What research related to cleaner marine fuels could Canada play a leading role in and why?

Clean NG & H_2 Fuels + Hybrid Electric Propulsion + Optimal Operation

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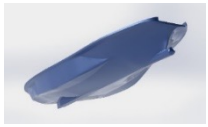
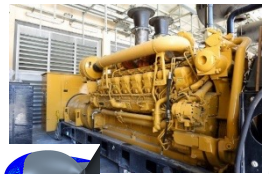
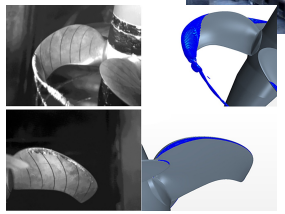
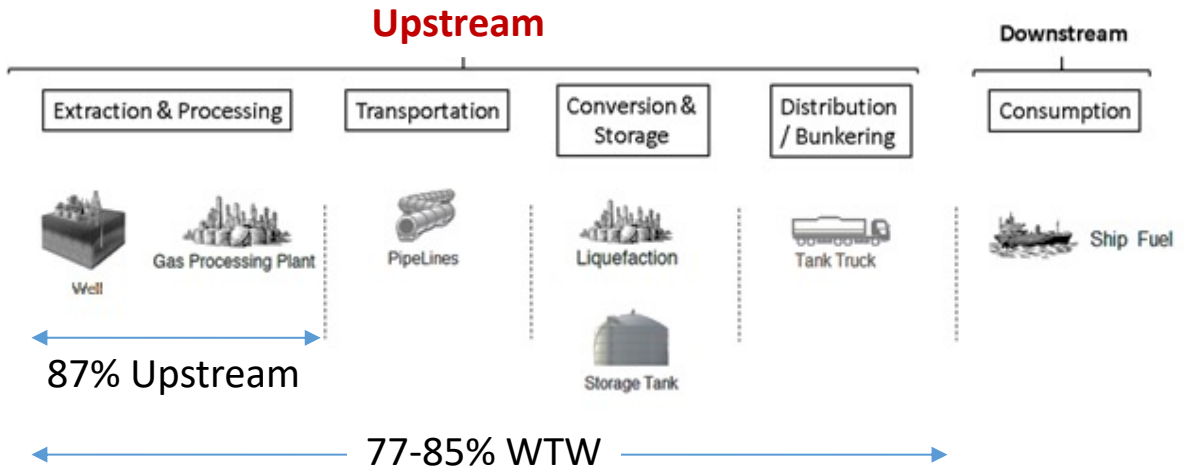






A Systematic Evaluation of GHG/CO2e Emissions in the Upstream Fuel Supply Chain of LNG/NG in BC, Canada

- **Babak Manouchehrinia** (Ph.D. Work/*Energy Reports,* 2020)
  - BC Ministry of Environment and Ministry of Natural Gas Development of BC, Transport of Canada, and Seaspan
  - Interviewed **47** oil and gas companies in BC to have more accurate GHG emission estimates
- **Upstream NG Supply Chain in BC, Canada**
- **Compared: dual-fuel NG vs low-sulfur diesel engines**
- **NG: Reduced SOx** (86%), **NOx** (97%), **& PM Emissions**
- **WTW CO_{2e} Emissions: GREET, GHGenius & BC Data** (55% lower due to New Processes & Clean Grid Power)
- **Downstream: 77-85% of All CO_{2e} Marine Emissions**
- **Only 2% WTW CO_{2e} Emissions Reduction**
  - Considering additional processing/combustion leaks
  - Critical to reduce PTW CO_{2e} Emissions (New Technology)



Total well to wake (WTW) CO_{2e} per crossing	Fuel Type	Downstream CO_{2e} (kg/crossing)	Upstream CO_{2e} (kg/crossing)		Total CO_{2e} (kg/ crossing)	
			Lower bound	Higher bound	Lower bound	Higher bound
Scenario 1	Dual-fuel NG engine	6391	1109	1401	7500	7924
	Low-sulfur diesel engine	6312	1882	1882	8193	7854
+ 43% Additional Methane Pro. Leak	Dual-fuel NG engine	6391	1185	1463	7575	7986
	Low-sulfur diesel engine	6312	1882	1882	8193	8486
+ 43% & 2.3-5% NG	Dual-fuel NG engine	7023	1185	1463	8207	8049

