The Greening of the Tugboat
Options for Reducing Emissions and Fuel Use
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Presentation Outline

• Brief history - Who are we?
• Ship Handling Tugs - overview
• Powering Requirements
• Operating Profiles
• Propulsion and Powering Methods: Conventional and Emerging
• Relative Fuel/Emissions Efficiency
• “GREEN (bucks)” Considerations: CAPEX & OPEX
• Options Summary
• Questions and Comments
Company History

- Canada’s most senior firm of Naval Architects
- Founded in 1930 in Vancouver
Company History

• Three Generations of Family Ownership:
  • Robert Allan (Robert) President 1930 – 1960
  • Robert F. Allan (Bob) President 1960 – 1981
  • Robert G. Allan (Rob) President 1982 – 2008
Company History

- 2008, new era of Management Ownership
- Current technical staff ~ 70
- Diverse Management Team
80+ Years

- Always a Focus on Innovative and Diverse designs

CNG-powered Short-Sea Drop Trailer Ferry

US Navy Z-Tech Harbour Tugs

Arctic Shipping

Self-loading/unloading Log Barges
RAnger Class - Fireboats

- Vancouver - WJ
- Los Angeles - Voith
- Philadelphia - WJ, 35 kn
- Baltimore - FPP
- Shenzhen - China, FPP
- Dongguan China - FPP
- HKMD - FPP
- Chicago - Ice-Class FPP
- Portland Maine - FPP, Ambulance role
- Massport - just delivered
- New York 4 x CPP, 8000 hp, 50,000 gpm. 2 - delivered
Independent Engineering Services

- Not affiliated with any equipment manufacturers, shipyards or ship owners
- We work with them all to provide independent professional design services.
Greening of Tugboats

• Various tugboat duties and operating conditions:
  • Long-haul towboats and pushboats
    • Tend to have medium to high load factors (average power vs. rated power), typically in the range of 40% to 60%, and relatively high annual runtime, perhaps 5,000 hrs/year or greater
    • Relatively consistent operating conditions
  • Harbour and escort duty tugs – commonly called ship handling tugs
    • Tend to have low load factors, typically in the range of 20 to 35%.
    • Widely varying operating conditions
    • Annual runtime can range from 1,000 to 5,000 hours, typically about 2,500.
    • Short-haul towboats and pushboats often have similar operating conditions

• Focus of this Green Tugs discussion is on ship handling tugs
Ship Handling Harbour and Escort Duty Tugboats
Ship Handling Tugboats: Going Green

- Greener Operations = lower environmental impact and potentially lower operating costs
- Low environmental impact = low energy footprint resulting from high energy efficiency
- For Naval Architects, high energy efficiency = low resistance
- Save fuel and reduce emissions by efficient vessel design using efficient propulsion technologies
- Save fuel and reduce emissions by lower operating speeds
  - e.g. 20% speed reduction = 25% more transit time = 40% less fuel
- Reduce emissions by using low-carbon fuels
  - e.g. natural gas = 20% lower CO₂ than diesel fuel for same energy input, plus:
    - = up to 99% lower particulates than diesel
    - = up to 60% lower fuel cost than diesel
Operating Profile of Ship Handling / Escort Tugs

Vessel Average Operating Profile
Average propulsion power typically = 25% of rated propulsion power

% of Operating Time at Power

Vessel % Required Power
• Ship Handling Tugs

Modern harbour or escort class tugs typically have twin Z-drive propulsors or twin Voith Schneider Propellers (cycloidal drives). Omni-directional maneuverability and high bollard pull are primary functional characteristics.
Propulsion Technologies: diesel-mechanical DM version

Wärtsilä main engines shown are typical for medium-speed applications

- Wärtsilä 8L26
  - 2720 kW at 1000 rpm

- Ship's Services
  - 200 kW at 1500 rpm

- CS300-2800HR

- 50 Hz Feeders

- ~ 88 TBP

Propulsion power: ~5.400 kW

Installed Prop Power: 5.400 kW

slide images courtesy of: © Wärtsilä 16 May 2016
Propulsion Technologies:
diesel-electric DE version
(hybrid with energy storage battery optional)
Wärtsilä main engines shown are typical for medium-speed applications

Propulsion power: ~5,000 kWm
Installed Power: 5,400 kWm = 5,130 ekW

slide images courtesy of: © Wärtsilä 16 May 2016
Propulsion Technologies:
DM vs. DE

