Developing the World's first Sea Going Roll On Roll Off Vehicle and Passenger Diesel Electric Hybrid Ferries

Wednesday 02 May 2012

Jim Anderson
Caledonian Maritime Assets Limited owns the ferries, ports and harbours and infrastructure necessary for vital ferry services serving the West coast of Scotland and the Clyde Estuary.

We are wholly owned by the Scottish Government with Scottish Ministers the sole shareholders. The Caledonian Maritime Assets Limited Board have an executive management team and supporting staff at headquarters in Port Glasgow.
Caledonian MacBrayne Ltd previously provided the majority of Clyde and Hebrides ferry services and owned the associated vessels and a number of the harbour facilities. The company was wholly owned by Scottish Ministers with these services requiring an annual revenue deficit grant from the Scottish Executive to maintain lifeline service levels.

In order to comply with European guidelines on State Aids in Maritime Transport, an open public tender was deemed necessary in respect of these ferry services. The then Scottish Executive tendered the Clyde and Hebrides Ferry Services (CHFS) as a single bundle, with the exception of the Gourock-Dunoon service.

In recognition of the uniqueness of the fleet and in order to ensure a level playing field for all bidders, on 1 October 2006 Caledonian MacBrayne Ltd was split into two companies:

An asset-owning company, Caledonian Maritime Assets Ltd (CMAL).
A new operating company, CalMac Ferries Ltd (CFL).
We aim to provide efficient, cost-effective and safe ferries, harbours and port infrastructure for operators, communities and users in and around Scotland.

Our responsibilities include:

- Maintaining, improving and enhancing assets such as vessels and the land and property around piers and harbours.
- Seeking extra investment to invest in ferries and harbour facilities, making a real difference for people and businesses using these life line services.
- Working with stakeholders within Scotland and the wider maritime community to be acknowledged as the principal provider of the most cost-effective yet innovative ferries and port infrastructure to the benefit of the communities we serve.
Isle of Skye
Sconser to Raasay
Hybrid Ferries Project

- 36 Cars
- 250 Passengers
- 18 Knots

The Fleet – Loch Shira
Hybrid Ferries Project

The Fleet – Isle of Lewis

- 123 Cars
- 700 Passengers
- 18 knots
Hybrid Ferries Project

The Fleet – Clansman

- 100 Cars
- 638 Passengers
- 16.5 knots
The Fleet – Eigg

- 6 Cars
- 164 Passengers
- 8 knots
Hybrid Ferries Project

The Fleet – Finlaggan

- 85 Cars
- 550 Passengers
- 16.3 knots
Measures in the transport sector which will contribute to the delivery of the 34% Scottish target in 2020 include:

- Improved energy efficiency of new ships
- Public sector investment in new vessels for subsidised lifeline ferry services
- Supporting the development of emissions reduction targets in shipping operations
- By 2020, a 5-10% emissions reduction through technology measures and another 10% reduction through demand and fleet management

The main reference framework for the safety standards should be the 1974 International Convention for the Safety of Life at Sea (the 1974 SOLAS Convention), as amended, which encompasses internationally agreed standards for passenger ships and high-speed passenger craft engaged on international voyages, as well as appropriate Resolutions adopted by the IMO and other measures complementing and interpreting that Convention.

A “passenger ship” means a ship which carries more than 12 passengers.

A “ro-ro passenger ship’ means a ship carrying more than 12 passengers, having ro-ro cargo spaces or special category spaces.
Passenger ships are divided into the following classes according to the sea area in which they operate:

**Class A**
Means a passenger ship engaged on domestic voyages other than voyages covered by Classes B, C and D.

**Class B**
Means a passenger ship engaged on domestic voyages in the course of which it is at no time more than 20 miles from the line of coast, where shipwrecked persons can land, corresponding to the medium tide height.

**Class C**
Means a passenger ship engaged on domestic voyages in sea areas where the probability of exceeding 2,5 metres significant wave height is smaller than 10% over a one-year period for all-year-round operation, or over a specific restricted period of the year for operation exclusively in such period (e.g. summer period operation), in the course of which it is at no time more than 15 miles from a place of refuge, nor more than 5 miles from the line of coast, where shipwrecked persons can land, corresponding to the medium tide height.

