

ALTERNATIVE FUEL FOR MARINE APPLICATIONS: ETHANOL-POWERED DUAL-FUEL TECHNOLOGY FOR EMD-710 ENGINE



AMERICAN WATERWAYS OPERATORS (AWO), AUGUST 13, 2025

EMD 1-710 Engine, 11.6 L

ESSAM EL-HANNOUNY (Principal Investigator)
Doug Longman (Manager)
Advanced Power Systems Research
Argonne National Laboratory



Argonne National Laboratory is a
U.S. Department of Energy laboratory
managed by UChicago Argonne, LLC.

ACKNOWLEDGEMENTS

This presentation has been created by UChicago Argonne, LLC, Operator of Argonne National Laboratory (“Argonne”). Argonne, a U.S. Department of Energy Office of Science laboratory, is operated under Contract No. DE-AC02-06CH11357. The U.S. Government retain for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distributed copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

The authors would like to thank:

- **S. Khan, K. Stork, and G. Singh** – DOE VTO technology/program managers
- **J. Messner** – DOE BETO program manager
- **R. Subramanya and F. Devani, Progress Rail (PR) - A Caterpillar Company** for providing engine and technical support



■ <https://gc1-app.matterport.com/show/?m=ovp5WfniE9V>

PRESENTATION OUTLINE:

- **ABSTRACT**
- **INTRODUCTION**
- **SETUP**
- **RESULTS**
- **CONCLUSION**

ABSTRACT

This study explores the potential of dual-fuel technology for marine engines, specifically focusing on the use of alcohol-based fuels to address the environmental challenges associated with diesel engines. Diesel engines are known for their high efficiency and power, making them ideal for off-road applications such as rail and marine. However, they contribute to emissions of NO_x, particulate matter, and greenhouse gases. Alcohol-based fuels, such as ethanol/methanol, offer cleaner combustion, making them promising alternatives.

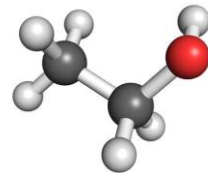
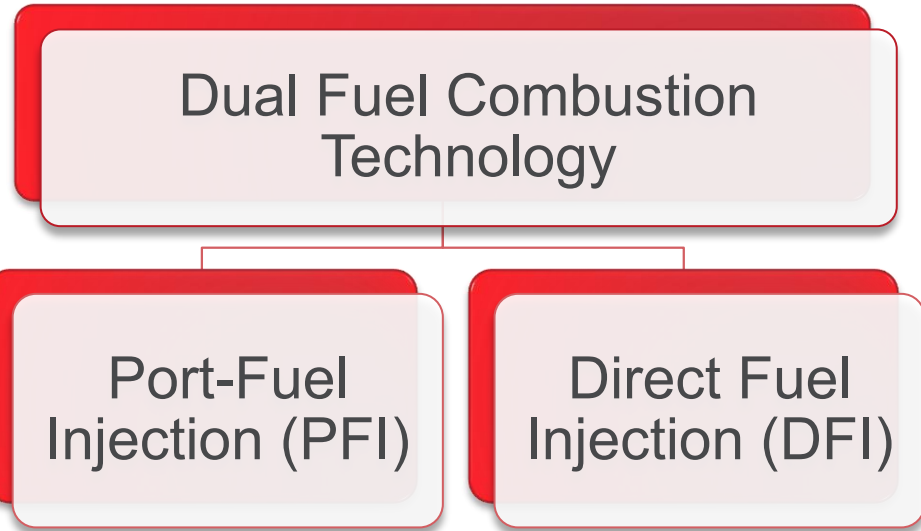
However, the transition to alcohol-based fuels presents some technical challenges to the fuel injection system and ignition, engine as well as the emissions control technologies. This study investigates a dual-fuel approach using a single-cylinder, 2-stroke marine engine, where a portion of the diesel fuel is replaced with alcohol fuel. This involves alcohol port injection, which introduces a hydrous-ethanol mixture into the intake port via injection. This approach aims to leverage the benefits of alcohol fuels while maintaining the performance characteristics of diesel engines, potentially reducing emissions and improving environmental sustainability in marine applications.

This method requires minor modification to the engine which can be implemented by adding a low-pressure fuel injector, a separate fuel tank, lines and controls. The goals are to demonstrate the technology and investigate its effect on the engine performance and emissions.

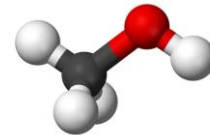
INTRODUCTION

- **Dual-fuel combustion**, a process where an engine uses two different fuels simultaneously
- **Basic principle:** use a high-reactivity fuel (like diesel) as a pilot to ignite a premixed, low-reactivity fuel-air mixture (like ethanol and methanol)
- **Alcohol Fuels:** Methanol and Ethanol are currently mass-produced alternative fuels.

	Methanol (CH ₃ OH)	Ethanol (C ₂ H ₅ OH)	Diesel Fuel (~C ₁₂ H ₂₃)
LHV	22.7 MJ/kg	29.7 MJ/kg	42 - 46 MJ/kg
Oxygen Content (mass)	~50%	~34%	~0%
Stoichiometric Air-Fuel Ratio	6.4:1	9.0:1	14.6:1



Ethanol
(C₂H₅OH)



Methanol
(CH₃OH)

DUAL FUEL COMBUSTION TECHNOLOGY

Port Fuel Injection (PFI) & Direct Fuel Injection (DFI)

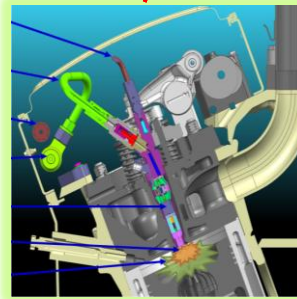
Air Box



Port Fuel Injection (PFI)