- DM is simple, conventional and with modern engines provides good efficiency over a wide range of load factors.
- DM may require CPPs for some engine applications (+$)
- DE can usually be configured for FPPs (-$)
- DM typically runs 3 engines at all load conditions:
  - 2 x mains + 1 x genset
- DE offers ability to run only 1 engine for light load conditions. This may result in net fuel + maintenance cost saving for some operating profiles
- DE is typically not an economical propulsion choice for ship handling and escort tugs, but may suit some local application conditions. Added CAPEX usually not offset by OPEX saving.
- Careful evaluation is required to determine the most suited propulsion arrangement. Life-cycle cost considerations (investment rate and time period) should be made and may override intuitive selection of the best technology
Propulsion Technologies:
diesel-mechanical (DM) vs. diesel-electric (DE)

Specific Fuel Consumption Comparison:
Fixed Speed 60 Hz Marine Genset Engine
vs.
Variable Speed Marine Propulsion Engine

Typical Marine Auxiliary Engine:
1900 bkW at 1800 rpm

Typical Marine Propulsion Engine:
1865 bkW at 1800 rpm

Typical Marine Genset:  SFC with
generator efficiency  kg/ekW.h

Typical Propulsion Motor/Drive: SFC
with propulsion motor/drive
efficiency:  kg/skW.h
Propulsion Technologies:
DM-DE mechanical-electrical hybrid version
Wärtsilä main engines shown are typical for medium-speed applications

- PTO / PTI 850 kW
- CS300-2800 HR
- 50 Hz Feeders
- HS Harbor 200 kW at 1500 rpm
- Battery (optional)
- Wärtsilä 8L20 1600 kW at 1000 rpm
- Wärtsilä 6L20 1140 kWe at 1000 rpm
- ~82 TBP

Propulsion power: ~4,900 kWm
Installed Power: 5,600 kWm = 3200 kWm + 2,280 ekW

slide images courtesy of: © Wärtsilä 16 May 2012
Propulsion Technologies: DM-DE-Hybrids

- DM-DE Hybrids combine the best characteristics of DM and DE (+$)
  - Good efficiency over a wide range of load factors.
  - Ability to run only 1 engine for light load conditions. (-$ for maintenance plus may be more efficient overall than DM or DE)
  - Can be configured for FPPs (-$) (subject to engine performance)
- Can add battery energy storage to provide silent operation + zero vessel emissions for short periods (+$)
- May be able to downsize the installed engine power IF battery storage is fitted and if maximum propulsion power is only required for short periods = battery capacity
- Economics of CAPEX vs. OPEX can improve compared to DE but is still difficult to cost-justify compared to DM for many ship handling tug applications.
- Emissions for DM-DE hybrids are typically lowest of all.
Naval Architecture Fundamentals: Speed – resistance – power relationship

Propulsion power kW vs. speed kts

- e.g. 10 kts speed = 1100 kW;
- 8 kts speed = 650 kW

= - 40% fuel/emissions for + 25% time
Operating methods for reduced fuel burn/emissions

- **Speed:** is there really a rush to get there, or to get back?

- **Slowing down lowers resistance = less power = less fuel**
  - + 25% transit time can yield 40% or more in reduced fuel/emissions

- **Loiter time:** Minimize by slowing down the transit speed
  - Some operations noted to transit to rendezvous point at 10 kts and then loiter (drift or hold position) for an hour or more while awaiting the target vessel. This works well — but isn’t efficient, and isn’t green!
  - Some operations transit to base at 10 kts and then hold dock-side waiting for next task. This works well — but isn’t efficient, and isn’t green. Could have returned at lower speed.

- **Communication and scheduling can minimize fuel burn and emissions**
  - Empower and reward the crew to save fuel.

- **Reap the “greenbacks” that result from optimizing operations.**
Alternate Fuel: biodiesel fuelled tugs; conventional fuel bunkering and storage

- Biodiesel fuels are primarily derived from renewable plant oils

- Different processes yield different characteristics:
  - **FAME fuel**: Fatty Acid Methyl Esters. Used pure can result in 10% to 30% reduction in CO$_2$ and PM; but 10% to 25% increase in NO$_x$. This is presently the most commonly available biodiesel but is generally more expensive than conventional diesel and may not be appropriate for some engines at high concentrations. Best left as applicable to low % blends with conventional diesel with reductions/increases proportional to blend.
  - **HDRD fuel**: Hydrogenation Derived Renewable Diesel. Similar reductions in CO$_2$ and PM, less increase in NO$_x$ due to better ignition/combustion characteristics. Not commonly available but probably could be lower cost than FAME and more suited to use in engines at higher concentrations. Projected to become more common and potentially closer to conventional diesel cost.
  - **OTHER**: Variety of processes and characteristics and costs. No widespread availability but some may develop to being viable and cost effective

- Biodiesel is legislated as blends with conventional diesel in some regions: e.g. B2, B5, B20.