**Class D**
Means a passenger ship engaged on domestic voyages in sea areas where the probability of exceeding 1,5 metres significant wave height is smaller than 10% over a one-year period for all-year-round operation, or over a specific restricted period of the year for operation exclusively in such period (e.g. summer period operation), in the course of which it is at no time more than 6 miles from a place of refuge, nor more than 3 miles from the line of coast, where shipwrecked persons can land, corresponding to the medium tide height.
DIRECTIVE 2009/45/EC

Class C
Means a passenger ship engaged on domestic voyages in sea areas where the probability of exceeding 2.5 metres significant wave height is smaller than 10% over a one-year period for all-year-round operation, or over a specific restricted period of the year for operation exclusively in such period (e.g. summer period operation), in the course of which it is at no time more than 15 miles from a place of refuge, nor more than 5 miles from the line of coast, where shipwrecked persons can land, corresponding to the medium tide height.

Domestic Voyage
Means a voyage in sea areas from a port of a Member State to the same or another port within that Member State.
In new class B, C and D and existing class B ships, and new ships constructed on or after 1 January 2003 with a length of 24 metres and above, a double bottom shall be fitted extending from the forepeak bulkhead to the afterpeak bulkhead as far as this is practicable and compatible with the design and proper working of the ship.

**RULES & REGULATIONS**

**Double Bottom**

760mm High
Daily Record
Jobs boost as world's first 'hybrid ferries' to be built by Ferguson Shipbuilders in Port Glasgow
Nov 3 2011 By Paul Ward

Lloyd’s List
Ferguson wins first hybrid ferry contract

The Herald
CIVIL shipbuilding is returning to the Clyde, creating around 100 jobs, after a £22 million deal to build the world’s first hybrid-powered ferries was clinched.

http://www.horizonsbusiness.com/episode/future-transport/
### MAIN PARTICULARS

<table>
<thead>
<tr>
<th>Main Dimensions</th>
<th></th>
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<tbody>
<tr>
<td>Length Overall</td>
<td>43.5m</td>
</tr>
<tr>
<td>Length between PP</td>
<td>39.99m</td>
</tr>
<tr>
<td>Breadth (moulded)</td>
<td>12.2m</td>
</tr>
<tr>
<td>Draught</td>
<td>1.73m</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Capacities</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Deadweight</td>
<td>135 tonnes</td>
</tr>
<tr>
<td>Cars</td>
<td>23</td>
</tr>
<tr>
<td>HGVs</td>
<td>2</td>
</tr>
<tr>
<td>Passengers</td>
<td>150</td>
</tr>
<tr>
<td>Crew</td>
<td>3</td>
</tr>
<tr>
<td>Speed</td>
<td>8-9 kts</td>
</tr>
</tbody>
</table>
SHIP SHORE INTERFACE

1: 8 Slipway
### Trial Conditions, BF2

<table>
<thead>
<tr>
<th>Draught (m)</th>
<th>PD (kW)</th>
<th>N (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.73m</td>
<td>267.5</td>
<td>87.2</td>
</tr>
</tbody>
</table>
- Max Beam Wind: 37 kts
- Total Propulsion Power: 2 x 375kW Voith Units = 750kW
- Total Power (Pd) for 9kts Service Speed: 267.5kW
HOW TO CONFUSE POWER

PE effective power
PT thrust power
PD delivered power at propeller
PS shaft power
PB brake power, also known as engine output (used in fuel calculation)

ηH hull efficiency (which, surprisingly, can be over 100%)
ηB propeller efficiency behind ship (this one is usually below 100%)
ηS shafting efficiency, often close to 100%
ηT transmission efficiency, which includes generator and gearbox losses
## PROPULSION MACHINERY OPTIONS

<table>
<thead>
<tr>
<th>Diesel Mechanical</th>
<th>Diesel Electric</th>
<th>Hybrid</th>
</tr>
</thead>
</table>
Sconser - Raasay Route
Daily Average Duty Cycle

Percentage of day at Power Range

Percentage of Available Power

- 1.5%: 3%
- 6-10%: 24%
- 11-15%: 13%
- 16-20%: 9%
- 21-25%: 12%
- 26-30%: 10%
- 31-35%: 11%
- 36-40%: 9%
- 41-45%: 3%
- 46-50%: 1%
- 51-55%: 0%
- 56-60%: 0%
- 61-65%: 0%
- 66-70%: 0%
- 71-75%: 0%
- 76-80%: 0%
- 81-85%: 0%
- 86-90%: 0%
- 91-95%: 0%
- 96-100%: 0%
Prop Power – 375kW

