Lloyd's Register Educational Trust

UNIVERSITY OF Southampton

Green Ship Design & Technology

by

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The LRET Research Collegium
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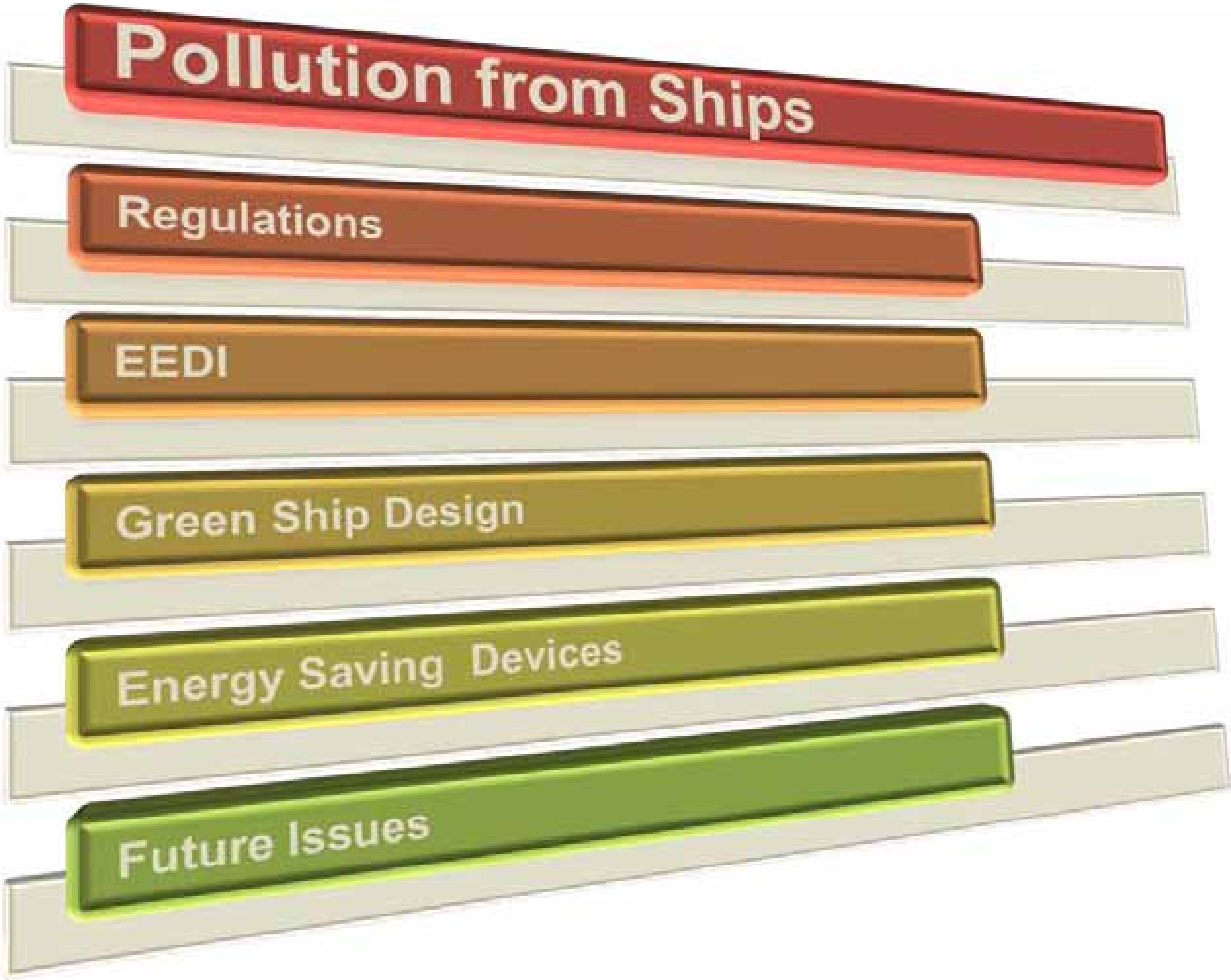

Pollution from Ships
Regulations
EEDI
Green Ship Design
Energy Saving Devices
Future Issues

Pollution from Ships

Tokyo Protocol (1997)
MEPC(2008)

→ Regulations by IMO & MARPOL

Key Actions by IMO

Ship Design:
- **EEDI(Energy Efficiency Design Index)**

Ship Operation:
- SEEMP(Ship Energy Efficiency Management Plan)
- **EEOI(Energy Efficiency Operational Indicator)**

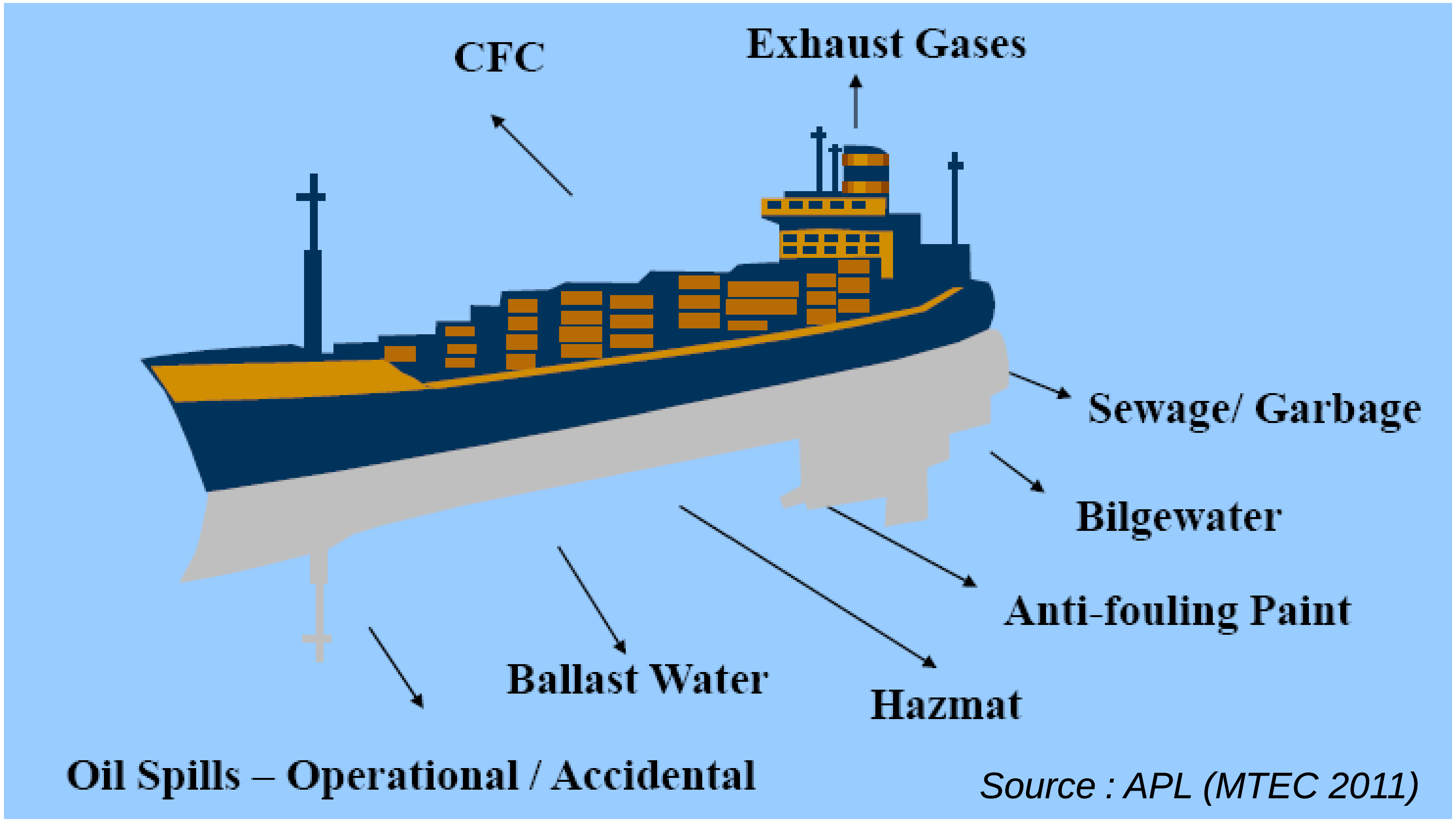
Ship Market:
- MBM(Market-Based Measure, Market-Based Mechanism)

Pollution from Ships

Air pollution on voyage	Water pollution on voyage	Ground pollution on voyage	Pollution on ship recycling
SOx	Waterproof oil	Precipitates	Paint
NOx	Bilge water	Wastes	Plastic
GHG*	Cooling water	Chemical residues	Electrical product
PM*	Grey water	Oil residues	Sealed gas
VOC*	Antifouling materials		Chemical product
	Ballast water		
	Noise		

***GHG (Green House Gas; CO2)**
***PM (Particulate Matter)**
***VOC (Volatile Organic Compound)**

Environmental Aspects and Impacts



Pollution from Ships

Ship is the most efficient transportation in view of CO_2 emission

Pollution from Ships

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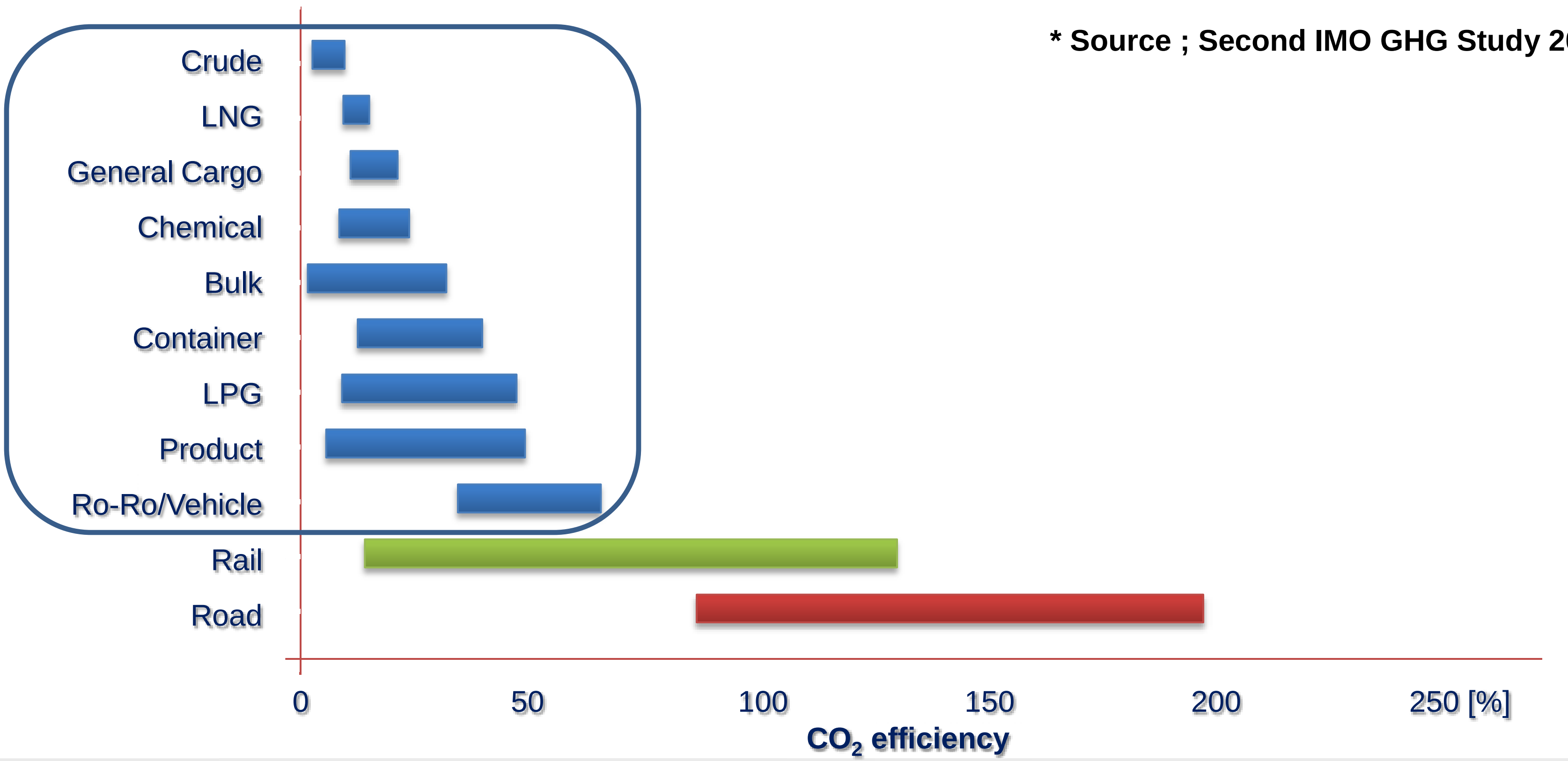