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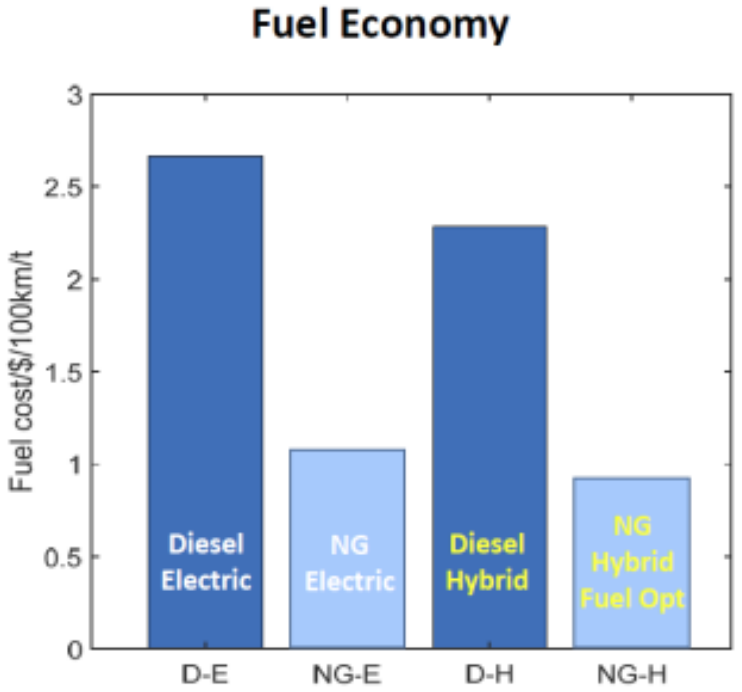
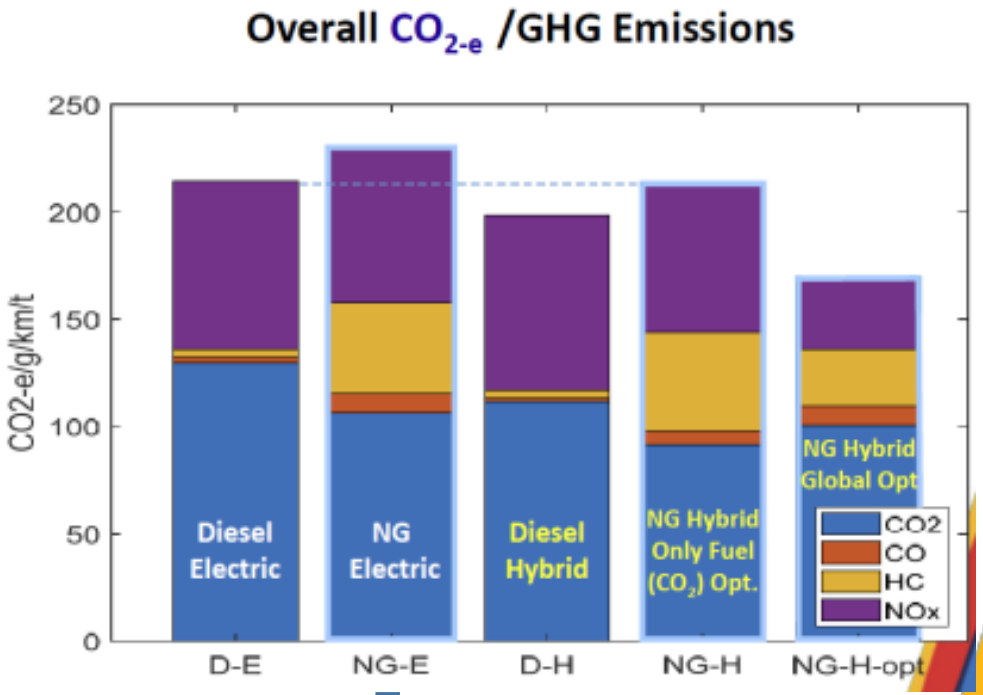
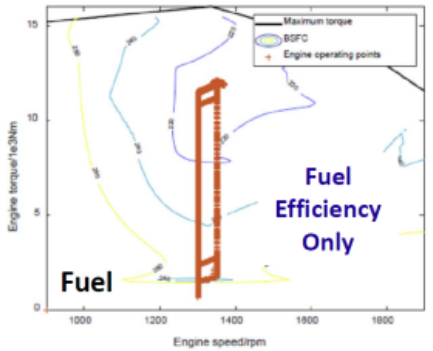
Real-time Global Optimal Control of NG Hybrid Electric Propulsion

- minimum fuel consumption (CO_2 emission) and HC/CO emissions (methane slip)