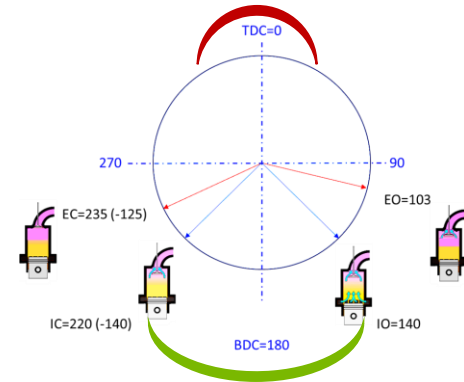


Inside cylinder

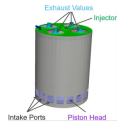


Progress Rail CR-DFI Technology

Direct Injection (DI)



Port Injection



2-Stroke EMD 1-710 (11.6L) Engine

Opportunity and Challenge for Dual-Fuel Technology

- ANL and others tested hydrous ethanol (EtOH) in a dual-fuel mode on HD/MD engines but not to our knowledge on marine engine. Very large 2-stroke engine for on-going ships uses water injection to control NO_x (Nitrogen oxides).
- Quick solution (**Retrofit option**)
- Could eliminate or reduce the size of the expensive NO_x control aftertreatment like Selective Catalytic Reduction (SCR), Urea fuel tank, Injection system,..)
- ❖ Additional fuel and fuel system on board

Objective

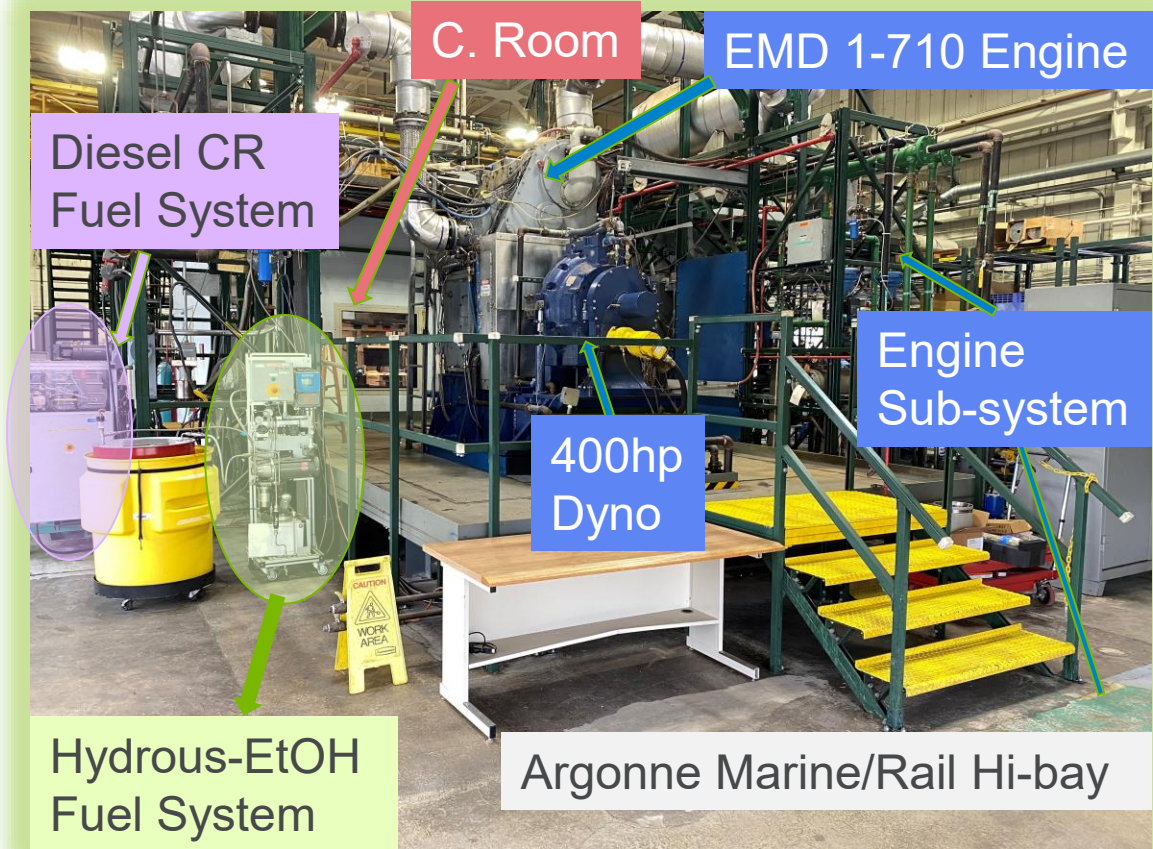
- ✓ Enable low-carbon and low- NO_x fuel-efficient engine designs for marine compression ignition (CI) engines using dual-fuel
- ✓ Evaluate the impact of the EtOH substitution on the engine performance and emissions

