Commercial Harbor Craft
Technology Assessment

September 9, 2014
Diamond Bar, California

South Coast AQMD

California Environmental Protection Agency
Air Resources Board

Overview

- Background
- Technologies
- Goals
- Deployment
- Summary
- Contacts

Summary – CHC Assessment

- Best technology depends on vessel type
- Turnover of engines is slow (<200/year)
- Deployment depends on:
  - Successful demonstration projects
  - Incentives/regulations for zero emission technologies
  - Alternative fuel and shore power infrastructure
- Likely deployment timeframe for technologies (with no incentives or research/demonstration programs)
  - 5 years – Tier 3 and 4 diesel, diesel hybrid, retrofit, biodiesel, efficiency improvements, LNG, LNG hybrid, renewables
  - 10 years – Tier 4+
  - 15 years – Fuel cell, battery electric

Vessel Characteristics

- Operate in harbors and coastal waters
- Wide range of vessel types and function
- Wide range in engine size, power, and age
- Essentially all current engines are diesel
- Long useful life (20+ years)
- Vessels/engines built to order

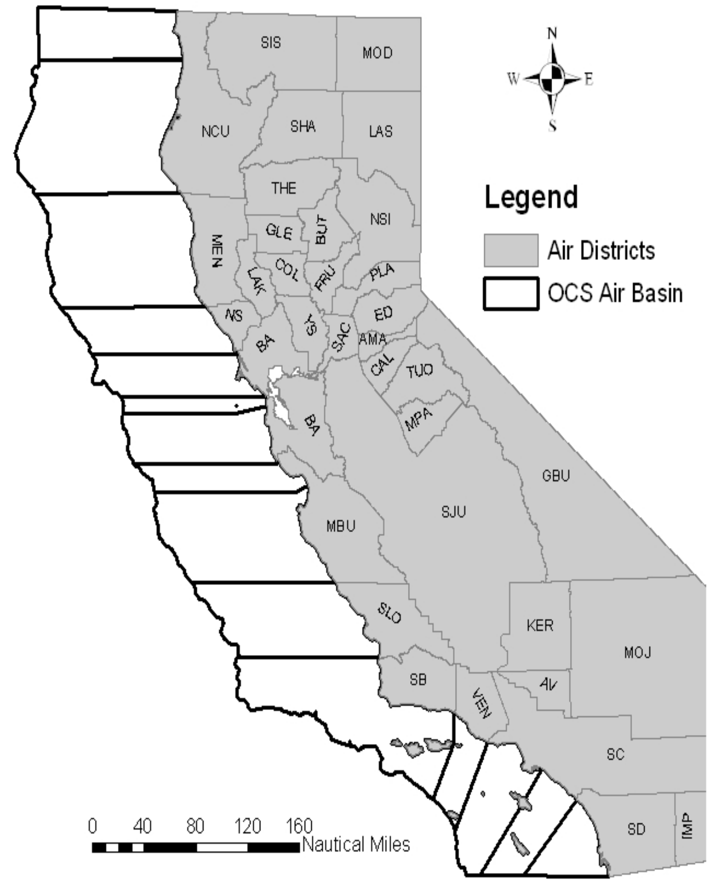
CHC Engine Characteristics

Vessel Types	Vessels	Propulsion Engines			Auxiliary Engines		
		Number	Hours	Horsepower	Number	Hours	Horsepower
Barges	88	4	1,510	251	314	550	346
Charter Fishing	563	997	1,591	381	422	2,102	50
Commercial Fishing	2,727	3,054	1,245	230	1,254	1,642	71
Crew and Supply	70	163	1,796	500	73	2,265	110
Dredges	18	6	1,800	2,708	77	2,300	812
Ferry/Excursion	416	836	1,824	733	512	1,265	94
Other	136	151	680	281	63	399	56
Pilot Vessel	27	46	1,017	408	4	994	30
Towboat/Push boat	35	74	1,961	500	41	2,883	79
Tug Boat	128	246	2,347	1,274	204	2,505	111
Work boat	89	130	802	239	28	1,334	101
TOTAL	4,297	5,706	--	--	2,992	--	--

Staff Report: Amendments to the CHC regulation, May 7, 2010

CHC Population by Port Location

San Francisco/Oakland	35%
Los Angeles/Long Beach	18%
Monterey	9%
San Diego	7%
North Coast	7%
Santa Barbara	5%
Ventura	5%
Others	14%