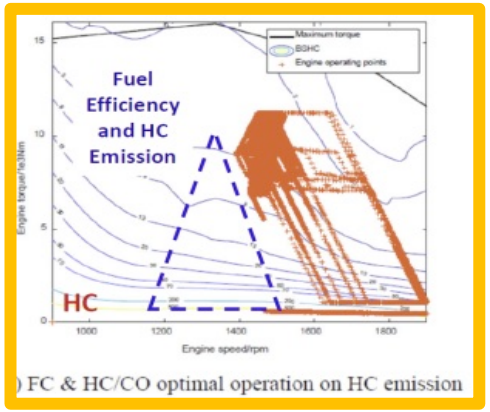
- **Case Study: A BCFS Ship Model**
- **NG Hybrid Electric** and **Real-time Optimal Control** Considering
  - Fuel Efficiency (CO_2 Emission)
  - HC, CO and NO_x Emissions
- **LNG: Cheaper &** (Potentially) **Cleaner**
  - 66% Fuel Cost Reduction
  - 19% CO_{2e} Emissions Reduction







(a) FC optimal control on FC map



) FC & HC/CO optimal operation on HC emission

$$\min G = \int_{t_0}^{t_f} \left(k_1 FC + k_2 HC + k_3 CO + k_4 NO_x \right) dt$$

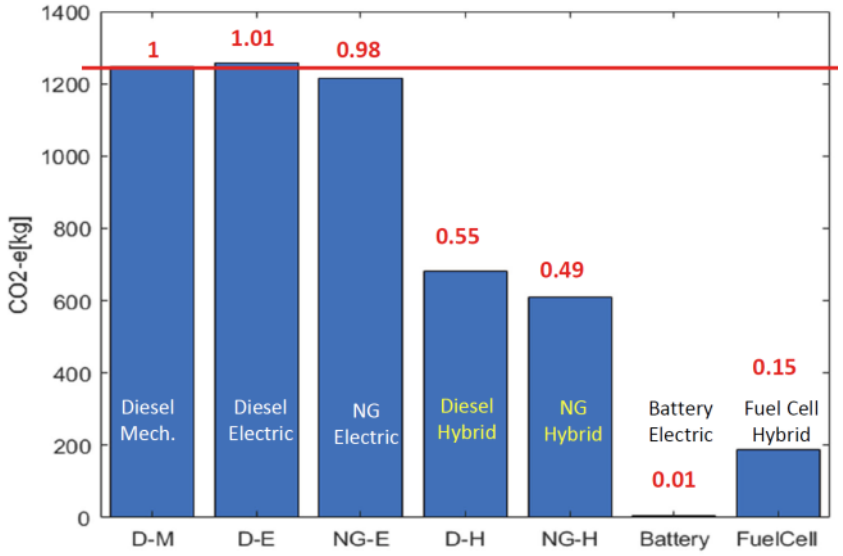
Study on PEM Fuel Cell Hybrid Electric Cargo Ship

- **Worked** on Transportation Fuel Cells in collaboration with **Ballard Power Systems (BC, Canada)** in 1990s
- **Designed** the Diesel-Fuel Cell Plug-in Hybrid Green Research Vessel in 2010, and recognized the lack of an integrated marine propulsion modeling, design and control optimization tool
- **Modelled and studied** the PEM fuel cell hybrid electric container feeder ship to reduce the container trucks emissions, using our new integrated modeling, design and control optimization tools
- **Compared** to diesel-mech/-electric, diesel-hybrid, NG-electric/-hybrid propulsion systems

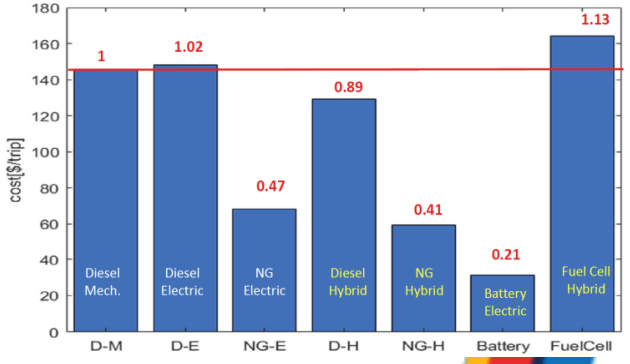
UVic Diesel-Fuel Cell Plug-in Hybrid Green Research Vessel, 2010

BC Ferries' M.V. Tachek

WTW CO_{2e} Emission (per trip)

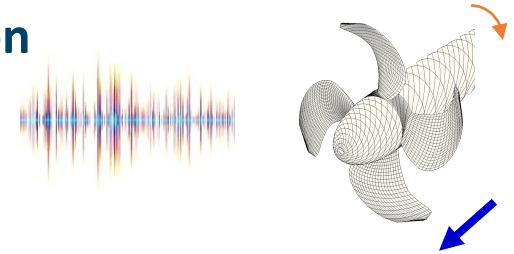


Fuel Cost (per trip)