Target

- Ferries, Barges and Tugboats
- Sea Ports and inland waterways

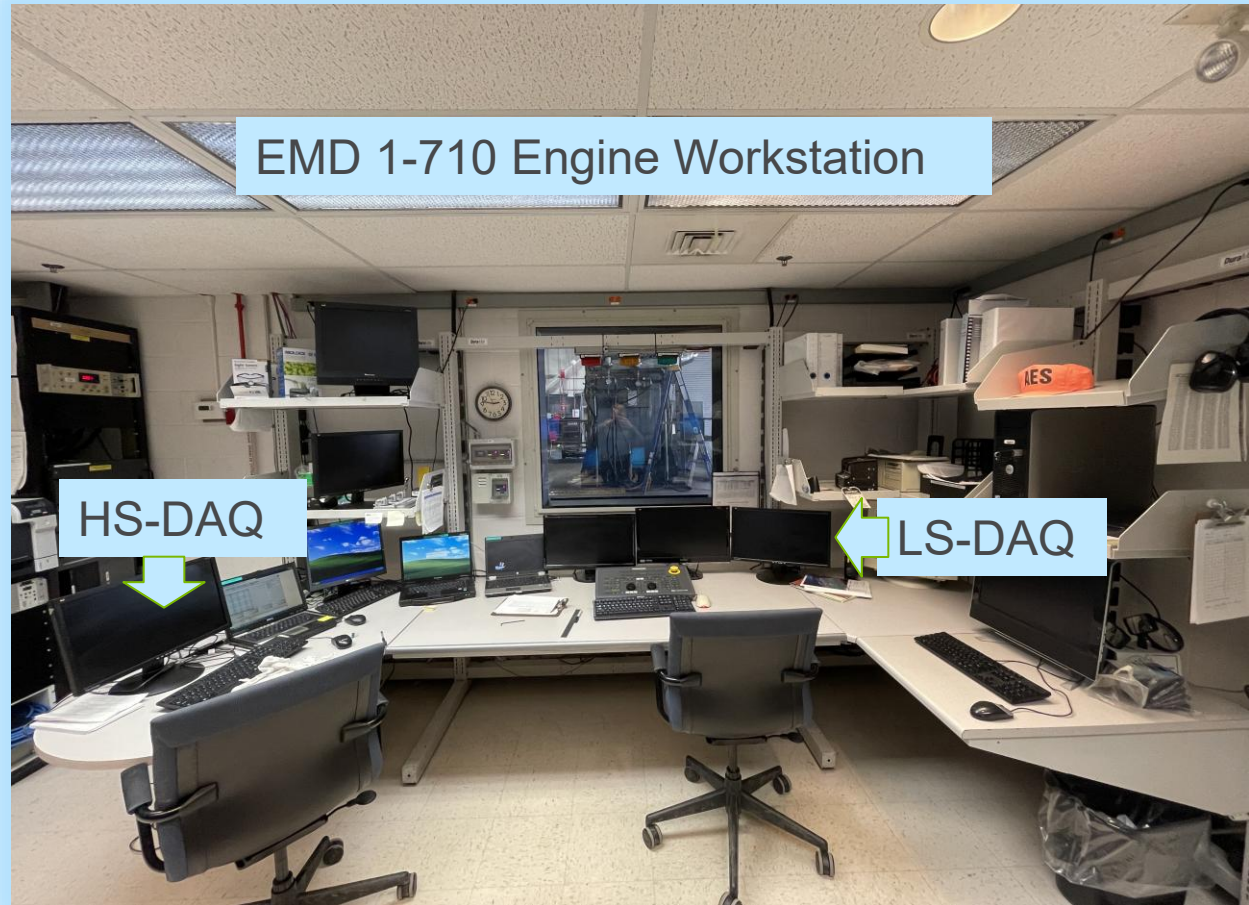
SETUP: EMD 710-SCE AT ARGONNE

- Fully instrumented 2-stroke
- Displ.= 710 in³ (11.6L/cyl)
- The engine has intake ports and is uniflow scavenged with four poppet exhaust valves in the cylinder head
- Max speed 900rpm
- Power=272 hp/cylinder
- **Port Fuel Injection (PFI): hydrous Ethanol**
- **Common Rail (CR): Diesel D2-DI**



SETUP: ENGINE CONTROL

- **HS-DAQ**, AVL IndiCom system
- **LS-DAQ**, AVL Digalog system
- **AVL AMA-i60** emission bench
- **AVL 415S** Smoke Meter
- **AVL 439** Opacity Meter



RESULTS: (E2/D2 CYCLES)

Marine Test Cycles

Table 1 Test cycles:

E2: Constant-speed main propulsion application

D2: Constant speed auxiliary engine application

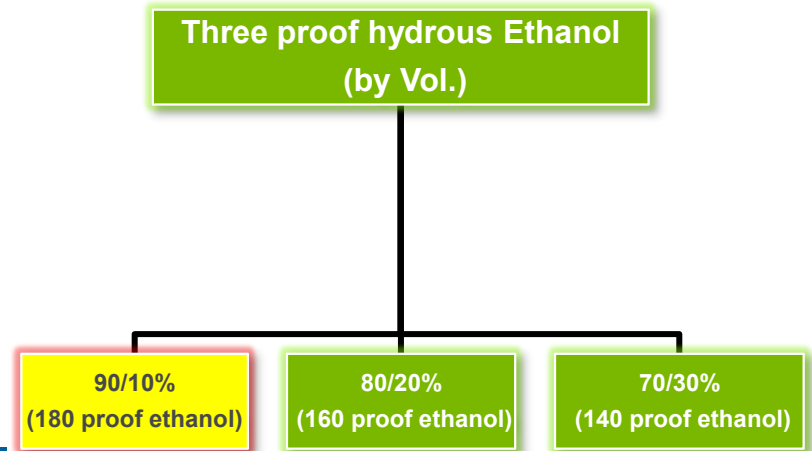
Test cycle E2/D2	Speed	100%	100%	100%	100%	100%
	Power	100%	75%	50%	25%	10%

Table 2 Test cycle:

E3: Propeller-law-operated main & propeller law operated auxiliary engine

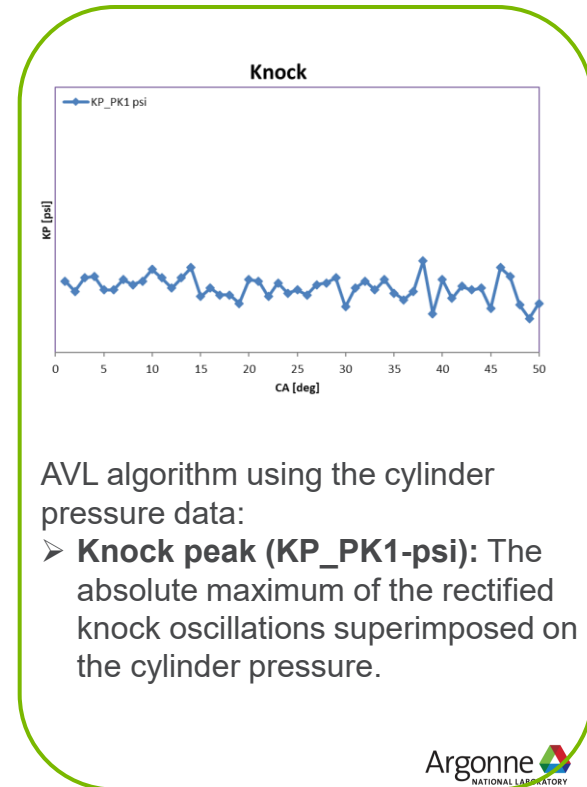
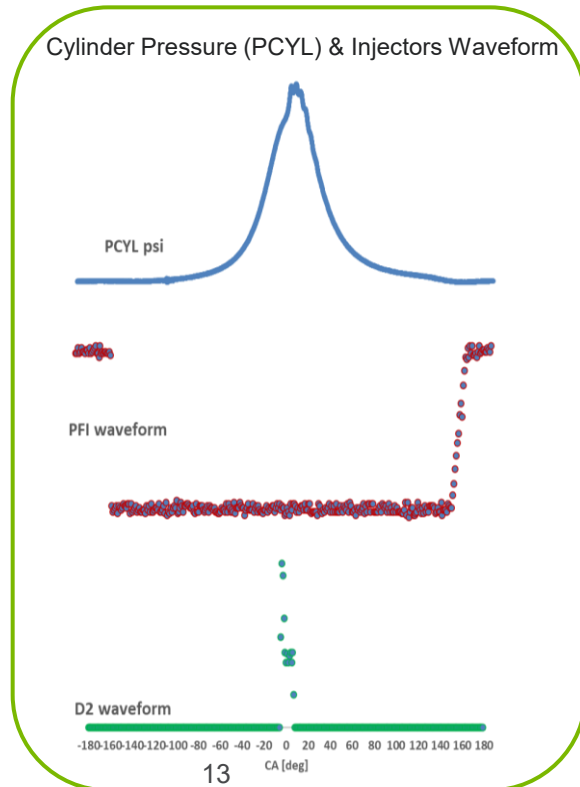
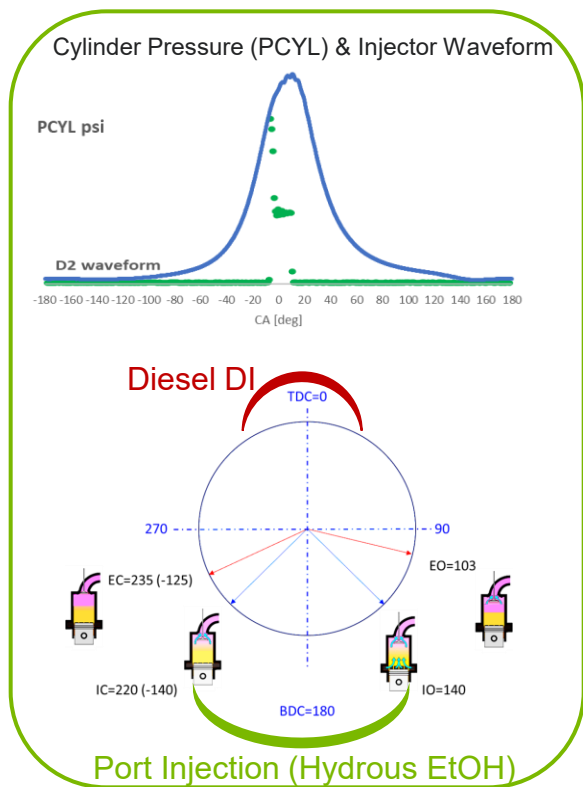
Test cycle E3	Speed	100%	91%	80%	63%
	Power	100%	75%	50%	25%

EtOH+H₂O Ratios:



SINGLE AND DUAL FUEL COMBUSTION FOR E2/D2

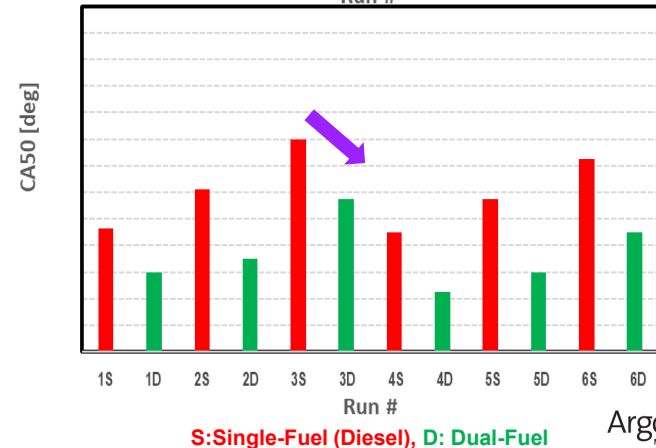
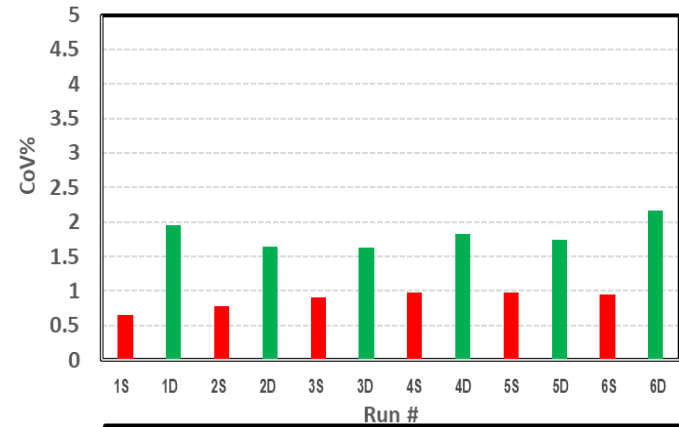
Cylinder Pressure, Injection, Knock