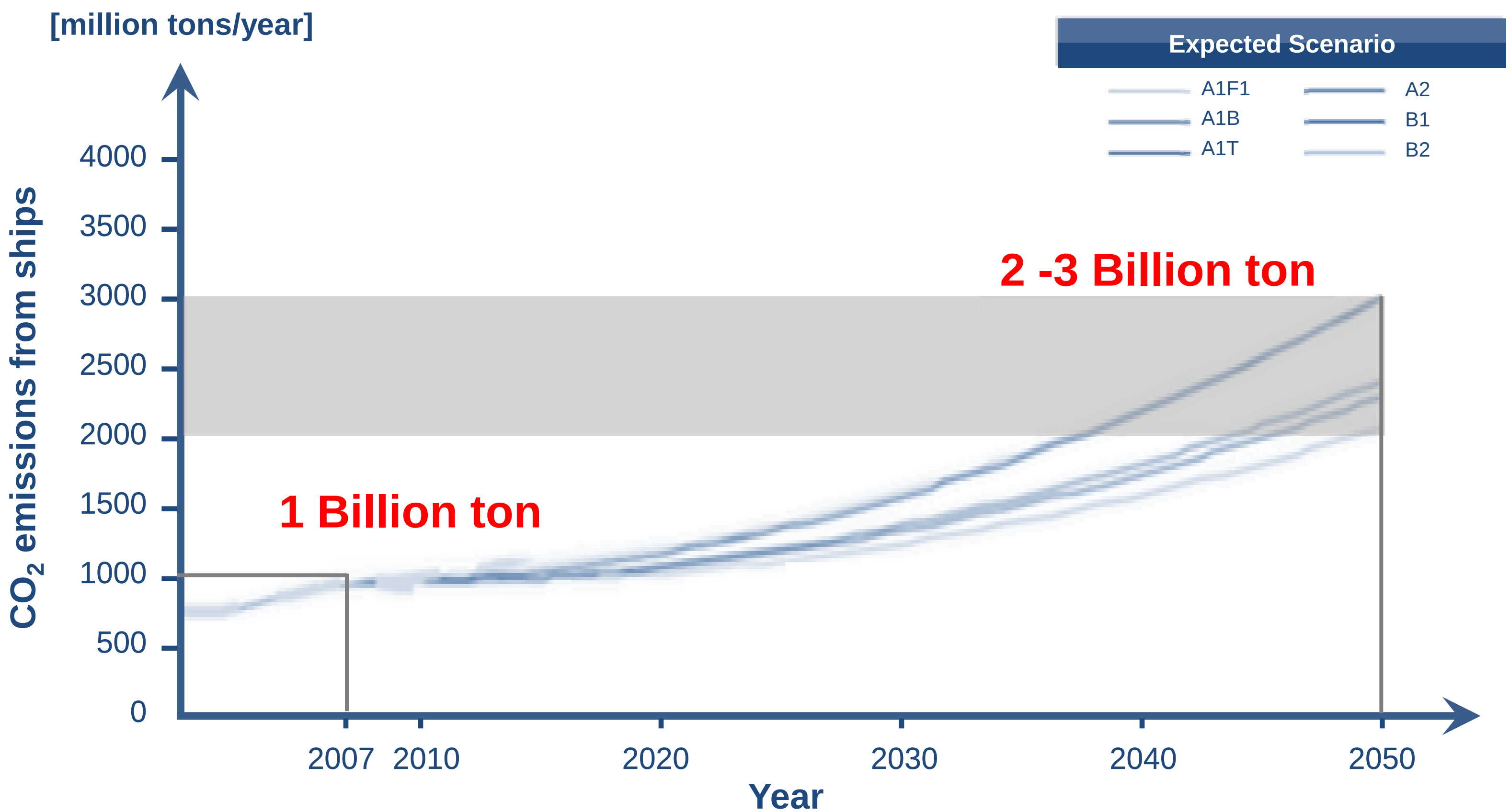
CO_2 efficiency = CO_2 / (tonne * kilometre) ≈ Fuel consumption

CO_2 = total CO_2 emitted from the vehicle within the period

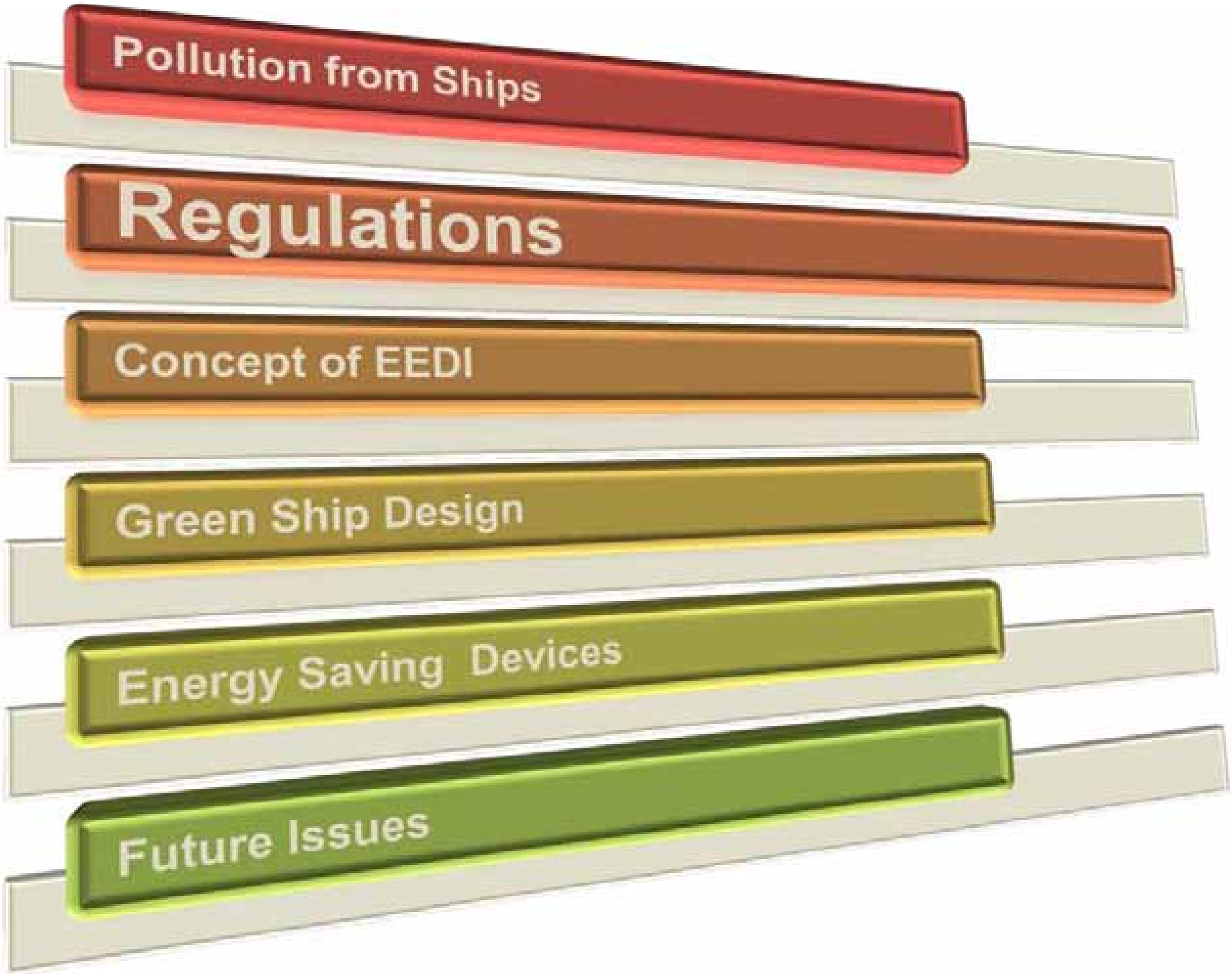
tonne*kilometre = total actual number of tonne-kilometres of work done within the same period