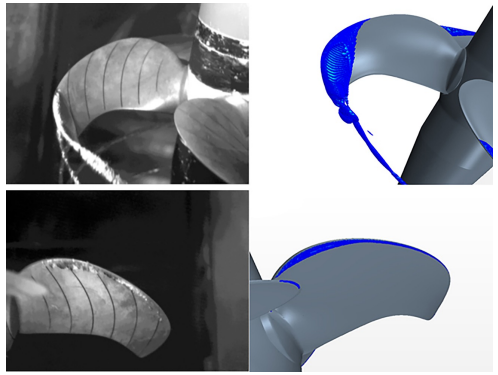


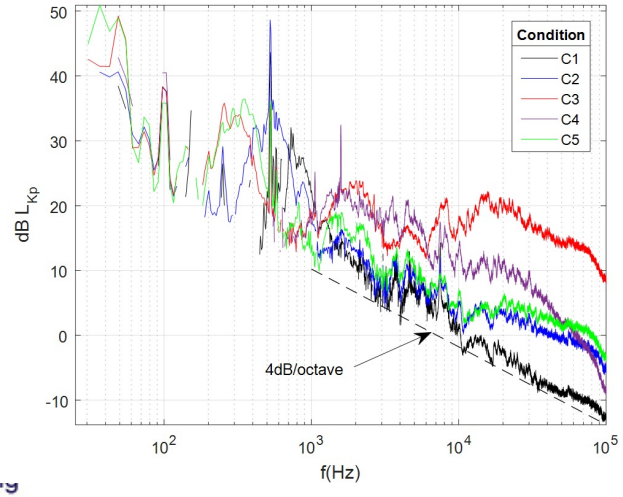
Modeling, Prediction & Control of Ship-Induced Propeller Cavitation Noise – Active and Leading Canadian Efforts

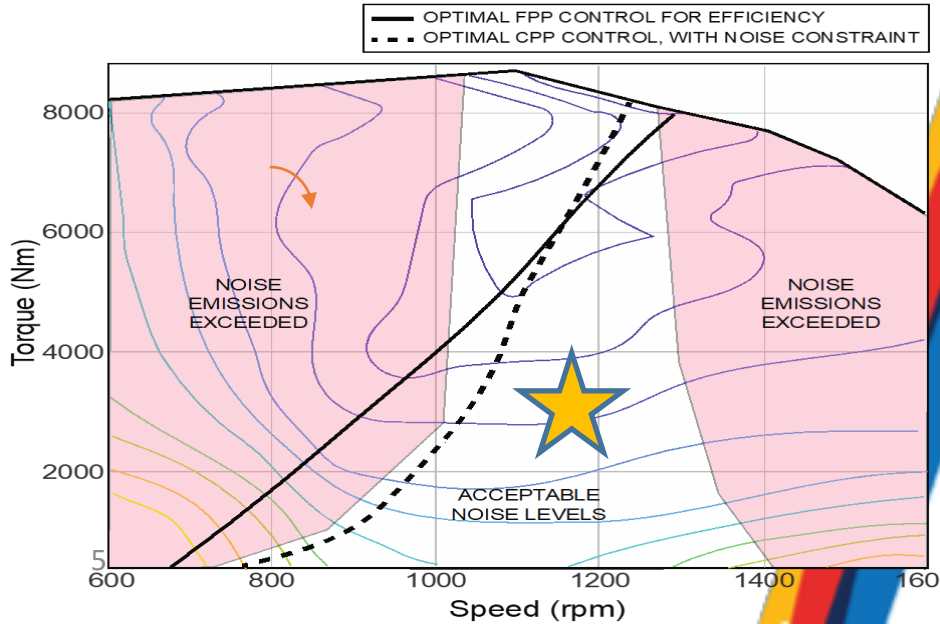
- **Propeller Cavitation: CFD Modeling, Reduced/Low-Order Models, and Exp Validation**
  - Transport Canada Supported Initial Work and Team's Continuous Effort
  - CFD Simulation and Cavitation Noise Modeling: M. Rahimpour, D. McIntyre & Dr. Peter Oshkai
  - Propeller Cavitation Noise (Water Tank) Experiments: University of Genova, Italy: Led by Dr. M. Viviani
  - Low-order Propeller Thrust/Cavitation Modeling - Collaboration with Marine Propulsion Res Lab, Newcastle Univ. (Prof. P. Liu)



- **Include Ship-induced Noise** (80% due to Propeller Cavitation) **as a Propulsion Pollution Component**
- **Propulsion System Design & Operation Control**: Propeller In-stream Speed - Vessel Speed & Marine Weather State on Route







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