COMBUSTION STABILITY AND PHASING E2/D2

Coefficient of Variance (CoV) and Mass Fraction Burned location

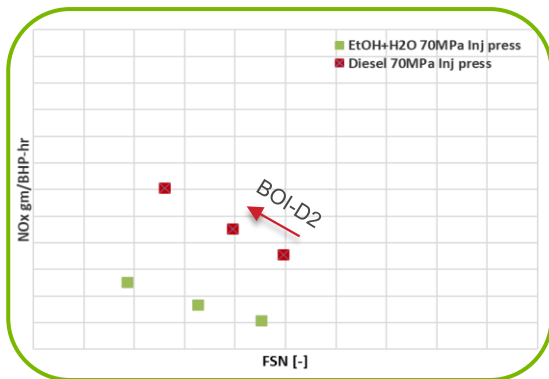
- Indicated Mean Effective Pressure (IMEP) CoV% ~2%, less than 5% (industry limit) for stable combustion
- CA50 = the crank angle degree of 50% heat release (50% mass fraction burn)
- CA50 → maximum pressure rise rate, combustion noise, and fuel conversion efficiency
- CA50 of the dual-fuel combustion is about 4-5deg earlier than diesel combustion as shown



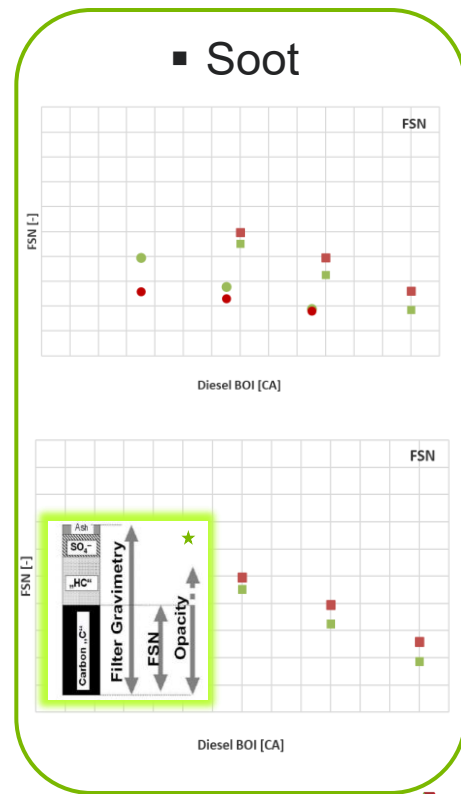
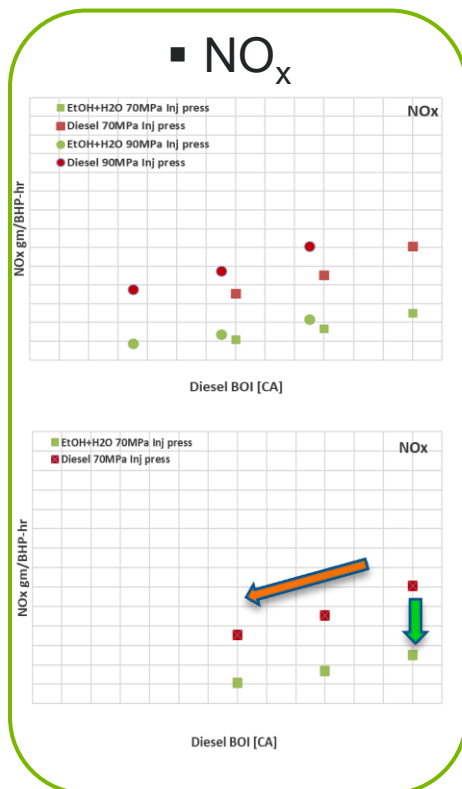
SINGLE AND DUAL FUEL COMBUSTION FOR E2/D2

E2/D2 @50% and 40% Energy Substitution:

- NO_x control:
 - ✓ Injection timing (BOI, Beginning Of Inj.) for the Diesel fuel (D2)
 - ✓ Peak cylinder temperature
- Soot (FSN, Filter Smoke Number)
 - ✓ FSN is the index which measures the amount of carbon particle (soot) available in the exhaust.



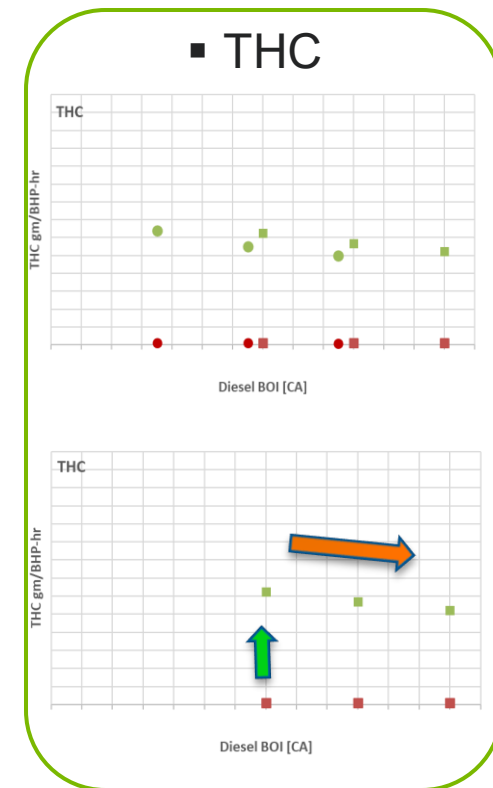
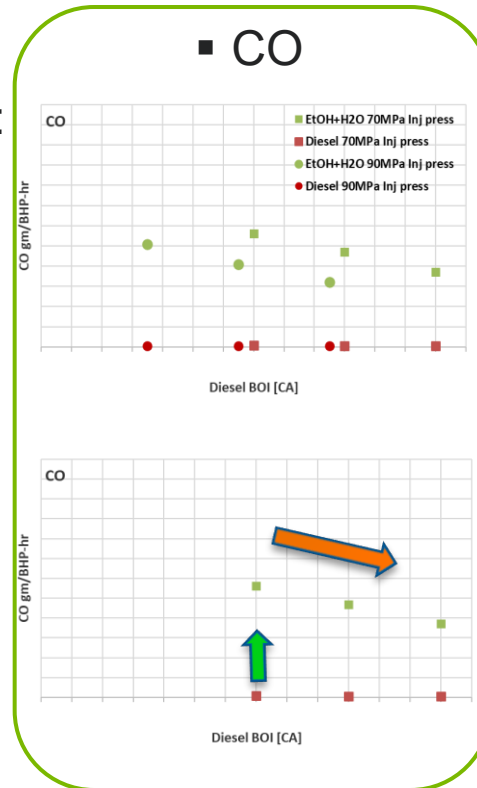
← NO_x -Soot trade-off



SINGLE AND DUAL FUEL COMBUSTION FOR E2/D2

E2/D2 @50% and 40% Energy Substitution:

- NO_x-Soot improved as shown previously at the expense of Slightly:
 - Higher THC
 - Higher CO (slightly lower thermal Efficiency)
- Improved NO_x-Soot mean less demand for aftertreatment
- Engine optimization is needed to reduce the THC, CO too.



