Natural Gas Hybridization

NGVTF
Gas Technology Institute
Ted Barnes

GTI Company Overview

> Independent, not-for-profit, established in 1941
> Over 300 employees (~100 in CA)
> 350 active projects
> 1,200 patents; 500 products
Reasons for Heavy Duty Hybrids

• Heavy Duty Truck Hybridization – Why?
  • Critical environmentally sensitive areas looking for “zero emission” options; natural gas hybrids allow for near-term, at scale, real-world applications
    • Increased range, smaller battery pack, ability to keep same duty cycle as diesel
  • Fuel economy and low-end torque improvements can be substantial
  • Allows for zero tailpipe emissions in critical areas for limited range or through overhead (or rail) power transfer
  • NOx emissions already “near-zero” for natural gas but GHG needs constant improvement (diesel-hybrid and biodiesel have significant NOx issues)

Current GTI Hybrids Projects

• Energy Commission – Hybrid Trucks
  • US Hybrid and UC Riverside major technology partners
  • Two projects with natural gas Class 8 trucks

• US DOE – SCAQMD – ZECT Program
  • BAE and Kenworth major technology partners
  • Drayage truck with natural gas “genset”, BAE Hybrid Drive propulsion, Plug-in, Pantograph for zero-emission operation
Abas Goodarzi, Ph.D., P.E. & Farzad Ahmadkhanlou, Ph.D., P.E.  
NGVT Forum 2016

Integrated Electric, Fuel Cell and Hybrid Powertrain Components Powering Clean Mobility

US Hybrid Group

- US Hybrid  
  HQ: Torrance, CA  
  Year Established: 1999  
  Core Competency: Electric Powertrain for Electric, Hybrid and Fuel Cell Heavy Duty Vehicles

- US FuelCell  
  South Windsor, CT  
  Year Established: 2013  
  Core Competency: Fuel Cell Power Plant

- Magmotor Corporation  
  Worcester, MA  
  Year Established: 1876 (Acquired by US Hybrid in 2008)  
  Core Competency: Servo Motors and Drives Automation, Robotic and Semiconductor Mfg.
Business Focus is Commercial Vehicles

<table>
<thead>
<tr>
<th>Class</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Medium</td>
<td>Heavy</td>
<td>Heavy</td>
</tr>
<tr>
<td>Weight Range (GVWR)</td>
<td>19,501-26,000</td>
<td>26,001-33,000</td>
<td>&gt;33,000</td>
</tr>
</tbody>
</table>

Examples

- Medium: Refuse, Construction, Drayage, Shuttle Bus
- Heavy: Municipality, Agriculture, Mining
- Heavy: Monorail, Sao Palo Brazil, Kuala Lumpur Malaysia, Mumbai India

Business Focus is Heavy Duty Commercial Vehicles

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US Hybrid Time Line

We have been making and operating Hybrid Heavy Duty Commercial Vehicles for decades

- 1999
- 2002
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018

- FC BOP to UTC
- PM-APU
- Parallel Hybrid
- Monorail Traction
- Series Hybrid
- PHEV Hybrid
- Near Zero Emission Powertrain
- Battery Electric Dragee Trucks
- Self Powered Carts
- PHEV Electric
- RV & FC Scooter
More than 50% of energy is wasted due to traffic

LNG or CNG?

Volumetric Ratio:
LNG = 1.7 DGE
CNG = 3.8 DGE

Diesel | LNG | CNG

15 Gal. | 26 Gal. | 58 Gal.
Class-8 Truck Powertrain System Configuration

LNG/CNG Hybrid  Electric

Fuel Cell Electric

LNG/CNG Plug-in Hybrid  Electric

Peterbuilt LNG Truck
- Model 384 with ISL-G engine
- Wheelbase was 189”
- Suspension, spring front and air rear.
- Stock weight is 13,360lbs.