- 2 x 450kWm Main Engines
- 2 x Gearboxes
- 2 x Voith Propeller Units
- 2 x 80kWe Gensets
3 x 368kVA Generators
400V, 50Hz, 3ph
Cos Ø = 0.9

375 kW
0 – 615 RPM

Hybrid Ferries Project
### TIMETABLE : SCONSER – RAASAY ROUTE

**Transit Time: 20mins**  
**Manoeuvring Time: 2mins**  
**At Slip: 8-23mins**

**30 March 2012 to 20 October 2012**

**RAASAY**

**SCONSER - RAASAY**

<table>
<thead>
<tr>
<th></th>
<th>SCONSER</th>
<th>RAASAY</th>
<th>RAASAY</th>
<th>SCONSER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depart</td>
<td>Arrive</td>
<td>Time from Dep - Arr</td>
<td>Transit</td>
</tr>
<tr>
<td>MON-SAT</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>08:25</td>
<td>08:50</td>
<td>00:25</td>
<td>00:25</td>
</tr>
<tr>
<td>A On Sat only, will dep Sconser</td>
<td>09:25</td>
<td>09:50</td>
<td>00:25</td>
<td>00:25</td>
</tr>
<tr>
<td>at 1830 arrive Raasay 1855</td>
<td>10:25</td>
<td>10:50</td>
<td>00:25</td>
<td>00:25</td>
</tr>
<tr>
<td>B Saturdays only</td>
<td>11:30</td>
<td>11:55</td>
<td>00:25</td>
<td>00:25</td>
</tr>
<tr>
<td></td>
<td>13:00</td>
<td>13:25</td>
<td>00:25</td>
<td>00:25</td>
</tr>
<tr>
<td></td>
<td>15:00</td>
<td>15:25</td>
<td>00:25</td>
<td>00:25</td>
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<td></td>
<td>16:15</td>
<td>16:40</td>
<td>00:25</td>
<td>00:25</td>
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<tr>
<td></td>
<td>17:35</td>
<td>18:40</td>
<td>01:05</td>
<td>00:25</td>
</tr>
<tr>
<td></td>
<td>18:45</td>
<td>19:10</td>
<td>00:25</td>
<td>00:25</td>
</tr>
<tr>
<td></td>
<td>21:00</td>
<td>21:25</td>
<td>00:25</td>
<td>00:25</td>
</tr>
</tbody>
</table>

**Transit Time:** 20mins  
**Manoeuvring Time:** 2mins  
**At Slip:** 8-23mins
30 March 2012 to 20 October 2012  
RAASAY

SCONSER - RAASAY

<table>
<thead>
<tr>
<th></th>
<th>mins</th>
<th>Hrs</th>
<th>kWh/day</th>
<th>Hrs/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Total/Day</td>
<td>360</td>
<td>6.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Man Total/Day</td>
<td>36</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>At Slip Total/Day</td>
<td>224</td>
<td>3.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>At Pier</td>
<td>0</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overnight/Day</td>
<td>820</td>
<td>13.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total/Day</td>
<td>1440</td>
<td>24.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Transit Total**

- **Transit**
  - 2124 kWh/day
  - 2190.00 Hrs/Year
- **Manoeuvring**
  - 91 kWh/day
  - 219.00 Hrs/Year
- **At Slip**
  - 388 kWh/day
  - 1362.67 Hrs/Year
- **Total**
  - 2603 kWh/day
  - 8760.00 Hrs/Year