RESULTS (E3 CYCLE)

Marine Test Cycles

Table 1 Test cycles:

E2: Constant-speed main propulsion application

D2: Constant speed auxiliary engine application

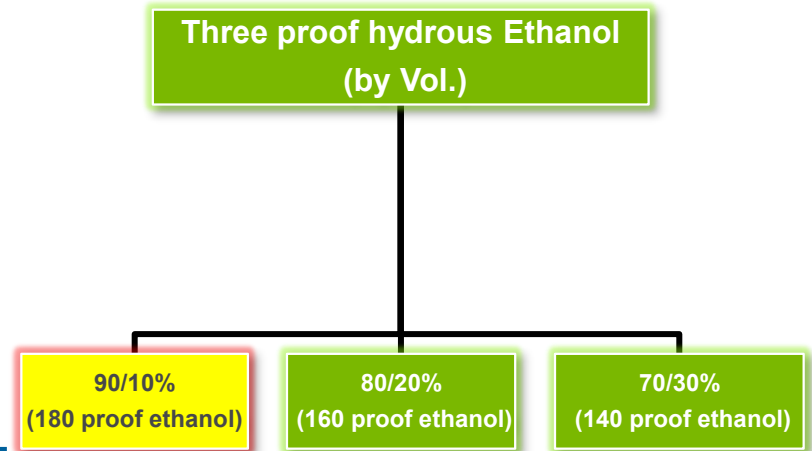
Test cycle E2/D2	Speed	100%	100%	100%	100%	100%
	Power	100%	75%	50%	25%	10%

Table 2 Test cycle:

E3: Propeller-law-operated main & propeller law operated auxiliary engine

Test cycle E3	Speed	100%	91%	80%	63%
	Power	100%	75%	50%	25%

EtOH+H₂O Ratios:

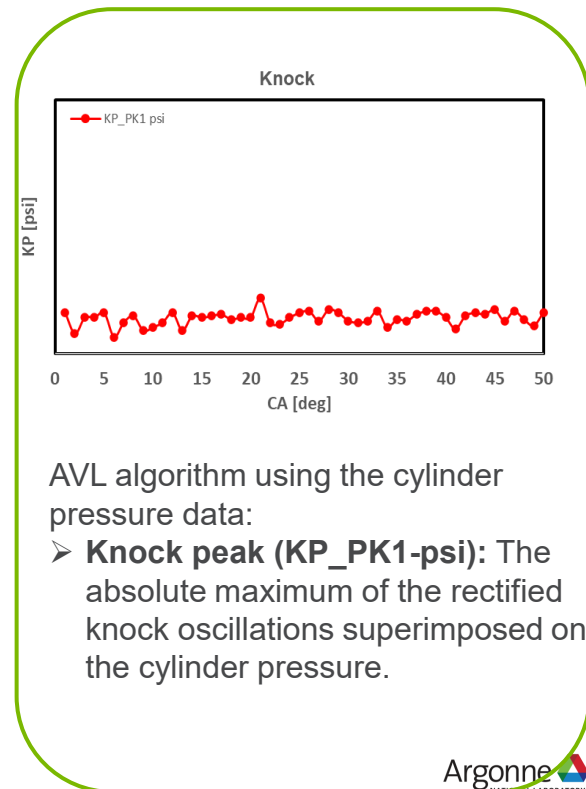
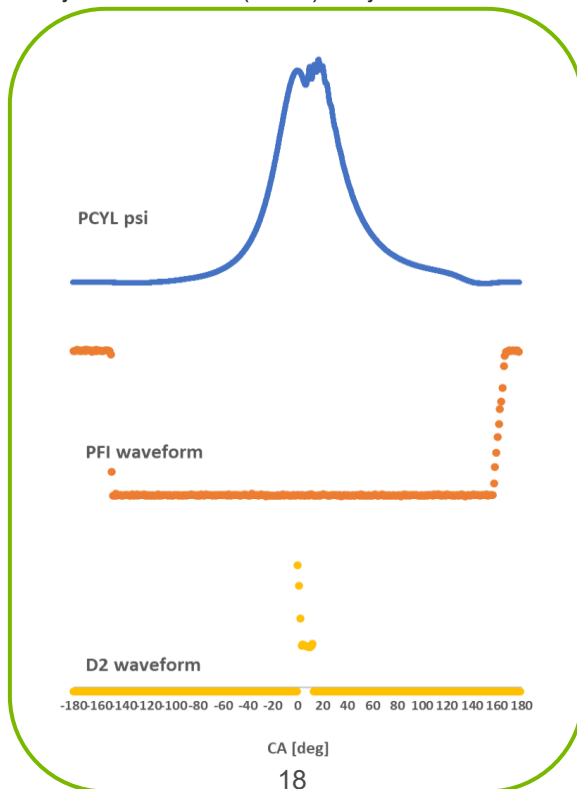
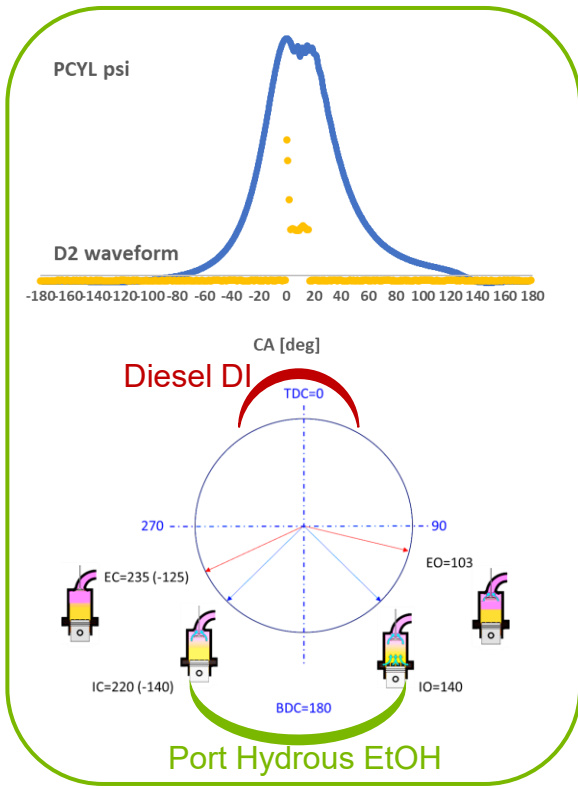