Pollution from Ships

GHG emissions from ships are predicted to be at least doubled by 2050



*** Source ; Second IMO GHG Study 2009.**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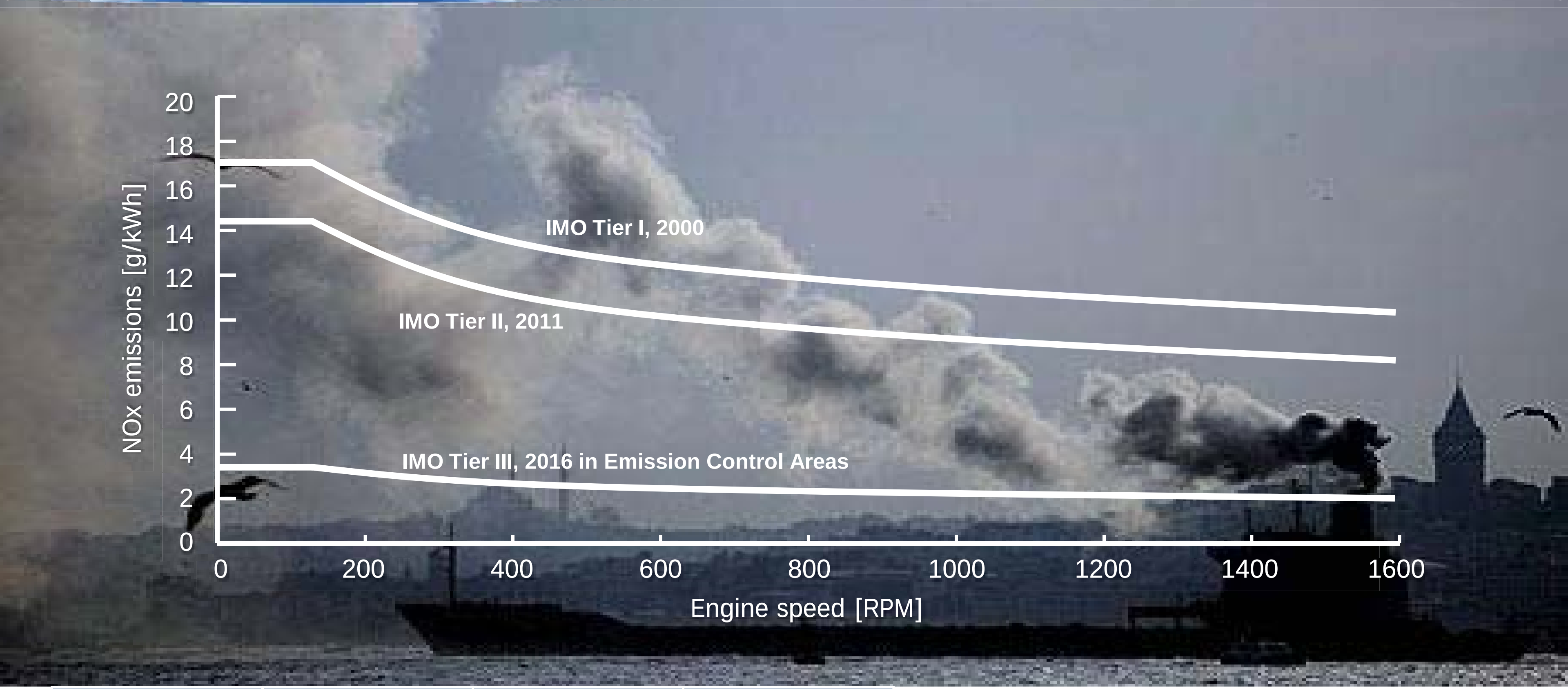
MARPOL 73/78 Regulations for Prevention & Control of Pollution from Ships

MARPOL ANNEX	Target
I	Oil
II	Noxious liquid substances in bulk
III	Harmful substances in packaged form
IV	Swages
V	Garbage
VI	Emissions

Emission Regulations - NOx



RPM	Tier 1 (current)	Tier Ⅱ (from 2011.1.1)	Tier Ⅲ (from 2016.1.1)
Under 130	17.0 g/kWh	14.4 g/kWh	3.4 g/kWh
130 ~ 2000	45.0×$n^{(-0.2)}$ g/kWh	44.0×$n^{(-0.23)}$ g/kWh	9×$n^{(-0.2)}$ g/kWh
Over 2000	9.8 g/kWh	7.7 g/kWh	2.0 g/kWh

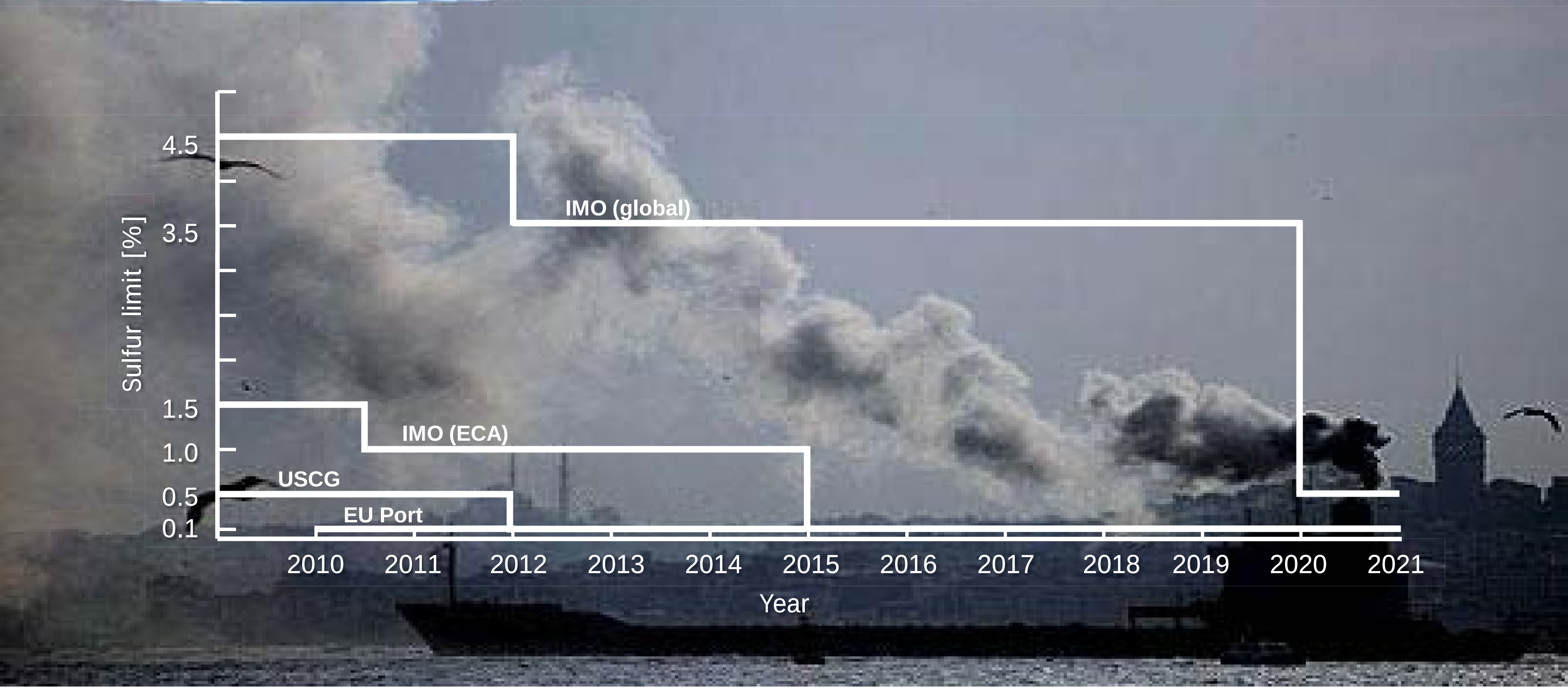
IMO NOx Tier II : Adopted on MEPC 58 (2008.10)

- After 1 January 2011 (Keel Laying)

IMO NOx Tier III : Tentative Assent

- After 1 January 2016 (Keel Laying)

Emission Regulations - SOx



Regulation or Area	Sulfur Content				
	2010		2012	2015	2020
Global Limit	4.5 %		3.5 %		0.5 %
IMO ECA	1.5 %	1.0 % (after 2010.07)		0.1 %	
EU Port	0.1 %				
USCG (within 24NM)	0.5 %		0.1 %		

Residual Fuel (IFO380 or LS380)

Distillate Fuel (MGO)

Emission Regulations – CO_2

EEDI (Energy Efficiency Design Index) – Technical Regulation

Design Specific

$$EEDI = \frac{CO_2\ Emissions\,(g/hr)}{DWT \times Speed\,(ton-knot)} = [g/ton-mile]$$

$$= \frac{\left\{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} C_{FMEi}\, SFC_{MEi}\, P_{MEi}\right)\right\} + \left(P_{AE}\, C_{FAE}\, SFC*_{AE}\right) + \left\{\left(\prod_{j=1}^{M} f_j \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{nWHR} f_{eff(i)}\, P_{AEeff(i)}\right) C_{FAE}\, SFC_{AE}\right\} - \left(\sum_{i=1}^{neff} f_{eff(i)}\, P_{eff(i)}\, C_{FMEi}\, SFC_{MEi}\right)}{\left(f_i\, Capacity\, V_{ref}\, f_W\right)}$$

Main engine

Aux. engine

Shaft motor

Waste heat recovery system

Energy saving device & design

Correction factor (by ship type)

Capacity factor

Transportation capacity & speed

Weather factor(wave, wind)

Goal of EEDI

- Mitigate CO_2 emissions
- Increase cargo carrying capacity
- Enhance speed performance

If using LNG as ship fuel,

➡ Reducing CO_2 emission of Main engine & Aux. engine

➡ Reducing EEDI

EEOI (Energy Efficiency Operational Indicator) – Operational Regulation

Voyage Specific

$$EEOI = \frac{CO_2\ Emissions\,(g)}{DWT \times Miles\,(ton-knot)} = [g/ton-mile]$$

$$= \frac{\left(\sum_{i=1} FC \times C_{carbon}\right)_{FuelType1} + \left(\sum_{i=1} FC \times C_{carbon}\right)_{FuelType2} + \left(\sum_{i=1} FC \times C_{carbon}\right)_{FuelType3} + \ldots}{\sum_{i=1} m_{cargo,i} \times D_i}$$

Carbon content of fuel

Fuel consumption

Distance of voyage

Transportation capacity

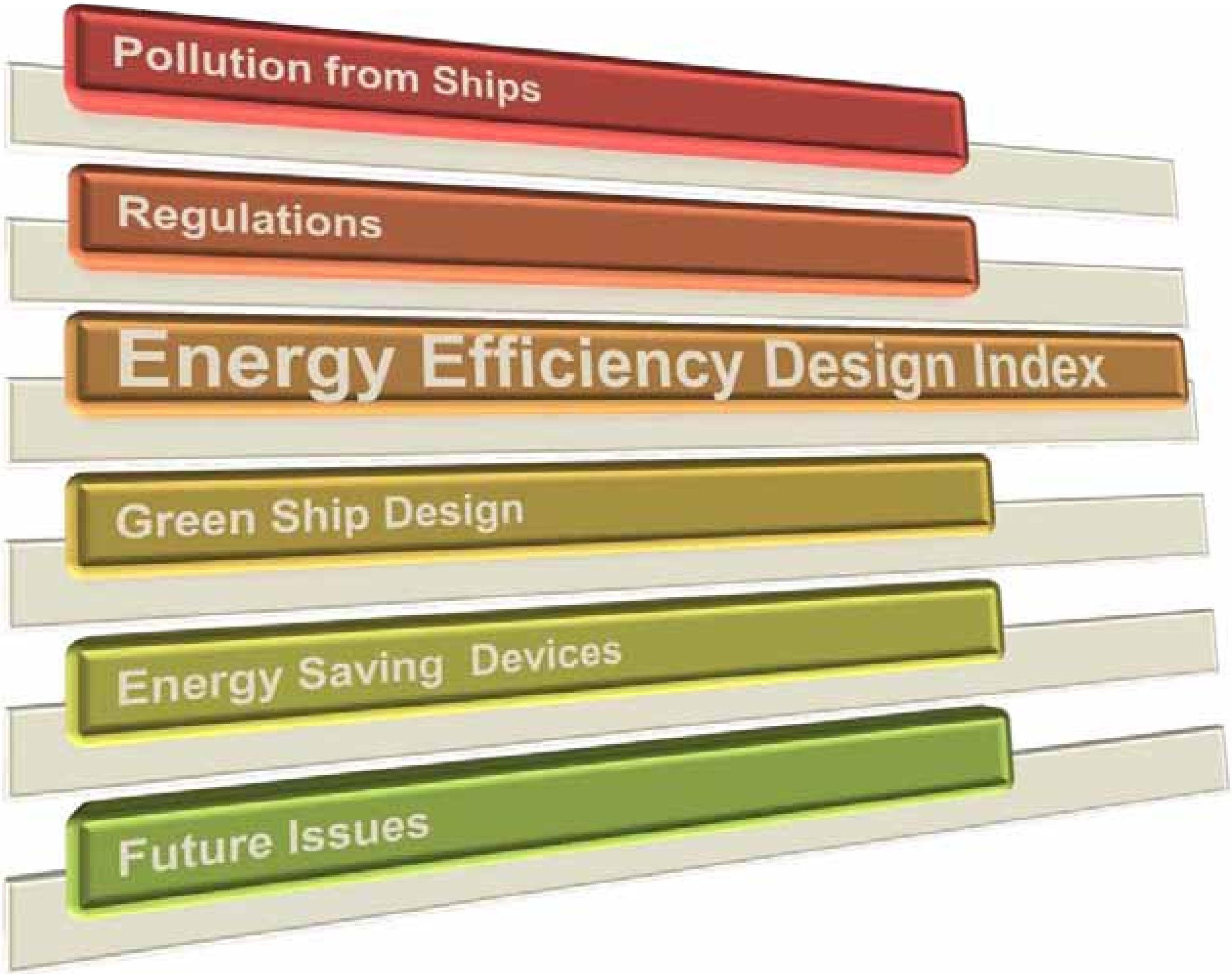
Effect of slow steaming

Ship speed	Engine power
100 % Service Speed	90% MCR
70 % Service Speed	30% MCR
50 % Service Speed	15% MCR