**Estimated Loads (including losses)**

- **Transit**
  - 354 kW
- **Manoeuvring**
  - 152 kW
- **At Slip**
  - 104 kW

36% of Operational Day at Slipway
## FUEL CALCULATIONS – DIESEL MECHANICAL

### Diesel Mechanical 2 x 450kW Engines

<table>
<thead>
<tr>
<th></th>
<th>Max Propulsion Power</th>
<th>9 knots</th>
<th>MAN</th>
<th>PORT</th>
<th>OVERNIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAILY HOURS</strong></td>
<td>25.0%</td>
<td>2.5%</td>
<td>15.5%</td>
<td>57%</td>
<td></td>
</tr>
<tr>
<td><strong>DAILY HOURS</strong></td>
<td>6.0 h</td>
<td>0.6 h</td>
<td>3.7 h</td>
<td>13.7 h</td>
<td></td>
</tr>
<tr>
<td><strong>SHAFT POWER</strong></td>
<td>750 kW</td>
<td>267.5 kW</td>
<td>120 kW</td>
<td>72 kW</td>
<td></td>
</tr>
<tr>
<td><strong>MAIN ENGINE POWER (MCR)</strong></td>
<td>450 kW</td>
<td>450 kW</td>
<td>450 kW</td>
<td>450 kW</td>
<td></td>
</tr>
<tr>
<td><strong>NUMBER CONNECTED</strong></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL INSTALLED ME POWER (MCR)</strong></td>
<td>900 kW</td>
<td>900 kW</td>
<td>900 kW</td>
<td>900 kW</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ME POWER DEMAND</strong></td>
<td>840 kW</td>
<td>291 kW</td>
<td>130 kW</td>
<td>78 kW</td>
<td></td>
</tr>
<tr>
<td><strong>MAIN ENGINE LOAD</strong></td>
<td>86%</td>
<td>32 %</td>
<td>14 %</td>
<td>9 %</td>
<td></td>
</tr>
<tr>
<td><strong>FUEL CONSUMPTION</strong></td>
<td>441 litres/day</td>
<td>22 litres/day</td>
<td>85 litres/day</td>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

**Estimated Total Fuel Consumption**: 548 litres/day
# FUEL CALCULATIONS – DIESEL ELECTRIC

## Diesel Electric 3 x 360kW Engines

<table>
<thead>
<tr>
<th></th>
<th>Max Propulsion Power</th>
<th>9 knots</th>
<th>MAN</th>
<th>PORT</th>
<th>OVERNIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAILY HOURS</strong></td>
<td></td>
<td>25%</td>
<td>2.5%</td>
<td>15.5%</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.0 h</td>
<td>0.6 h</td>
<td>3.7 h</td>
<td>13.7 h</td>
</tr>
<tr>
<td><strong>SHAFT POWER</strong></td>
<td>750 kW</td>
<td>267.5 kW</td>
<td>120 kW</td>
<td>72 kW</td>
<td></td>
</tr>
<tr>
<td><strong>MAIN ENGINE POWER (MCR)</strong></td>
<td>360 kW</td>
<td>360 kW</td>
<td>360 kW</td>
<td>360 kW</td>
<td></td>
</tr>
<tr>
<td><strong>NUMBER CONNECTED</strong></td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL INSTALLED ME POWER (MCR)</strong></td>
<td>1080 kW</td>
<td>360 kW</td>
<td>360 kW</td>
<td>360 kW</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL ME POWER DEMAND</strong></td>
<td>848 kW</td>
<td>322 kW</td>
<td>144 kW</td>
<td>87 kW</td>
<td></td>
</tr>
<tr>
<td><strong>MAIN ENGINE LOAD</strong></td>
<td>79%</td>
<td>89%</td>
<td>40%</td>
<td>24%</td>
<td>Total</td>
</tr>
<tr>
<td><strong>FUEL CONSUMPTION (litres/day)</strong></td>
<td>434 litres/day</td>
<td>19 litres/day</td>
<td>85 litres/day</td>
<td></td>
<td></td>
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</tbody>
</table>

**Estimated Total Daily Fuel Consumption**: 538 litres/day
# Fuel Calculations - Comparison

## Daily Fuel Consumption

<table>
<thead>
<tr>
<th></th>
<th>Diesel Mechanical</th>
<th>Diesel Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Fuel Consumption</td>
<td>548 litres/day</td>
<td>538 litres/day</td>
</tr>
</tbody>
</table>

## Engine Load

<table>
<thead>
<tr>
<th>Engine Load</th>
<th>Diesel Mechanical</th>
<th>Diesel Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine load at 9knots</td>
<td>32%</td>
<td>89%</td>
</tr>
<tr>
<td>Engine load during manoeuvring</td>
<td>14%</td>
<td>40%</td>
</tr>
<tr>
<td>Engine load at port</td>
<td>9%</td>
<td>24%</td>
</tr>
</tbody>
</table>
DIESEL ELECTRIC SYSTEM – BATTERIES CONNECTED TO AC BUS