SINGLE AND DUAL FUEL COMBUSTION FOR E3

Cylinder Pressure, Injection, Knock

Cylinder Pressure (PCYL) & Injector Waveform

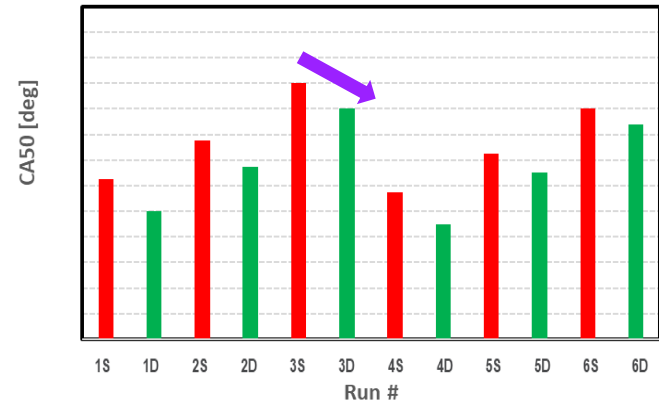
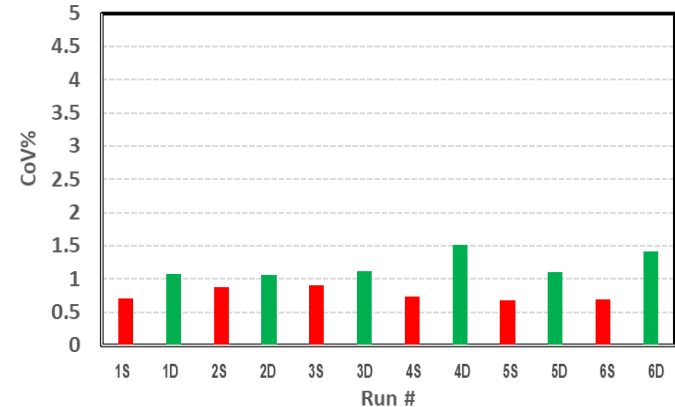
Cylinder Pressure (PCYL) & Injectors Waveform



COMBUSTION STABILITY AND PHASING E3

Coefficient of Variance (CoV) and Mass Fraction Burned location

- Indicated Mean Effective Pressure (IMEP) CoV% = 1.5%, less than 5% (industry limit) for stable combustion
- CA50 = the crank angle degree of 50% heat release (50% mass fraction burn)
- CA50 → maximum pressure rise rate, combustion noise, and fuel conversion efficiency
- CA50 of the dual-fuel combustion is about 2 deg earlier than diesel combustion as shown

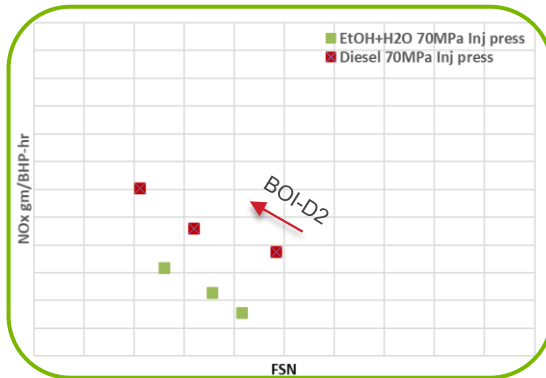


S: Single-Fuel (Diesel), D: Dual-Fuel

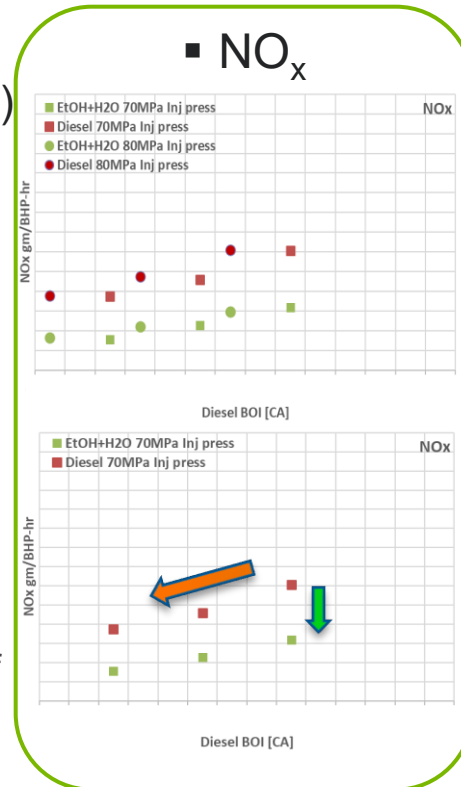
SINGLE AND DUAL FUEL COMBUSTION FOR E3

E3 @50% and 40% Energy Substitution:

- NO_x control:
 - ✓ Injection timing (BOI, Beginning Of Inj.) for the Diesel fuel (D2)
 - ✓ Peak cylinder temperature
- Soot (FSN, Filter Smoke Number)
 - ✓ FSN is the index which measures the amount of carbon particle (soot) available in the exhaust.