Service speed = guarantee speed at NCR with 15% sea margin

Slow steaming as 70 % of design speed

- ➡ Reducing fuel consumptions down to abt. 30 %
- ➡ Reducing EEOI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Key Words in Current Green Ship Technology

1. Technical Energy Saving and CO2 Reduction

- Hull optimization appendages
- New propulsion system
- Waste energy recovery and renewable energy utilization

2. Slow Steaming Operation

- Lower ship speed

3. Increase Ship Capacity

- Increase DWT

CO2 Reduction Potential by Known Technology and Practices

Category	Fuel/CO2 Saving	Combined	Combined
DESIGN (New ships)		10 ~ 50 %	25 ~ 75 %
Concept, speed &capability	2 ~ 50%		
Hull and superstructure	2 ~ 20%		
Power and propulsion systems	5 ~ 15%		
Low-carbon fuels	5 ~ 15%		
Renewable energy	1 ~ 10%		
Exhaust gas CO2 reduction	0%		
OPERATION (All ships)		10 ~ 50 %	
Fleet management, logistics &incentives	5 ~ 50%		
Voyage optimization	1 ~ 10%		
Energy management	1 ~ 10%		

*** Source ; IMO 2nd GHG Study**

EEDI

$$EEDI = \frac{CO_2\ Emissions\,(g/hr)}{DWT \times Speed\ (ton-knot)} = [g/ton-mile]$$

$$= \frac{\left\{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} C_{FMEi}\,SFC_{MEi}\,P_{MEi}\right)\right\} + \left(P_{AE}\,C_{FAE}\,SFC^{*}_{AE}\right) + \left\{\left(\prod_{j=1}^{M} f_j \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{nWHR} f_{eff(i)}\,P_{AEeff(i)}\right) C_{FAE}\,SFC_{AE}\right\} - \left(\sum_{i=1}^{neff} f_{eff(i)}\,P_{eff(i)}\,C_{FMEi}\,SFC_{MEi}\right)}{\left(f_i\ Capacity\ V_{ref}\ f_W\right)}$$

Main engine
Aux. engine
Shaft motor
Waste heat recovery system
Energy saving device & design
Correction factor (by ship type)
Capacity factor
Transportation capacity & speed
Weather factor(wave, wind)

$$EEDI = \frac{CO_2 \text{from propulstion} + CO_2\ \text{from Auxiliaries - Efficient use of energy}}{f_t \cdot (\text{DWT}) \cdot (\text{ship speed}) \cdot f_w}$$

EEDI Reduction

Propulsion power reduction

Lower resistance mechanisms
Hull form optimization
Course Optimization
Propulsion efficiency
Energy saving appendages
Propulsion machinery efficiency
Fuels with less carbon, e.g. LNG

Reduction of aux power

Reduce hotel load
HVAC
Lighting
Aux machinery efficiency
Fuels with less carbon

Clean energy and recovery

Waste Heat Recovery(WHR)
Wind power, e.g. Sails, Kite, Flettner rotors
Solar power
CO2 capturing

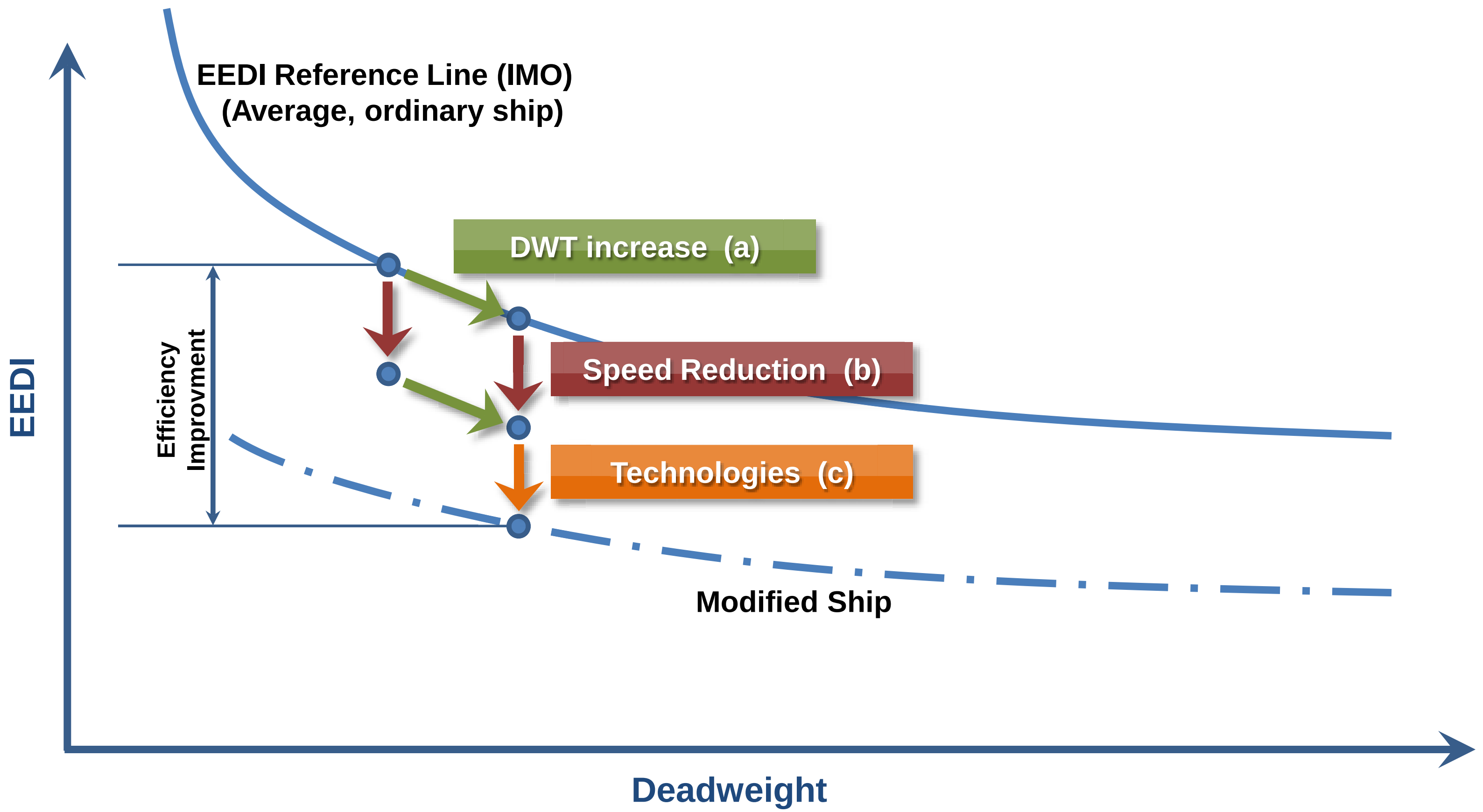
$$\text{EEDI} = \frac{CO_2 \text{ from propulstion} + CO_2 \text{ from Auxiliaries - Efficient use of energy}}{f_t \cdot (\text{DWT}) \cdot (\text{ship speed}) \cdot f_w}$$

Increase capacity

Higher speed with same power
Speed reduction
Reduce ship weight
Lighter material
Larger ship and/or payload
Structural optimization