Staff Report: Amendments to the CHC regulation, May 7, 2010

Regulatory Framework

- Federal New Marine Engine Standards*

	NOx	PM
• 100 - 800 HP (Tier 3)	5.6-5.8	0.10-0.25
• 800 - 5,000 HP (Tier 4)	1.3	0.03

  - Fully phased-in by 2018

- ARB In-Use CHC Regulation
  - New engines or vessels meet current standard
  - Turn-over of Tier 1 and older high use engines
    - Turn-over schedule by model year
    - Turn-over requirement ends in 2023
    - All engines meet at least Tier 2 standard

*Category 1 and 2 (L/cyl < 30) in g/bhp-hr: Ref. 40 CFR 1042.101

CHC Technologies

- Cleaner diesel engines
- Retrofit technology
- Biodiesel and natural gas fuels
- Diesel electric hybrid
- Fuel cell
- Battery electric
- Renewable energy (solar and wind)
- Efficiency improvement

Cleaner Diesel Engines

- New Tier 4 standard for <800 HP
  - Technology similar to larger CHC engines
  - SCR, engine modifications, EGR
  - Potential reductions from Tier 3: NOx = 77%
PM = 70%
- New Tier 4+ standard for 800-5000HP
  - Larger SCR catalysts
  - Additional engine/fuel injection improvements
  - Thermal management at lower loads
  - Potential reductions from Tier 4: NOx = 50%
PM = 30%

Cleaner Diesel Engines

- Benefits
  - Known technologies from off-road Tier 4 engines
  - Does not require new fuel infrastructure
  - Conventional engine room layout
  - Older vessels can be repowered to low emissions
- Challenges
  - No engine development without new standards
  - May not fit older vessels

Retrofit Technologies

- SCR/DPF retrofit systems
  - San Francisco Bay Express Ferries (BACT)
  - ARB AQIP Long Beach Tugboat Demonstration

- Reductions from Tier 2 (ISO marine cycle)
  - PM: >85%
  - NOx: >85%

    >90% at $\geq$75% of rated power

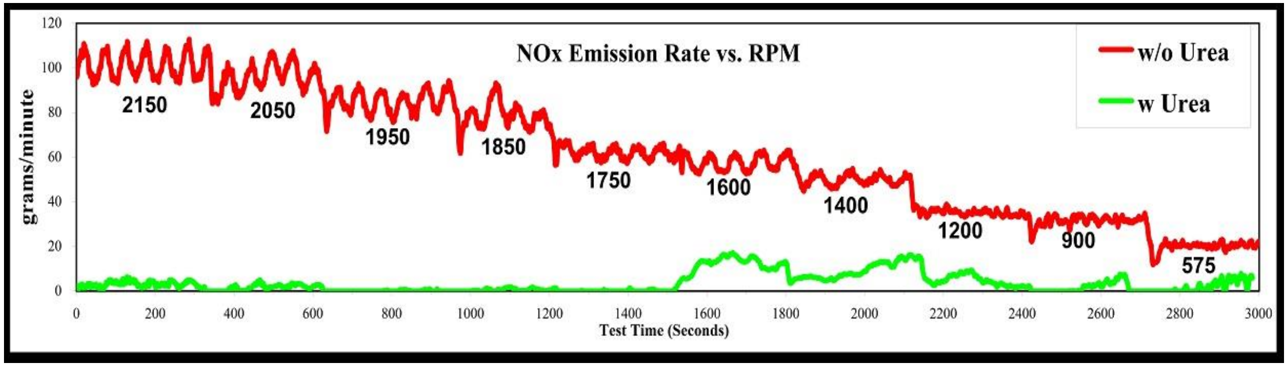
Retrofit Technologies

- Benefits
  - SCR, DPF, and DOC are known technologies
  - Achieves Tier 4 emissions from Tier 2 engines
  - Used in European harbor/river craft
  - Lower cost than other technologies
- Challenges
  - SCR requires urea
  - May not fit some vessels
  - Requires regular maintenance
  - Requires ARB verification

Retrofit Technologies

SCR on a Tugboat and Ferry

Representative NOx Data from Ferry[1]



[1]Engine Fuel and Emission Engineering, Inc. (www.efee.com)

Biodiesel and Natural Gas Fuels

- Biodiesel >20% by volume
  - Commercially available
  - Conventional diesel engine
  - Demonstrated in Tier 2 ferry[1]
    - PM decreased
    - NOx increased
    - CO decreased

[1] "Effect of Biodiesel on Emissions from a Tier 2 Marine Propulsion Engine," Final Report, ARB Contract 06-412, UCR CE-CERT, November, 2009.