3 x 368kVA Generators
400V, 50Hz, 3ph
Cos 𝜃 = 0.9

375 kW
0 – 015 RPM

375 kW
0 – 65 RPM

Battery Bank 350kWh

Ships Service

DC Link

Prop 1

Prop 2

Shore Supply

Battery Bank 350kWh

Variable Speed Drives

G1

G2

G3
SERIAL HYBRID SYSTEM

3 x 368kVA Generators
400V, 50Hz, 3ph
Cos Ø = 0.9

Solid State Generator

G1

G2

Shore Supply

G3

Ships Service

Battery Bank 350kWh

DC Link

Variable Speed Drives

Solid State Generator

375 kW 0 – 015 RPM

M1

Prop 1

375 kW

375 kW

375 kW 0 – 65 RPM

M2

Prop 2

Hybrid Ferries Project
### 3 x 360 kWm Diesel Generator Configuration

One generator shall have the capacity to supply the normal propulsion and hotel load with the other 2 generators in standby.

On loss of power there will be an automatic start and connect of the standby machines to the switchboard.

The battery banks will act as a transitional source of power during this start up period.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Pd from Model Tests</th>
<th>Sea Margin</th>
<th>Pd with Sea Margin</th>
<th>Efficiency of VSP</th>
<th>Ps</th>
<th>Electrical System Efficiency</th>
<th>Pb</th>
<th>Hotel Load</th>
<th>Total Power Demand</th>
<th>Engine Rating</th>
<th>% ENGINE MCR</th>
<th>20.00% % ENGINE MCR with Batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>One Engine 2 Engines 3 Engines One Engine 2 Engines 3 Engines</td>
</tr>
<tr>
<td>Kts</td>
<td>kW</td>
<td>%</td>
<td>kW</td>
<td>%</td>
<td>kW</td>
<td>%</td>
<td>kW</td>
<td>kWm</td>
<td>%</td>
<td>MCR</td>
<td>% MCR</td>
<td>% MCR</td>
</tr>
<tr>
<td>9</td>
<td>267.50</td>
<td>0.00%</td>
<td>267.50</td>
<td>0.94</td>
<td>284.57</td>
<td>0.884</td>
<td>321.9</td>
<td>32.00</td>
<td>353.92</td>
<td>360</td>
<td>98.31%</td>
<td>49.16%</td>
</tr>
<tr>
<td>9</td>
<td>267.50</td>
<td>15.00%</td>
<td>307.63</td>
<td>0.94</td>
<td>327.26</td>
<td>0.884</td>
<td>370.2</td>
<td>32.00</td>
<td>402.20</td>
<td>360</td>
<td>111.72%</td>
<td>55.86%</td>
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<tr>
<td>8.5</td>
<td>212.00</td>
<td>0.00%</td>
<td>212.00</td>
<td>0.94</td>
<td>225.53</td>
<td>0.884</td>
<td>255.1</td>
<td>32.00</td>
<td>287.13</td>
<td>360</td>
<td>79.76%</td>
<td>39.88%</td>
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<td>8.5</td>
<td>212.00</td>
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<td>243.80</td>
<td>0.94</td>
<td>259.36</td>
<td>0.884</td>
<td>293.4</td>
<td>32.00</td>
<td>325.40</td>
<td>360</td>
<td>90.39%</td>
<td>45.19%</td>
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<td>8</td>
<td>167.30</td>
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<td>167.30</td>
<td>0.94</td>
<td>177.98</td>
<td>0.884</td>
<td>201.3</td>
<td>32.00</td>
<td>233.33</td>
<td>360</td>
<td>64.81%</td>
<td>32.41%</td>
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<td>8</td>
<td>167.30</td>
<td>15.00%</td>
<td>192.40</td>
<td>0.94</td>