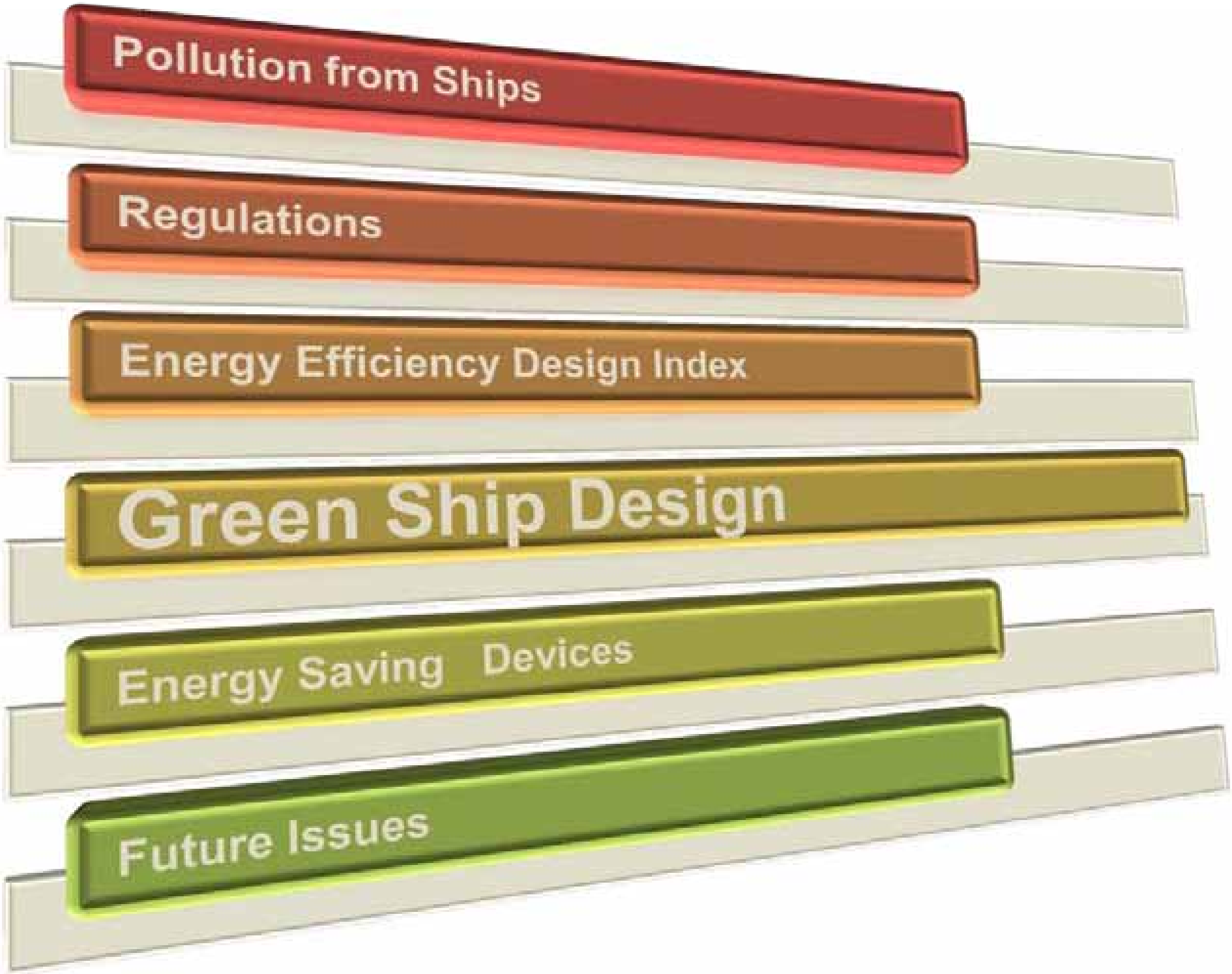
Key Strategy of EEDI Reduction

Speed reduction, Increased Capacity, Improved technology



EEDI Reduction Requirement by IMO

Ship Type	DWT	2013-2014	2015-2019	2020-2024	2025-
Bulk	Over 20K	0	10	20	30
	10K-20K	N/A	0-10	0-20	0-30
Gas Tanker	Over 10K	0	10	20	30
	2K-10K	N/A	0-10	0-20	0-30
Tanker	Over 20K	0	10	20	30
	4K-20K	N/A	0-10	0-20	0-30
Containership	Over 15K	0	10	20	30
	3K-15K	N/A	0-10	0-20	0-30
General Cargo Ship	Over 15K	0	10	15	30
	3K-15K	N/A	0-10	0-15	0-30
Refrigerated Cargo Ship	Over 5K	0	10	15	30
	3K-5K	N/A	0-10	0-15	0-30
Combination Carrier	Over 20K	0	10	20	30
	4L-20K	N/A	0-10	0-20	0-30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Estimated Time-Scale for Realization of Energy Efficiency Measures

	% reduction in CO_2 emissions/tonne-mile with respect to 2008 baseline				
	2010	2015	2020	2030	2050
Operational measures*	10	25	30	30	30
Technical measures# (excluding fuels)	-	5	10	20	30

* new & existing ships # newbuildings

Source: IMO – MEPC 58 / Info 14

We need quick action in ship operation. Technology development requires longer-term activity.

Green Ship Design Based on EEDI Evaluation

Expected CO2 Reduction in Different Methods

Energy	LNG Fueled Propulsion	23%
Design	Optimized Hull Form Design High Efficiency Propeller Design Bulbous Bow Optimization	2~3%
Device	Shaft Generator	1%
	Pre-Swirl Stator (PSS), Ducted PSS, Rudder Bulb Fin	3~6%
	Waste Heat Recovery System (WHRS)	3~4%
	NOx Reduction Device, SOx Reduction Device	
	Air Cavity System, Micro Bubble	7~10%
Material	Advanced A/F Paint	2~5%
Operation	Trim Optimization	3~4%
	Optimum Weather Routing	4~5%

Resistance Components of Commercial Ships

Components	% in calm water
Wave resistance	5~30%
Air (wind) drag	1~5%
Frictional drag	60~80%
Form drag	10~30%

Wave resistance, Air (wind) drag → Increases in actual sea condition: 10~50%

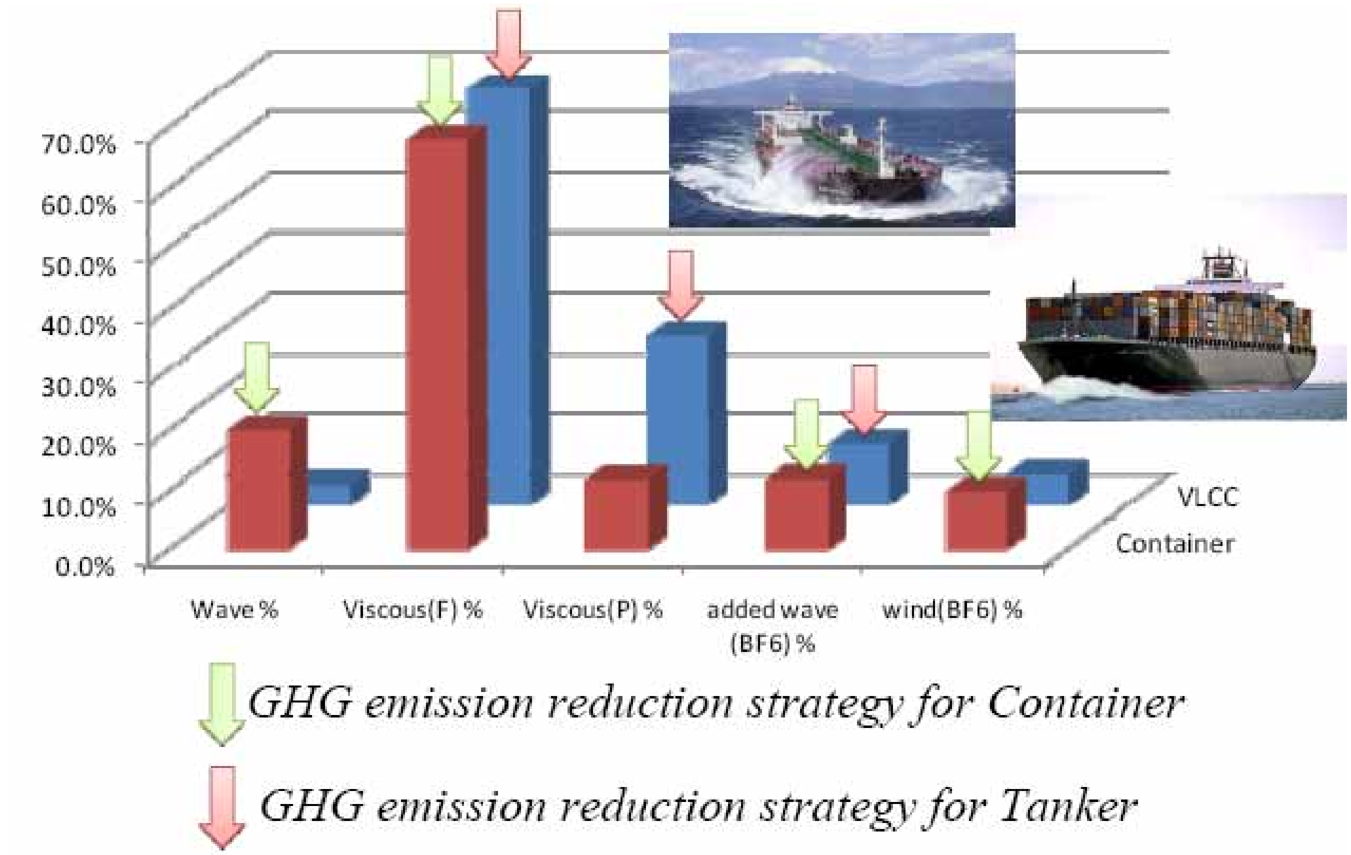
Frictional drag → Effective, but hard to reduce

Form drag → Hull design optimization

Strategy should be different for different ship types.

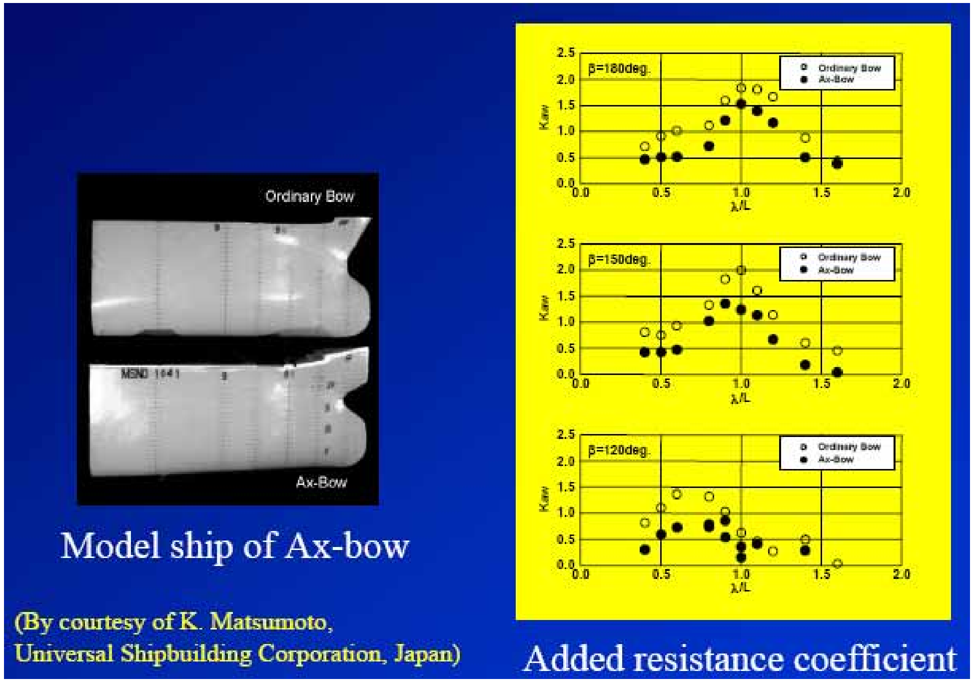
Strategy Example: VLCC (15kt) and Containership (22.5 kt)

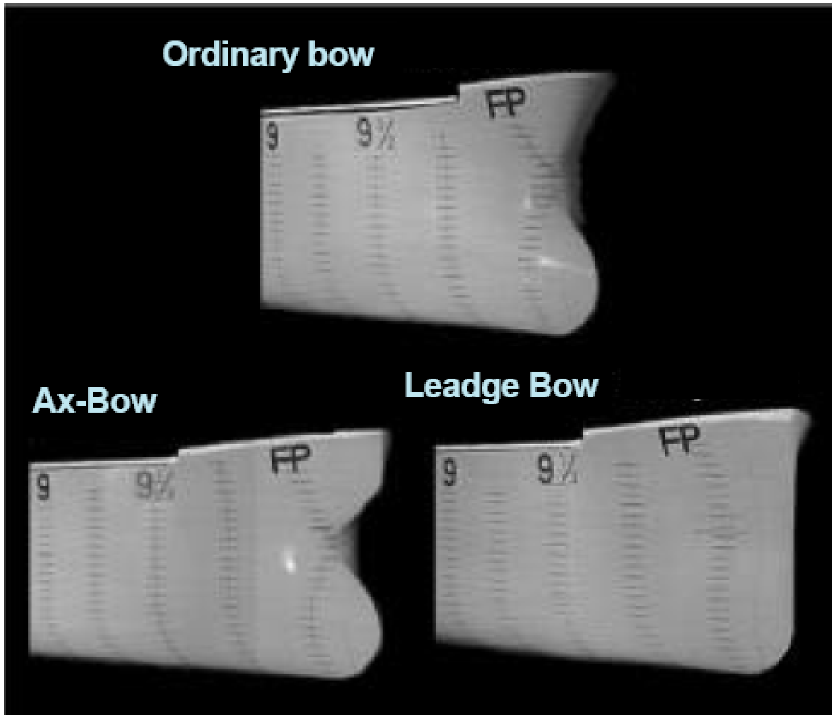
(N. Sasaki, NMRI)