Enabling Near Zero Goods Movement
Double Power, Torque and Fuel Economy, 80% less NOx
LNG/CNG Hybrid Electric Powertrains

- Electric Regen Braking
- Electric only operation during que and traffic
- Idle control (Engine off operation)
- Manages low duty engine operation

Specs of Electric Motor and Engine

**Electric Motor**
- 1700 N.m @ 1500 RPM
- 350 hp

**ISL-G 320 Engine (8.9 Liters)**
- 1365 N.m @ 1300 RPM
- 240 kW
Double Power and Torque

Modeling and Simulation
Conventional versus EV and HEV

Speed and Acceleration
Torque and Power

**Total Torque**

- Conventional
- EV
- HEV

**Total Power**

- Conventional
- EV
- HEV

Drive Cycle 1: Port 710-110

Composite of Drayage and Highway
Battery Energy and SOC

Simulation Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PHEV Loaded</th>
<th>PHEV Unloaded</th>
<th>Conventional Loaded</th>
<th>Conventional Unloaded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque $T_{\text{max}}$ (N.m)</td>
<td>2856</td>
<td>1517</td>
<td>1354</td>
<td>1304</td>
</tr>
<tr>
<td>Power $P_{\text{max}}$ (kW)</td>
<td>478</td>
<td>303</td>
<td>239</td>
<td>239</td>
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<tr>
<td>Power $P_{\text{ave}}$ (kW)</td>
<td>140</td>
<td>79</td>
<td>144</td>
<td>96</td>
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<tr>
<td>EV Range (miles)</td>
<td>19.5</td>
<td>39.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MPG (Diesel Equivalent)</td>
<td>5.0</td>
<td>9.2</td>
<td>4.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Fuel Efficiency Increase</td>
<td>+22%</td>
<td>+35%</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Considering the idling time, the fuel economy is doubled
Drive Cycle 2: Drayage Port-Ware Houses

Battery SOC

Charge Depleting
EV Mode

Charge Sustaining
HEV Mode
**Simulation Results**

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<tr>
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<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loaded</td>
<td>Unloaded</td>
</tr>
<tr>
<td>Torque $T_{\text{max}}$ (N.m)</td>
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<td>3003</td>
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<tr>
<td>Power $P_{\text{max}}$ (kW)</td>
<td>478</td>
<td>474</td>
</tr>
<tr>
<td>Power $P_{\text{ave}}$ (kW)</td>
<td>74</td>
<td>33</td>
</tr>
<tr>
<td>EV Range (miles)</td>
<td>22.7</td>
<td>58.6</td>
</tr>
<tr>
<td>MPG (Diesel Equivalent)</td>
<td>5.8</td>
<td>13.0</td>
</tr>
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<td>Fuel Efficiency Increase</td>
<td>+23%</td>
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</tr>
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Considering the idling time, the fuel economy is doubled.

**Hybrid Electric LNG/CNG Class 8 truck**

Commercially viable Near Zero Goods Movement

Hybrid Electric ISL-G at the same cost as ISX-15G with double the range/fuel economy

Peterbuilt LNG Truck
- Model 384 with ISL-G engine
- Wheelbase was 189"
- Suspension, spring front and air rear.
- Stock weight is 12,000 lbs.
LNG/CNG Hybrid Electric Powertrains

LNG/CNG Hybrid Electric Vehicle
LNG/CNG Hybrid Electric Specification

Plug-in Hybrid Electric Drayage Truck “PHET”

Fuel Cell Electric Heavy duty Powertrain

Zero & Near Zero Emission Road map
Charge Fueling Time and Convenience

Limitation of Battery Electric MD/HD Trucks

Conclusions

- Plug-in Hybrid Electric with 30 miles Battery range (dual battery)
- Hybrid Electric with 5 miles, 30 minutes Port queuing battery operation (single battery)

Hybrid NG Electric, Commercially feasible, Commercial Delivery: Q2-2017, taking orders now

- Take up more space
- Refueling takes considerably longer

+ Safety advantage in the case of a leak
+ Lower cost to produce and store
+ Double the range (miles) with Hybrid
+ No need to fuel twice a day → saves time
Thank you!

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