<td>204.68</td>
<td>0.884</td>
<td>231.5</td>
<td>32.00</td>
<td>263.53</td>
<td>360</td>
<td>73.20%</td>
<td>36.60%</td>
</tr>
<tr>
<td>Max Power</td>
<td>705.00</td>
<td>0.00%</td>
<td>705.00</td>
<td>0.94</td>
<td>750.00</td>
<td>0.884</td>
<td>848.4</td>
<td>32.00</td>
<td>880.42</td>
<td>360</td>
<td>244.56%</td>
<td>122.28%</td>
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<table>
<thead>
<tr>
<th>Speed</th>
<th>Pd from Model Tests</th>
<th>Sea Margin</th>
<th>Pd with Sea Margin</th>
<th>Efficiency of VSP</th>
<th>Ps</th>
<th>Electrical System Efficiency</th>
<th>Pb</th>
<th>Hotel Load</th>
<th>Total Power Demand</th>
<th>Alternator Rating</th>
<th>% ALTERNATOR MCR</th>
<th>20.00% % ALTERNATOR MCR with Batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>One Engine 2 ALTs 3 ALTs One Engine 2 ALTs 3 ALTs</td>
</tr>
<tr>
<td>Kts</td>
<td>kW</td>
<td>%</td>
<td>kW</td>
<td>%</td>
<td>kW</td>
<td>%</td>
<td>kW</td>
<td>kWm</td>
<td>%</td>
<td>MCR</td>
<td>% MCR</td>
<td>% MCR</td>
</tr>
<tr>
<td>9</td>
<td>267.50</td>
<td>0.00%</td>
<td>267.50</td>
<td>0.94</td>
<td>284.57</td>
<td>0.920</td>
<td>309.3</td>
<td>32.00</td>
<td>341.32</td>
<td>332</td>
<td>102.81%</td>
<td>51.40%</td>
</tr>
<tr>
<td>9</td>
<td>267.50</td>
<td>15.00%</td>
<td>307.63</td>
<td>0.94</td>
<td>327.26</td>
<td>0.920</td>
<td>355.7</td>
<td>32.00</td>
<td>387.72</td>
<td>332</td>
<td>116.78%</td>
<td>58.39%</td>
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<tr>
<td>8.5</td>
<td>212.10</td>
<td>0.00%</td>
<td>212.10</td>
<td>0.94</td>
<td>225.64</td>
<td>0.920</td>
<td>245.3</td>
<td>32.00</td>
<td>277.26</td>
<td>332</td>
<td>83.51%</td>
<td>41.76%</td>
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<tr>
<td>8.5</td>
<td>212.10</td>
<td>15.00%</td>
<td>243.92</td>
<td>0.94</td>
<td>259.48</td>
<td>0.920</td>
<td>282</td>
<td>32.00</td>
<td>314.05</td>
<td>332</td>
<td>94.59%</td>
<td>47.30%</td>
</tr>
<tr>
<td>8</td>
<td>167.30</td>
<td>0.00%</td>
<td>167.30</td>
<td>0.94</td>
<td>177.98</td>
<td>0.920</td>
<td>193.5</td>
<td>32.00</td>
<td>225.46</td>
<td>332</td>
<td>67.91%</td>
<td>33.95%</td>
</tr>
<tr>
<td>8</td>
<td>167.30</td>
<td>15.00%</td>
<td>192.40</td>
<td>0.94</td>
<td>204.68</td>
<td>0.920</td>
<td>222.5</td>
<td>32.00</td>
<td>254.47</td>
<td>332</td>
<td>76.65%</td>
<td>38.32%</td>
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<tr>
<td>Max Power</td>
<td>705.00</td>
<td>0.00%</td>
<td>705.00</td>
<td>0.94</td>
<td>750.00</td>
<td>0.920</td>
<td>815.2</td>
<td>32.00</td>
<td>847.22</td>
<td>332</td>
<td>255.19%</td>
<td>127.59%</td>
</tr>
</tbody>
</table>
### FUEL CALCULATIONS

#### Operational Hours

<table>
<thead>
<tr>
<th></th>
<th>Transit</th>
<th>Man</th>
<th>At Slip</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>hours</strong></td>
<td>6</td>
<td>0.6</td>
<td>3.7</td>
<td>10.3</td>
</tr>
</tbody>
</table>