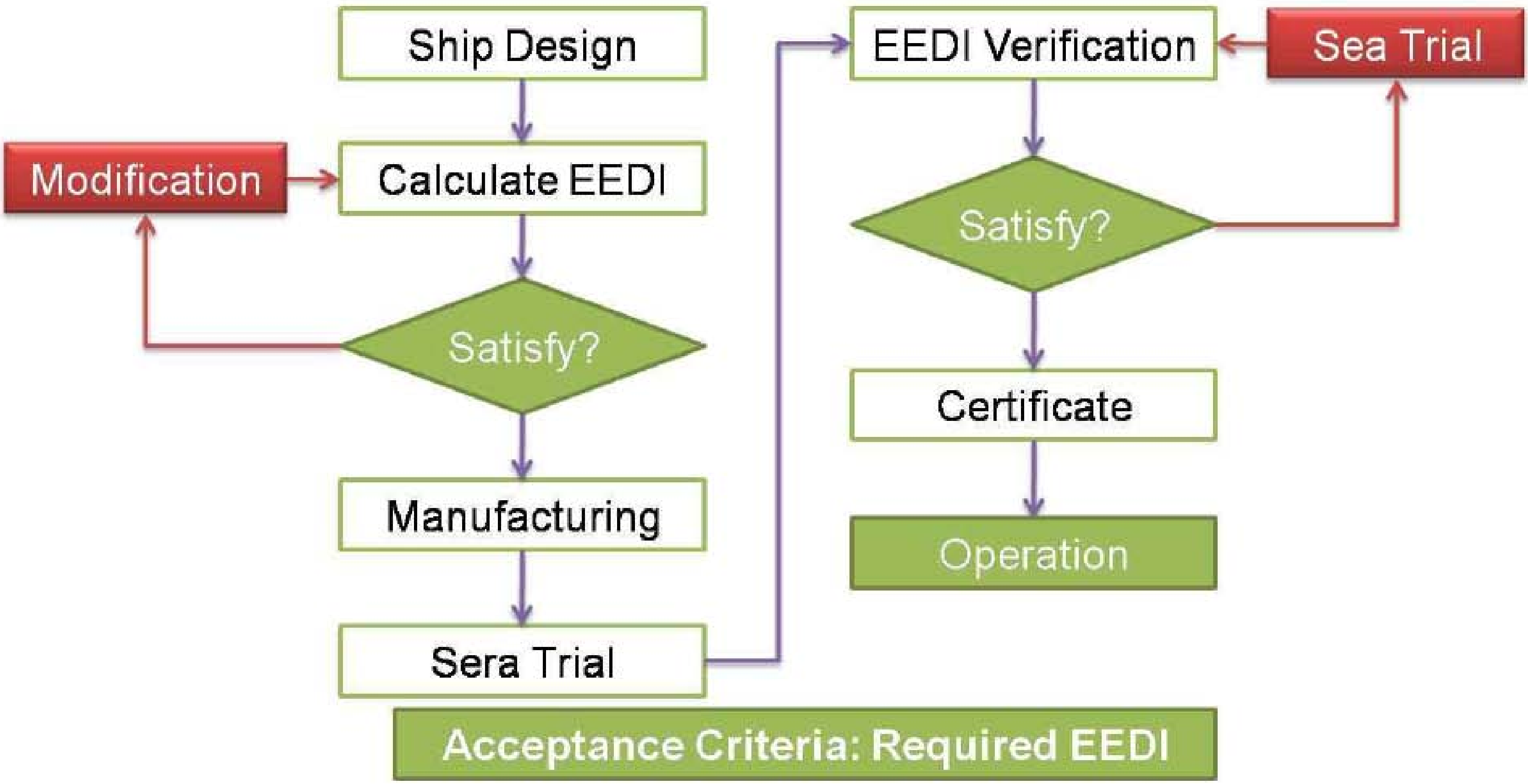
Hull form design to reduced added resistance

- Added resistance is a key parameter in power reduction in waves.
- Optimum hull form design is needed in the viewpoint of added resistance.





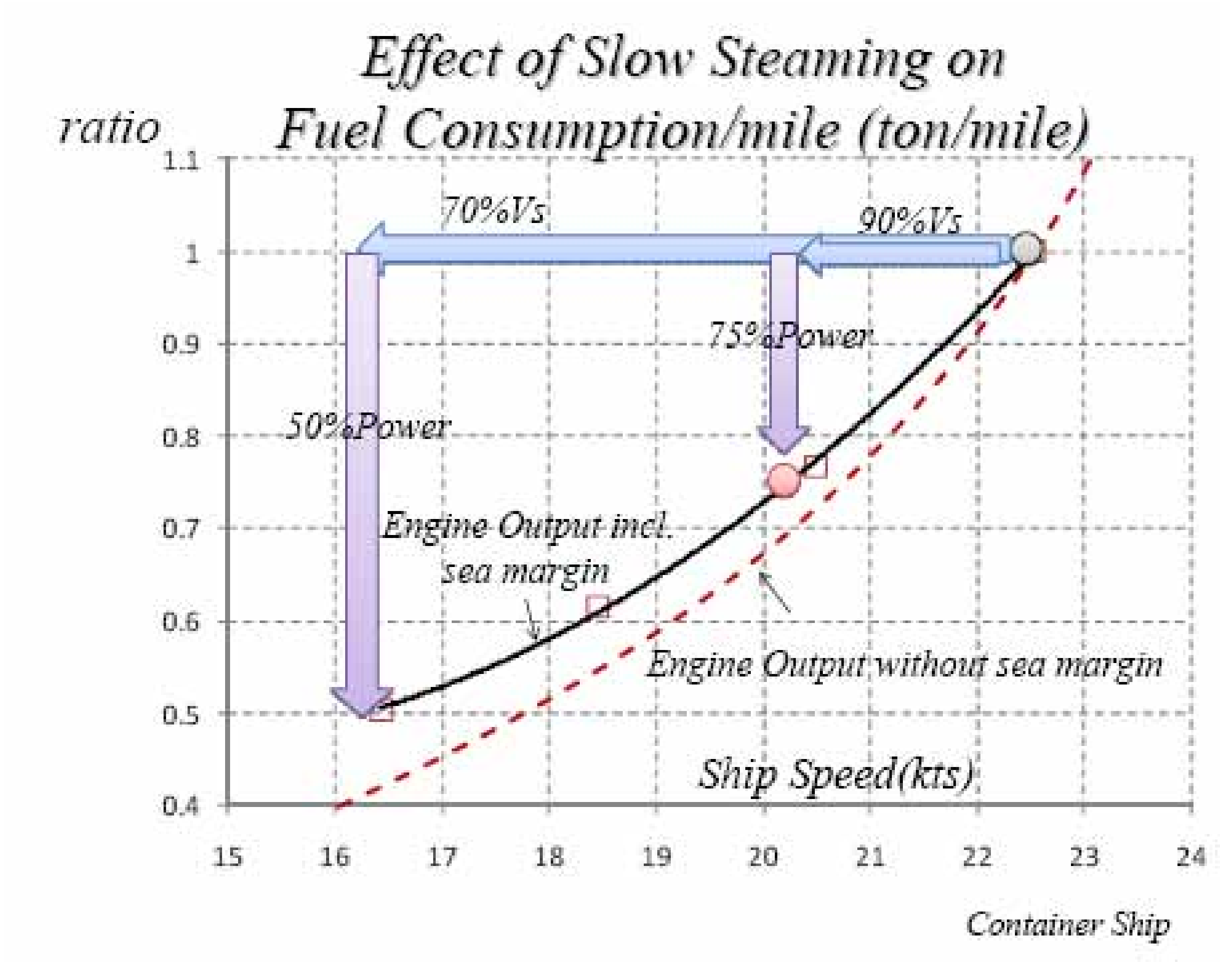
Ship Design Procedure based on EEDI Concept



Green Ship Design Based on EEDI Evaluation

Strategy of Operation (e.g. Lloyd's Register)

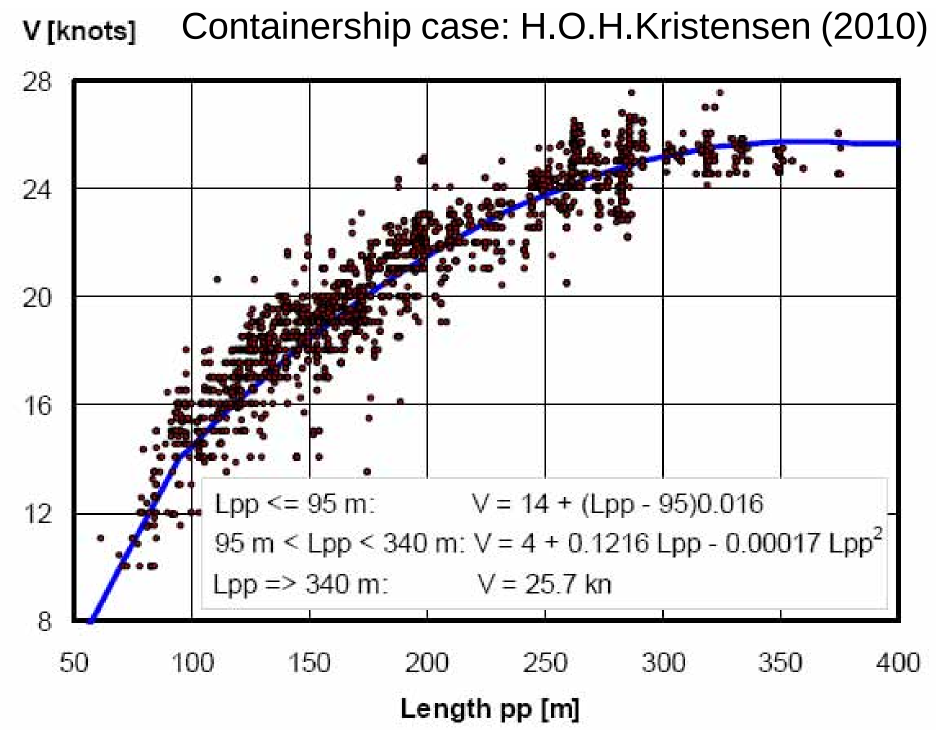
Effects of Slow Steaming

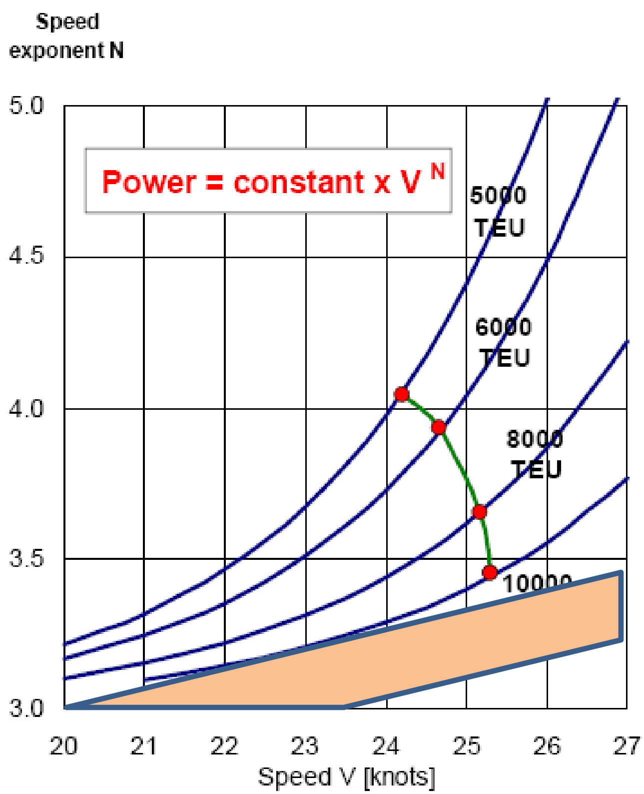


Source: N. Sasaki (NMRI)