← NO_x-Soot trade-off



20



SINGLE AND DUAL FUEL COMBUSTION FOR E3

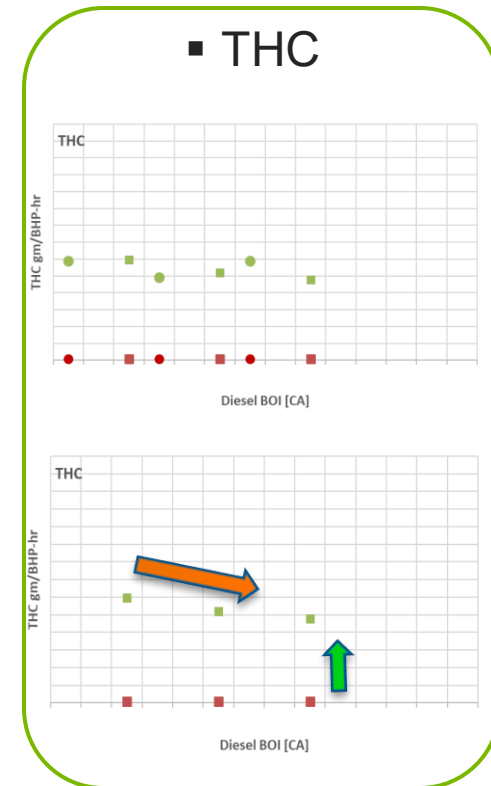
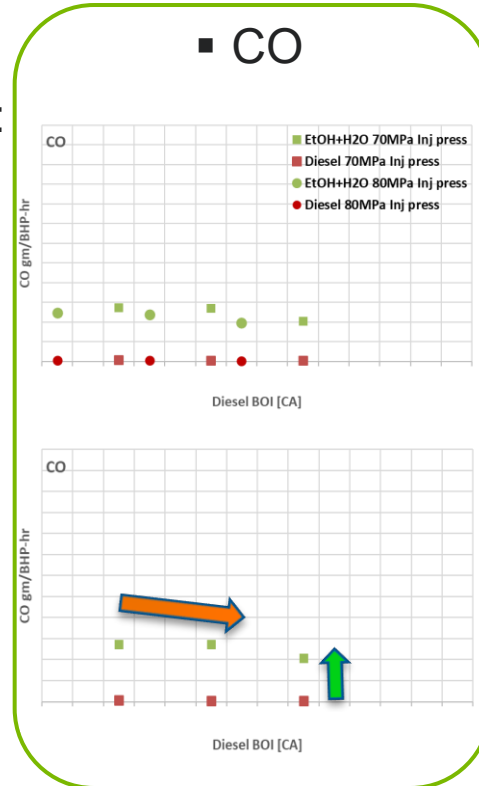
E3 @50% and 40% Energy Substitution:

➤ NO_x-Soot improved as shown previously at the expense of Slightly:

- Higher THC
- Higher CO (slightly lower thermal Efficiency)

➤ Improved NO_x-Soot mean less demand for aftertreatment

➤ Engine optimization will be the next step to reduce the THC, CO



SUMMARY AND FUTURE WORK:

- Dual fuel technology was demonstrated on the EMD 710 2-stroke SCE using DI-diesel and PFI hydrous ethanol for E2/D2 and E3 marine combustion cycles
- PFI hydrous ethanol was an effective tool to reduce NO_x on the expense of a slight increase in THC and CO
- Engine optimization is need to reduce the THC and CO emissions and improve the fuel economy
- Engine simulation will be conducted to guide the engine optimization process

ENABLING METHANOL COMPRESSION IGNITION: DFI

Objective:

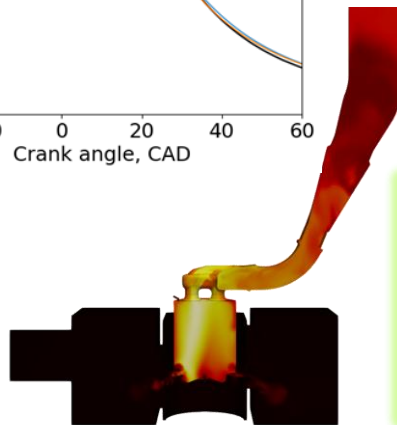
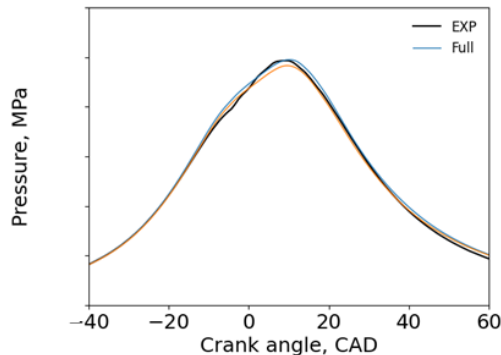
- ✓ Enable compression ignition (CI) **methanol** for marine application using direct fuel injection (DFI) technology
- ✓ Demonstrate 95% MeOH and 5% Diesel engine performance
- ✓ Retain high efficiency on methanol

Approach:

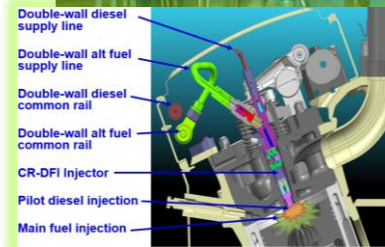
- Engine Testing
- CFD Combustion Modeling
- Spray Simulation

Team:

- ❖ Progress Rail
- ❖ Convergent Science Inc.
- ❖ Argonne National Laboratory



Temperature distribution from CFD for EMD-710



2-stroke EMD-710 (11.6L) Engine and Progress Rail CR-DFI Technology

(CRADA in progress)

LOCOMOTIVE & MARINE RESEARCH FACILITY

<https://gc1-app.matterport.com/show/?m=ovp5WfniE9V>

THANK YOU!

Essam Elhannouny
eel-hannouny@anl.gov
630-252-4976