Biodiesel and Natural Gas Fuels

- Natural Gas (LNG)
  - Commercially available engines (trucks, stationary)
  - Spark ignition engines modified for NG
  - Potential to achieve lower PM and NOx than diesel
  - Reductions compared to Tier 2 diesel engine
    - PM decreased
    - NOx decreased
    - CO_2 decreased (tank to wheel)

Biodiesel and Natural Gas Fuels

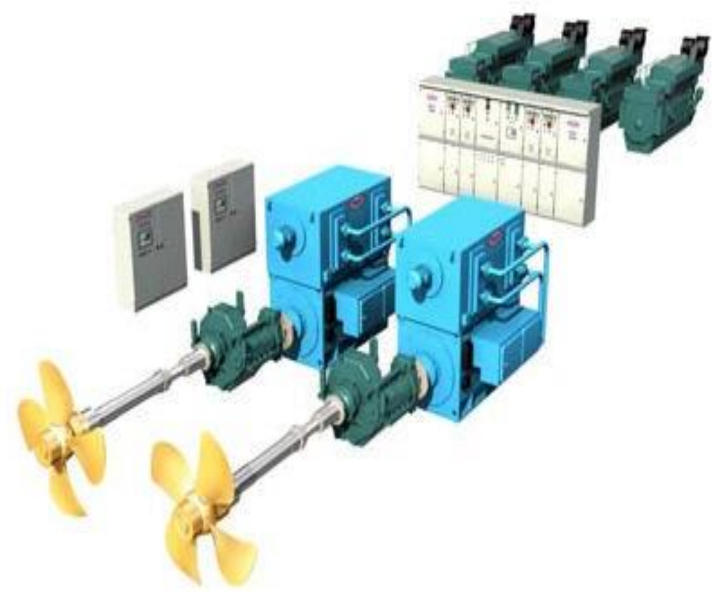
- Dual Fuel (diesel and natural gas)
  - Conventional diesel engine
  - Supplemental natural gas injection system
  - Blends natural gas and diesel fuel
  - Retrofit kits commercialized but not used in CHC
- Natural Gas (with diesel pilot ignition)
  - Modified diesel engine
  - Natural gas direct injection into cylinders
  - Diesel fuel starts engine and ignites natural gas
  - Natural gas provides energy above idle
  - Technology commercialized but not used in CHC

Biodiesel and Natural Gas Fuels

- Benefits
  - Biodiesel and natural gas fuels reduce PM
  - Dual fuel systems can be retrofitted
  - Natural gas price usually lower than diesel
- Challenges
  - Biodiesel blends may increase NOx
  - Biodiesel price usually higher than diesel
  - Natural gas may increase methane emissions

Diesel-Electric Hybrid

- Diesel gensets provide electric power
- Electric power runs propulsion motor(s), lighting and auxiliary equipment
- Various configurations (AC/DC, multiple thrusters)
- May include battery storage



Diesel–Electric Hybrid

- Benefits:
  - Each engine can operate at optimum rate
  - Well suited for vessels with:
    - Low loads with occasional short high loads
    - Multiple propellers or thrusters
  - Lower fuel cost – potentially lower emissions than large engine designed for high load
- Challenges:
  - Complex genset power controls
  - Higher capital cost than diesel propulsion engine
  - Retrofit constraints

Diesel–Electric Hybrid

Examples of diesel electric hybrids

- ARB AQIP Foss Maritime Hybrid Retrofit Demonstration
  - EPA Verified up to 3700 kw
  - 25% NOx reduction
  - 30% PM reduction
  - 30% CO_2 reduction

- Foss Maritime Hybrid Tugboat
  - Designed and built as hybrid
  - Dual Tier 2 diesel generators
  - Electric propulsion motors
  - Battery storage
  - All electric auxiliary equipment

Fuel Cells

- Hydrogen proton exchange membrane (PEM) fuel cell
  - Baseload power for propulsion
  - Auxiliary equipment
  - Battery recharge
- Battery
  - Idling time auxiliary power
  - Power demand above fuel cell capacity
- Electric motors for propulsion and auxiliaries
- Cryogenic fuel storage
- Well-suited for vessels with
    - Steady power loads
    - Long periods of low load with intermittent high load

Fuel Cells

- Benefits
  - Zero emissions
  - Reduced noise and vibration
  - Low maintenance
  - Size, weight and cost per Kw is dropping
- Challenges
  - Fuel cell size
  - Limited refueling infrastructure

Fuel Cells

Examples of marine fuel cells

- Small fuel cells are available for auxiliary power on pleasure boats
- Large fuel cells have been demonstrated for military ship propulsion.
- In Amsterdam, small ferries and excursion vessels are powered by fuel cells in demonstration projects.