- US Navy has expressed target to use an average of 50% biodiesel.
Alternate Fuel: natural gas fuelled tugs; CNG or LNG fuel bunkering and storage

- Natural gas is the lowest carbon-content fossil fuel
- Gaseous form can be used in pure gas (spark ignited) or in dual-fuel diesel engines
- Typical engine emissions reduction compared to conventional diesel:
  - - 20 % CO₂ (may be partially offset by gas-slip for some engines)
  - - 90 % PM (compared to pre 2010 engines, similar to EPA Tier 4)
  - - 80 % NOx (compared to pre 2010 engines, similar to EPA Tier 4)
- Commonly available as gaseous pipeline distribution in or near most major ports
- For in-hull storage requires space for segregated tank hold for the compressed gas (CNG) or liquefied gas (LNG) storage tanks.
- Can be stored as CNG at nominal 250 bar (3600 psi) which needs ~7 to 10 x the spacial volume of diesel for the same energy content. Some new technologies store at ~500 bar (7000 psi) or higher = ~4 to 7 x spacial volume of diesel.
- CNG is common for automotive applications worldwide, especially South America. Some limited marine application history (including some small ferries in BC).
- CNG applications typically have a shoreside compression and storage station to supply the on-vessel storage cylinders.
- Variety of CNG storage cylinders, some may be accepted for marine applications
- CNG requires compression energy but needs less energy and emissions than liquefaction
CNG Storage Cylinders

- e.g. Lincoln Composites Titan tank system – 4 tank module
  - Module volume = ~71 m$^3$
  - CNG fuel energy content ~97,000 kW$_{f.h}$ @ 250 bar = 9.8 m$^3$ diesel equivalent
LNG Storage – likely the only practical choice for tugs

• Natural gas can be liquefied by cooling to -163 °C and stored at near atmospheric pressure in a cryogenic tank (e.g. “thermos” bottles).

• LNG can be heated and re-vaporized to gaseous fuel for distribution to engines.

• LNG storage tanks can typically sustain several days without use before temperature/pressure rises too much and re-cooling or venting is required. Time depends on effectiveness of insulation. Usually max pressure = 10 bar
LNG Storage

- LNG storage at low pressure (~ 2 to 5 bar)
- Vaporizer and pressure control system can be integrated with storage tank (tank room adjoins storage tank)
- Tank/tank room unit installs in a segregated tank hold with spacial volume ~ 4 x diesel equivalent
- Currently available tank shapes require premium space
  - Difficult to allocate LNG storage space on small vessels – especially tugs
  - More frequent bunkering needed than with diesel
- Availability of LNG bunkering must be considered
- LNG cost in order of $.03 to $.06 per kWf.h vs. $.085 for diesel (no taxes; LNG at $7.50 to $ 15 per GJ)
- Promising alternative fuel for higher power, higher runtime applications. May be difficult to cost-justify for some ship handling tug applications.
LNG storage tank with tank room

- Images courtesy Cryo AB (Linde group)
34 m x 85 t Harbour/Escort Tug
DM Dual-fuel – LNG Storage
Installed Prop Power: 5.400kW

Propulsion power: ~5.400kWm

Max: 87 TBP

slide images courtesy of: © Wärtsilä 16 May 2012
LNG tank hold location and capacity is challenging for small vessels.

- 30 m$^3$ gross = about 25 m$^3$ useable
- = about 12 hours at full load
- = about 40 hours at average loads

(Wartsila LNGPac tank system)

Rolls-Royce Bergen powered 36 m – 65 t pure-gas tug

LNG tank ~80 m$^3$ gross

(Cryo Ab tank system)
39 m x 80 t Harbour/Escort Tug
DM-DE Hybrid
Dual-fuel – LNG Storage
Wartsila: 2x 9L20DF-DM + 2x 6L20DF-DE; Dual-fuel Mechanical-Electrical DM-DE Hybrid

Propulsion power:
- Mech. engines: ~3,168 kW
- Elec. engines: ~2,112 kW
- Total: ~5,280 kWm

Est. losses:
- Mech: 0%
- Elec: ~8-9%

Installed Prop Power: 4,868 kW

Max: 81 TBP

Frequency drives

PTI 850 kW

60 Hz Feeders

CS300-2800 HR

HS Harbor

250 kW at 1800 rpm

WÄRTSILÄ 9L20DF

1584 kW at 1200 rpm

WÄRTSILÄ 6L20DF

1014 kW at 1200 rpm

WÄRTSILÄ 6L20DF

1014 kW at 1200 rpm

WÄRTSILÄ 9L20DF

1584 kW at 1200 rpm

CS300-2800 HR

PTI 850 kW

slide images courtesy of: © Wärtsilä  16 May 2012
LNG tank location and capacity is challenging for small vessels.