#### Fuel Consumption (without batteries)

<table>
<thead>
<tr>
<th></th>
<th>Transit</th>
<th>Man</th>
<th>At Slip</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.41</td>
<td>0.02</td>
<td>0.09</td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.46</td>
<td>0.02</td>
<td>0.09</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.33</td>
<td>0.02</td>
<td>0.09</td>
<td>0.44</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.37</td>
<td>0.02</td>
<td>0.09</td>
<td>0.48</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.32</td>
<td>0.02</td>
<td>0.09</td>
<td>0.42</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.36</td>
<td>0.02</td>
<td>0.09</td>
<td>0.46</td>
</tr>
</tbody>
</table>

### Operational Hours

<table>
<thead>
<tr>
<th></th>
<th>Transit</th>
<th>Man</th>
<th>At Slip</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>hours</strong></td>
<td>6</td>
<td>0.6</td>
<td>3.7</td>
<td>10.3</td>
</tr>
</tbody>
</table>

#### Fuel Consumption (with 20.00% batteries)

<table>
<thead>
<tr>
<th></th>
<th>Transit</th>
<th>Man</th>
<th>At Slip</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.32</td>
<td>0.02</td>
<td>0.07</td>
<td>0.41</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.37</td>
<td>0.02</td>
<td>0.07</td>
<td>0.45</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.26</td>
<td>0.02</td>
<td>0.07</td>
<td>0.35</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.30</td>
<td>0.02</td>
<td>0.07</td>
<td>0.38</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.21</td>
<td>0.02</td>
<td>0.07</td>
<td>0.30</td>
</tr>
<tr>
<td><strong>Tonnes/day</strong></td>
<td>0.24</td>
<td>0.02</td>
<td>0.07</td>
<td>0.33</td>
</tr>
</tbody>
</table>
INNOVATIVE SHIP POWER DISTRIBUTION NETWORK

Lithium Ion Batteries directly connected to DC Link. No additional electronics or voltage conversions required.

Voith Schneider Propulsion Units
Propulsion Electric Motors

Lithium Ion Batteries
Main Switchboard
Generators 330kW

Plug-in for Overnight Charging

Hybrid Ferries Project
The hybrid diesel electric propulsion system will use at least 20% less fuel than a diesel mechanical propulsion system operating at design speed and with the vessel fully loaded, resulting in at least a 20% reduction in CO2 emitted by the Vessel.

At lower speeds and light loaded conditions; greater fuel savings can be achieved and a greater reduction in CO2 emissions.

On days with reduced numbers of crossings it will be possible to operate on batteries only for some crossings.

In port the vessel is capable of operating on batteries only, zero emissions.
<table>
<thead>
<tr>
<th>Reasons for Considering Hybrid Propulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater redundancy</td>
</tr>
<tr>
<td>Reduce fuel consumption</td>
</tr>
<tr>
<td>Reduced impact of CO2 emissions and other pollutants</td>
</tr>
<tr>
<td>Uncertainty of future fuel costs</td>
</tr>
<tr>
<td>Insurance against increasing environmental regulation</td>
</tr>
<tr>
<td>Noise reduction</td>
</tr>
<tr>
<td>Possibility to operate in zero emission mode when vessel is at port</td>
</tr>
<tr>
<td>Lower maintenance</td>
</tr>
</tbody>
</table>
HYBRID MACHINERY ARRANGEMENT

- Voith Propeller
- Genset x 1
- Genset x 2
- Aft Engine Room
- Fwd Engine Room
- Aft Prop Room
- Fwd Prop Room
- Battery Compt
- Prop Motor VSD
- Main Swbd

Hybrid Ferries Project
Volvo Penta Marine Generating Set:

- Quantity - 3
- Engine Type D13 MG
- SFOC 191 g/kWh
- Rated Power 360 kWm
- Alternator Type Stamford HCM534D
- 400V, 3ph, 50Hz
- 332 kWe
- 368 kVA
- 0.9 Power Factor
- Weight 3185 kg
Variable Speed Drives:
- Quantity – 2
- 0.99 Power Factor
- Efficiency >98%
- Weight ****kg
Permanent Magnet Motor:

- Quantity – 2
- Rated Power - 375 kW
- Weight - 2210 kg
- Speed – 600 RPM
- Efficiency – 97%
- Power Factor – 0.96
- Water Cooled

Benefits:

- No Gearbox
- Space and Weight Saving
- Higher Efficiency
- Higher Power Factor
Voith Schneider Propulsion Units:
- Quantity - 2
- Type: 16 R5 EC/90-1
- No of Blades - 5
- Blade Length – 900mm
- Rated Power - 375 kW
- Weight - 6700 kg
- Input Speed – 605 RPM
LITHIUM ION BATTERY STRING

Total Weight for System – abt 7000kg

About the weight of 4 to 5 cars

- 2 x 350kWh Battery Pack
- 2 sets in parallel of 54 Batteries in series.
- Suits weight, volume, charging, discharging and costs
- Battery costs have decreased since we started this project
## BATTERY COMPARISON

<table>
<thead>
<tr>
<th>Feature</th>
<th>Lead Acid</th>
<th>Lithium Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of Discharge</td>
<td>50%</td>
<td>80%</td>
</tr>
<tr>
<td>Cycle life at 50% Depth of Discharge</td>
<td>1000</td>
<td>8000 &gt;3000 @ 80% DoD</td>
</tr>
<tr>
<td>Energy Density</td>
<td>20 Wh/kg</td>
<td>100 Wh/kg</td>
</tr>
<tr>
<td>Charge Efficiency</td>
<td>60%</td>
<td>95-99%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Maintenance required</td>
<td>Maintenance Free</td>
</tr>
</tbody>
</table>

Hybrid Ferries Project
The minimum DC link voltage is $400 \times \sqrt{2} \times 1.10 = 625$ Volts.

The lithium ion batteries provide an almost constant voltage from fully charged to 80% DoD.

The nominal voltage with 54 batteries in parallel being 691.2 Volts.
BATTERY SAFETY

- Battery Management System
- Classification Rules
- Safe Working and Battery Isolation
- Contactors
- Safe Voltage

Hybrid Ferries Project
ENERGY and POWER MANAGEMENT SYSTEM

- Energy Management System
- Power Management System
- Fully Automatic
- Fully Manual
- Easy to use controls
- Blackout Prevention
**PROPULSION MACHINERY OPTIONS**

Mode 1 - **Generator**
Mode 2 - **Generator + Battery**
Mode 3 - **Battery**
Mode 4 - **Battery charging**

**Rating of Shore Power:**
400V 3ph 50Hz, 125A
Overnight Charging:
- Power Supply – 400V, 3ph, 50Hz, 125A
- Advantage of cheaper overnight tariff
- No plans to charge during the operation day
- From renewable source
- 10 -13 hour overnight charging window
- Automatic plug in system under investigation
Lithium Batteries directly connected to DC Link. No additional electronics or voltage conversions required.

Lithium Ion Batteries

Variable Speed Drives

625V DC

Voith Schneider Propulsion Units

Propulsion Electric Motors

Lithium Ion Batteries

Main Switchboard

Generators 330kW

Plug-in for Overnight Charging

Hybrid Ferries Project
TESTING & TRIALS

- Optimisation Trials
- Crew Training
OTHER SYSTEMS

- Parallel Hybrid
- DC Bus
- Fuel Cells
- Solar
- Wind
- LNG
- Bio Fuels
SHIPBUILDER AND PARTNERS - LOCATION

Port Glasgow

- West of Scotland Science Park
- Southside of the Clyde close to BBC/STV
- Skypark Glasgow

Hybrid Ferries Project
HYBRID MACHINERY ARRANGEMENT
SHIPBUILDING PROGRAMME 1ST VESSEL

May 2013

- Vessel Delivery

Nov 2011
- Shipbuilding Contract for 2 Vessels Awarded

Dec 2011
- Major Equipment Ordered

Jan 2012
- Steel Cutting

Sep 2012
- String Test

Dec 2012
- Training

Mar 2013
- Launch

Apr/May 2013
- Sea Trials

May 2013
- Optimisation Trials
- Training

May 2013
- Delivery
SHIPBUILDING PROGRAMME 2nd VESSEL

Nov 2011
• Shipbuilding Contract for 2 Vessels Awarded

Dec 2011
• Major Equipment Ordered

Mar 2012
• Steel Cutting

Nov 2012
• String Test

Mar 2013
• Training

Jul 2013
• Launch

Jul/Aug 2013
• Sea Trials

Aug 2013
• Optimisation Trials

Aug 2013
• Training

Aug 2013
• Delivery

Aug 2013
• Vessel Delivery

Hybrid Ferries Project
Thank you for your attention