Effects of Slow Steaming

$$EEDI \propto Speed^{N-1}$$





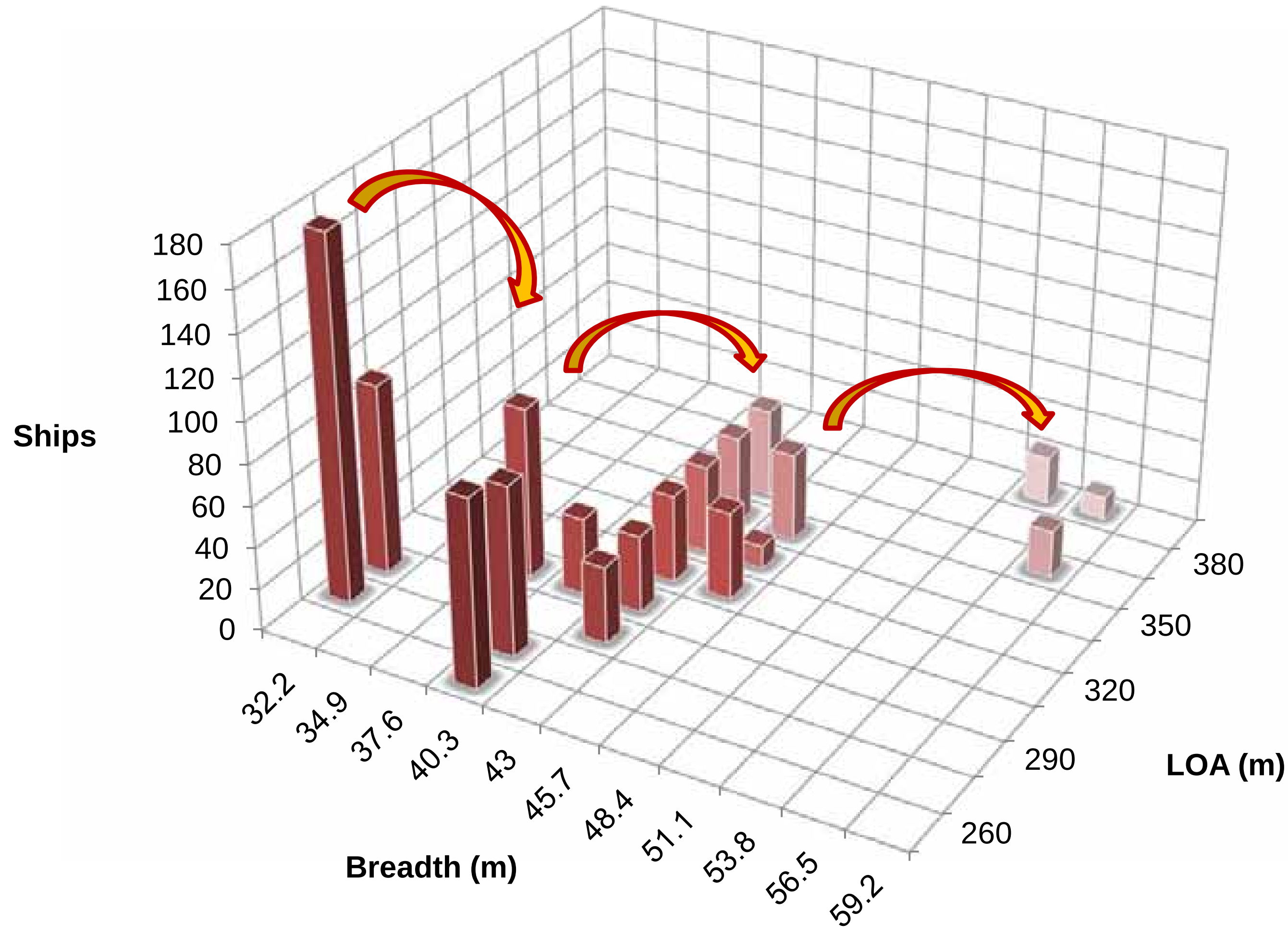
Reduction of 3 knots will reduce about 20~30% of EEDI and 40~50% of FOC.

Green Ship Design Based on EEDI Evaluation

Generation of Containerships

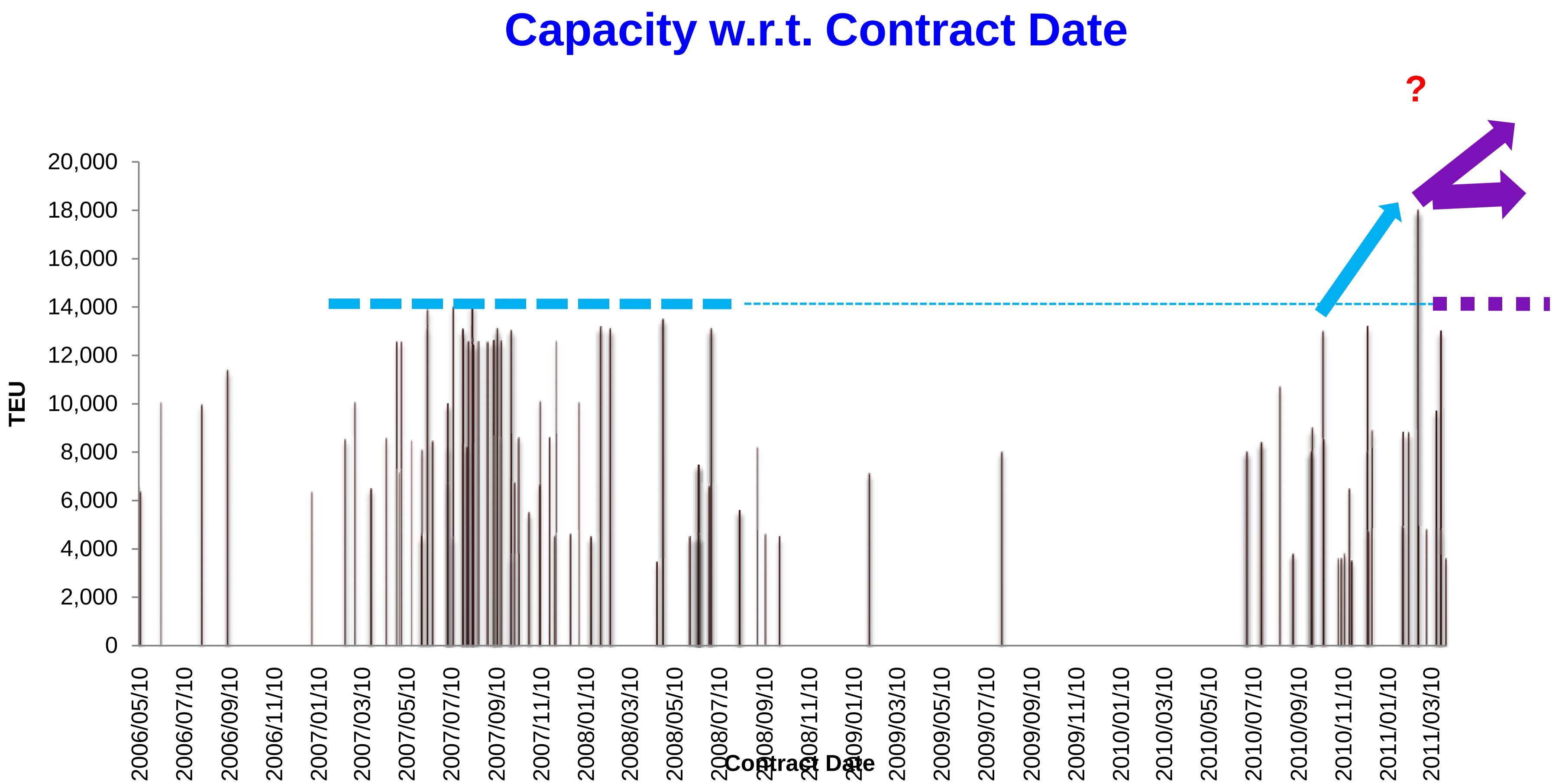
Generation	Length	TEU	Category
1 (1956~1970)	~200m	~800	
2 (~1980)	~215m	~2,500	
3 (~1988)	~290m	~4,000	 ***Panamax Class***
4 (~2000)	~305m	~5,000	 ***Post Panamax Class***
5 (~2005)	~335m	~8,000	 ***Post Panmax Plus Class***
6 (~2010)	~400m	~14,500	 ***New Panamax***
7 (2011~)	~440m ?	~20,000?	 ***Ultra Large***

Trend of Ship Size



Delivered in 2000~2008 (2003 is missed)

Containership Orderbook



A New Breakthrough of Capacity

http://en.wikipedia.org/wiki/Container_ship#cite_note-unctad56-45

Largest ships

[edit]

Main article: List of largest container ships

Economies of scale have dictated an upward trend in sizes of container ships in order to reduce costs. However, there are certain limitations to the size of container ships. Primarily, these are the availability of sufficiently large main engines and the availability of a sufficient number of ports and terminals prepared and equipped to handle ultra-large container ships. Furthermore, the permissible maximum ship dimensions in some of the world's main waterways could present an upper limit in terms of vessel growth. This primarily concerns the Suez Canal and the Singapore Strait.