33 m³ gross = about 28 m³ useable
  = about 14 hours at full load
  = about 40 to 45 hours at average loads
LNG tank location and capacity is challenging for small vessels.

40 m$^3$ gross = about 34 m$^3$ useable
= about 17 hours at full load
= about 45 to 55 hours at average loads
Energy Storage and Hybrid Tugs

- Battery energy storage
  - Can have high power = lots of kW of power for short periods
  - = limited kW.h of energy density

- Battery technology evolving to yield higher energy density and longer life with deep discharge cycles.

- Charge/discharge efficiency determines if storing energy is cost-effective compared to generate-and-use. Charging with shore power can be lower cost than on-board generation.

- Some ship handling tugs could do 90% to 99% of their missions on battery power only with shore sourced recharge. Limited on-board generation needed if tug is dedicated to this specific service.
Technology developments are helping
Fundamental Solutions to Greener Tugs

• Operations: Reduce vessel speed to minimize fuel burn/emissions where possible (to/from transits are the primary target)

• Alternate fuels for reduced emissions and potentially reduced costs:
  - Biodiesel
  - Natural gas; LNG as the most likely and practical storage medium
  - Fuel cells IF they evolve to include integral fuel reforming to enable conventional fuels instead of hydrogen (not discussed – not likely to be practical for harbour tug applications)

• Hybrids or alternatives for propulsion power:
  - diesel-electric (DE): typically does not reduce fuel burn for ship handling tugs
  - mechanical-electric (DM-DE) hybrid - with or without energy storage
  - pure electric hybrid (DE-DE): all normal operation from battery storage with DE for emergency use or long-slow transits/repositioning

• Conventional DM tug configurations with emissions treatment technologies:
  - e.g. IMO Tier III and/or EPA Tier 4 emission regulations pending 2014 to 2016 will significantly reduce current NO\textsubscript{x} and PM emissions – but little to no impact on fuel burn/CO\textsubscript{2}. Indications are that most engines will require aftertreatment system but OPEX implications should be small.
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<th>Options for Green Tugboat Operations</th>
<th>Typical Emissions Effect</th>
<th>Typical CAPEX/OPEX Effect</th>
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<td><strong>Existing Vessels:</strong></td>
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<tr>
<td>Scheduling to reduce average transit speeds</td>
<td>Reduced CO₂, NOₓ and PM relative to fuel burn</td>
<td>No CAPEX cost. OPEX saving per fuel burn</td>
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<tr>
<td>Increase use of biofuels</td>
<td>Lower CO₂, PM; Higher NOₓ</td>
<td>No CAPEX. Higher OPEX</td>
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<tr>
<td>Repower to EPA Tier 4 technology (2014 +)</td>
<td>-80% NOₓ</td>
<td>+ CAPEX (refit?). Same OPEX ±</td>
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<tr>
<td><strong>New Vessels:</strong></td>
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</table>
| Build conventional DM with EPA Tier 4 technology (2014 +). Will be mandatory for US flagged vessels, may be considered for Canada over IMO III | -80% NOₓ  
-80% to -90% PM (vs. pre-2010 vessels) | small + CAPEX (vs. IMO III). Same OPEX as IMO III |
| Build conventional DM for LNG fuelling to 95%+ substitution of diesel | Similar (or better?) than EPA T4 above | +20 to +40% CAPEX? - 30 to -60% OPEX? |
| Build for EPA T4 + DM/DE Mechanical-Electric hybrid | Better than EPA T4 by reduced fuel burn | +10 to 20% CAPEX? OPEX saving per reduced fuel burn |
| Build for EPA Tier 4 + DE Diesel Electric | Little or no gain, possible + overall | +10% to 15% CAPEX? -2% to +10% OPEX? |
Being Green can yield “green”backs = profits by being green

• Instant bottom line greenbacks result from efficient operations. Obvious and well known but not necessarily well practised.

• Long term greenbacks returns to more efficient vessels with task-optimized powering arrangements.

• Alternative fuels capability can yield long term net greenbacks. Future fuel costs vs. capital/operating cost premiums must be evaluated but trend looks promising for some tugboat applications.
Thanks for your interest

Comments and Questions invited