs.
- All electric power equipment air cooled.
ALLISON Energy Storage System
New Flyer Diesel-Electric Configuration
Hybrid System Details

Propulsion

- Engine: 213 kW
- Batteries: 52 kW at 600 VDC
- Transmission: CVT, 2 Electric Machines in the housing
- Gear reduction: 0.4 to 4.25
- Power inverters 3PH, 500 KVA, 800A
- Power system 600 VDC nominal
ISE HYBRIDS ARE DESIGNED TO REDUCE EMISSIONS

- Ford ULEV-rated engine
- Runs on standard gasoline
- Siemens electric drive
- 40’ New Flyer bus
- First bus in service at Omnitrans
Hybrid System Details

Propulsion

- 234 kW (315 hp) peak traction motor power
- Rated torque 2700 NM (1990 ft-lbs)
- Motor speed 10,000 RPM
- Gear reduction 3.5:1
- Power inverters 500 KVA, 800A
- Power system 600 VDC nominal
HYBRID HYDROGEN INTERNAL COMBUSTION ENGINE (HHICE) BUS

- Near Zero Emissions, Engine Production Ready, F

Ford V10 H2 Engine

Accessories

Energy Storage

Drive Motor

Generator

Inverter

Control System
New Flyer Products
Hybrid System Details

- Propulsion batteries
  - 6 Modules of 2x3 batteries packs,
  - NiMH
  - 600 VDC nominal, 31 kW-hr, 52 kW
  - Roof mounted
  - A/C source air cooled
  - 450 kg
NiMH System

2175mm (85.6")
1100mm (43.3”)
283m m (11.1 ”)
Clean Buses-Trolleys early 1900’s
Clean Buses—Back to the future—Trolleys early 2000’s
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