Battery Electric

- Recreational and small harbor excursion boats
- Not demonstrated or used in larger harbor craft

- Batteries best used in hybrid systems with on-board power source (engine, fuel cell, renewable) or for auxiliary power

Renewables

- Solar cells
  - Generate electricity usually for auxiliary equipment, lighting, and battery recharge
  - Commercially available for pleasure craft
  - Demonstrated on excursion vessel
- Wind turbines
  - Generate electricity to recharge batteries
  - Commercially available for pleasure craft
  - Demonstrated on excursion vessel

Renewables

- Sails and wind wings
  - Used for pleasure craft
  - Sails have been used in excursion vessels
  - Limited demonstration of wind wings

Renewables

- Benefits
  - Zero emissions
  - “Green” public relations
- Challenges
  - Power not available on-demand
  - Provide small fraction of total power demand

Renewables

Examples of solar and wind power

- Solar cell power systems are commercially available for auxiliary power to replace small diesel gen-sets.
- ARB AQIP demonstration of prototype wind-wing propulsion system with solar cell/battery system for controls.

- The Hornblower Hybrid Alcatraz uses dual Tier 2 diesel engines with hybrid electric drive and battery storage. Two wind turbines and roof mounted solar cells provide renewable power.

Efficiency Improvements

- Hull maintenance (up to 5% improvement)
  - Marine growth removal
  - Hull coatings
- Propeller design (up to 15% improvement)
  - Blade size and number
  - Blade pitch
  - Propeller shroud
  - Multiple vs single propeller

Efficiency Improvements

- Hull design (up to 5% improvement)
  - Bulbous bow
  - Stern flaps
  - Length to width ratio
- Vessel operation (up to 5% improvement)
  - Speed reduction

Efficiency Improvements

- Benefits
  - Reduced fuel consumption
  - Reduced GHG emissions
  - Potential reduced criteria emissions
  - Does not require internal modifications to vessel
- Challenges
  - Hull cleaning must be repeated periodically
  - Vessel must be in drydock to implement

Technologies by Vessel Type

Technology	Most Applicable to Vessel Types*
Diesel Tiers 4, 4+	All
Diesel Retrofit	Ferry, Tug, Barge, Dredge
Alternative fuels (LNG)	Ferry
Diesel Electric Hybrid	All
Fuel Cell	All
Battery Electric	Barges, Excursion
Renewable	Barges
Efficiency Improvements	Ferries, Fishing, Tow Boats, Crew and Supply

*Specific technologies may not be feasible for particular vessel types or individual vessels due to space limitations and capital cost

Goals for CHC Technologies

- Obtain in-use operational experience to
  - Establish life-cycle capital and operating costs
  - Establish emission benefit and cost effectiveness
  - Demonstrate durability and reliability
  - Facilitate selection of best technology
- Performance Goals
  - Range similar to diesel engines
  - On-demand vessel operation
  - Life-cycle cost similar to diesel engines
    - Capital cost: $200-$600/hp (11 repower projects)
    - Operating cost: $0.2-$0.3/hp-hr

Deployment Challenges

- CHC Industry/Market
  - Numerous vessel/engine configurations
  - Engine duty cycle varies by vessel type
  - Low turnover (20+ year life)
  - Small number of vessels (4,000)
  - Technology provider must team with vessel builder
  - Higher cost due to individual configurations

Deployment Challenges

- Technical
  - Each vessel is unique
  - Weight and space limitations
  - Scalability and modularity
  - Integration/optimization of retrofit/repower technologies
  - Infrastructure for alternative fuels or shorepower

Summary CHC Assessment

- Best technology depends on vessel type
- Turnover of vessels is slow (<200/year)
- Potential reductions

Potential reductions	NOx	PM	GHG
Lower emission engines	50-80%	30-70%	--
Tier 2 to Tier 4 retrofit	85-90%	85-95%	--
Alternative fuels	--	15-30%	--
Diesel electric hybrid	20-25%	20-30%	20-30%
Fuel cells	100%	100%	100%
Solar/wind	depends on vessel/technology		
Efficiency improvements	5-15%	5-15%	5-15%

- Deployment depends on:
  - Successful demonstration projects
  - Incentives/regulations for zero emission technologies
  - Infrastructure for alternative fuels and shore power

Contacts

Randall Pasek – SCAQMD
rpasek@aqmd.gov
(909) 396-2251

Renee Littaua – CARB
rlittaua@arb.ca.gov
(916) 324-6429