In 2008 the South Korean shipbuilder STX announced plans to construct a container ship capable of carrying 22,000 TEU,[71] and with a proposed length of 450 metres and a beam of 60 metres.[72] If constructed, the container ship would become the largest seagoing vessel in the world.[73]

Since even very large container ships are vessels with relatively low draft compared to large tankers and bulk carriers, there is still considerable room for vessel growth. Compared to today's largest container ships, Maersk Line's 15,200 TEU *Emma Mærsk*-type series, a 20,000 TEU container ship would only be moderately larger in terms of exterior dimensions. According to a 2011 estimate, an ultra-large container ship of 20,250 TEU would measure 440m x 59m, compared to 397.71 x 56.40m for the *Emma Mærsk* class.[74][56] It would have an estimated deadweight of circa 220,000 tons. While such a vessel might be near the upper limit for a Suez Canal passage, the so-called Malaccamax concept(for Straits of Malacca) does not apply for container ships, since the Malacca and Singapore Straits' draft limit of about 21 metres is still above that of any conceivable container ship design. In 2011, Maersk announced plans to build a new "Triple E" family of containerships with a capacity of 18,000TEU, with an emphasis on lower fuel consumption.[75]

Ten largest container ship classes, listed by TEU capacity [citation needed]

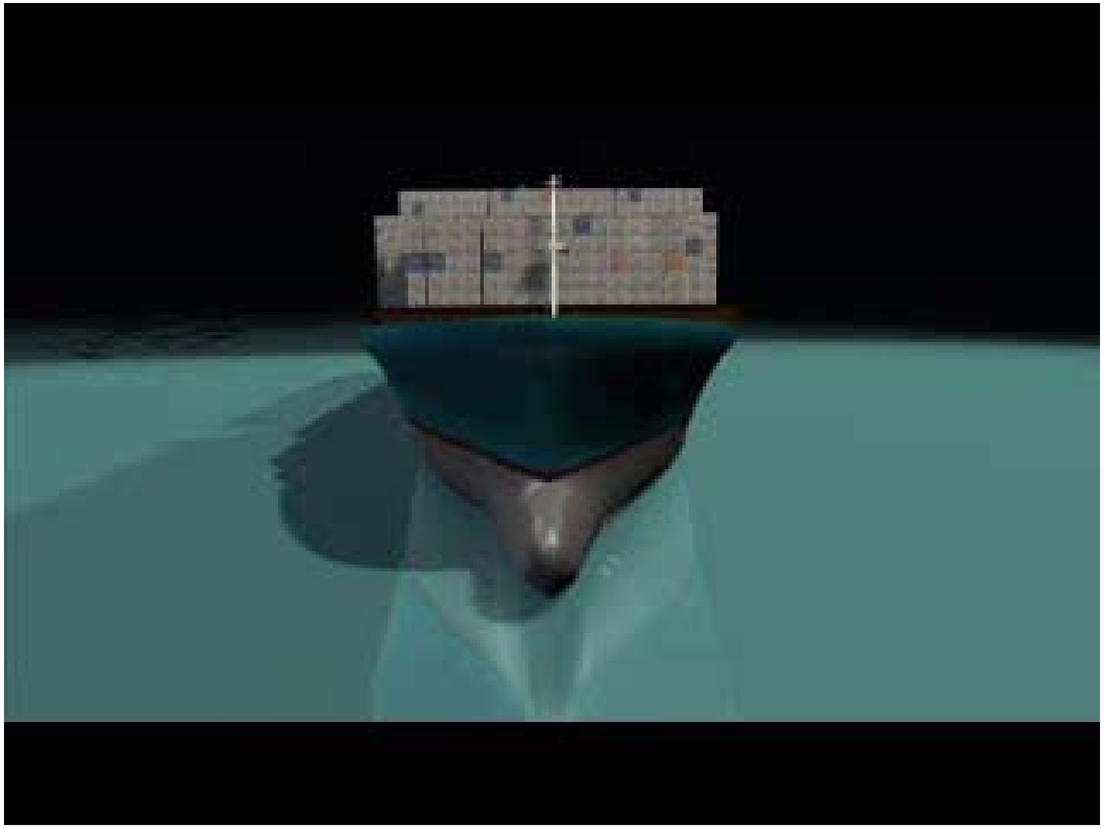
Built	Name	Class size	Maximum TEU	Sources
2006	*Emma Mærsk*	8	15,200–15,550	[13][55][56][57]
2009	*MSC Danit*	7	14,000	[58][59]
2009	*MSC Beatrice*	7	14,000	[60]
2008	*CMA CGM Thalassa*	2	10,960	[61]
2005	*Gudrun Mærsk*	6	10,150	[62]
2002	*Clementine Maersk*	7	9,600	[63][64]
2006	*COSCO Guangzhou*	5	9,500	[65][66]
2006	*CMA CGM Medea*	4	9,415	[67][68]
2003	*Axel Mærsk*	6	9,310	[69]
2006	*NYK Vega*	3	9,200	[70]

In the present market situation, main engines will not be as much of a limiting factor for vessel growth either. The steadily rising cost of fuel oil has prompted most container lines to adapt a slower, more economical voyage speed, of about 21 knots, compared to earlier top speeds of 25 or more knots. Subsequently, new-built container ships can be fitted with a smaller main engine. Engine types fitted to today's ships of 14,000 TEU are thus sufficiently large to propel future vessels of 20,000 TEU or more. Maersk Line, the world's largest container shipping line, nevertheless opted for twin engines (two smaller engines working to separate propellers), when ordering a series of ten 18,000 TEU vessels from Daewoo Shipbuilding in February 2011.[76] The ships will be delivered between 2013 and 2014.

Maersk Line ordered a series of ten 18,000 TEU vessels to Daewoo Shipbuilding in February 2011.

Youtube:

Maersk Line Triple-E Smarter design, with room for 18,000 containers



MAERSK

DSME
DAEWOO SHIPBUILDING & MARINE ENGINEERING CO.,LTD.

Green Ship EEDI Reduce Plan: Example of DSME

VLCC

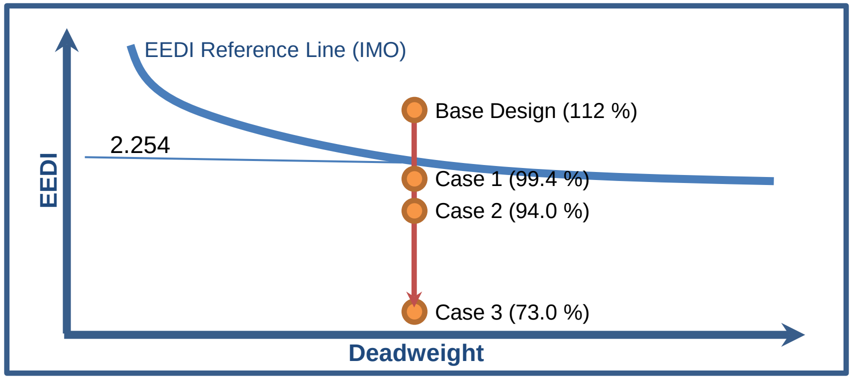
Dimension (Lbp x B x D x Td x Ts x Cb)
320 x 60 x 30.5 x 21 x 22.5 x 0.82

DWT (Ts) : 319,600 MT

Vs (Serv.) : 16.2 → 15.9 Kts

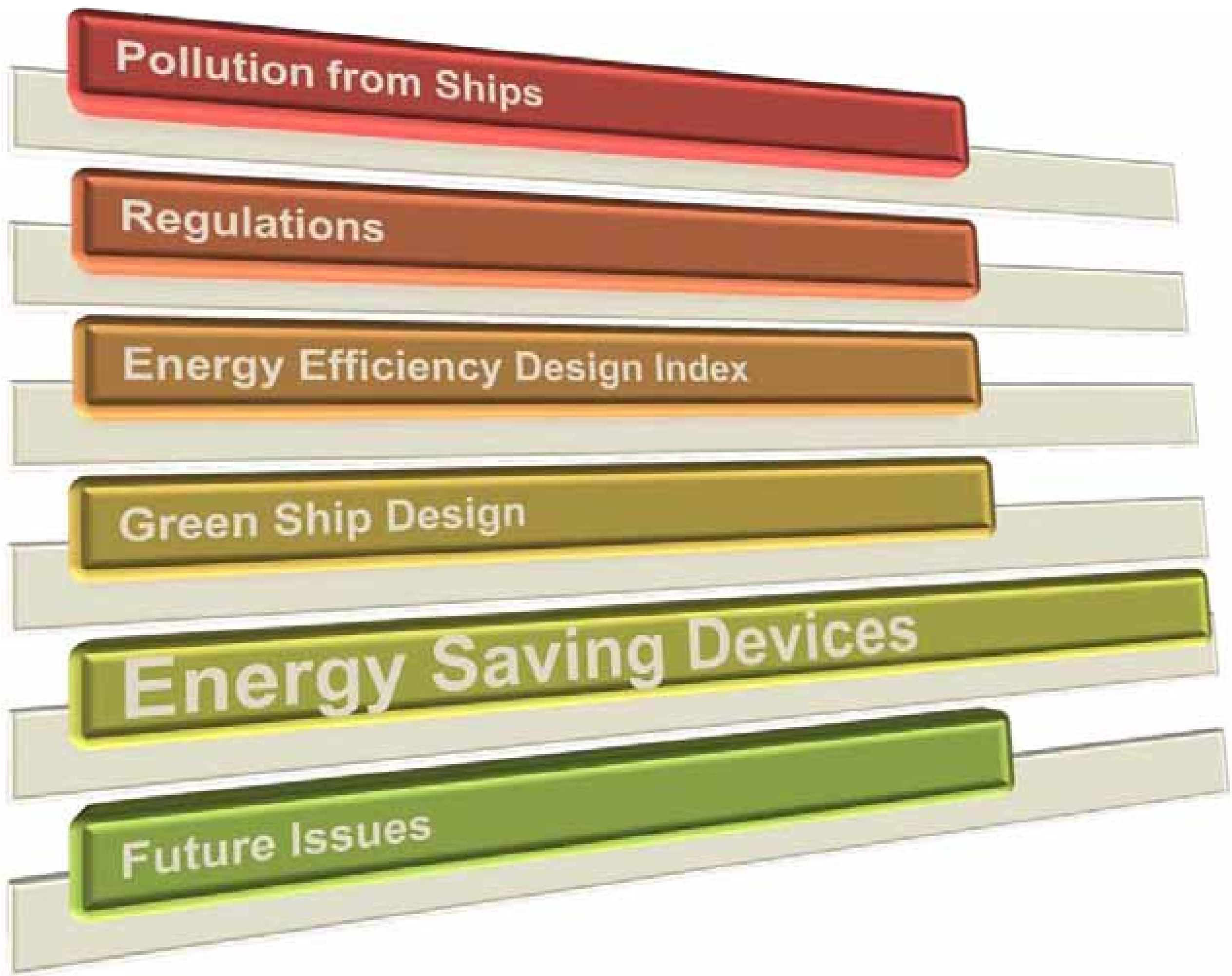
DFOC : 101.6 → 94.9 MT/day

Case 3) LFS design to be developed further



Parameter	Base Design	Improved (Case 1)	Improved (Case 2)	Improved (Case 3)
Applied Econologies	7S80MC-C8.2	←	←	7S80ME-C8.2-GI
	N/A(derated)	10 % derated	10 % derated	10 % Derated
	PSS	PSS	PSS + WHRS(1200kW)	PSS + LFS*
	Prop Dia. 10.0 m	←	←	←
MCR (kW) x RPM	29,260 kW x 78.0	26,330 kW x 75.3	←	←
EEDI speed (knots)	15.9	15.5	←	←
SFOC at 75% MCR (g/kWh)	168.1	166.1	168.1	141.2
CO2 Emission (g/h)	12,075,373	10,757,969	10,166,380	8,182,817
EEDI (g/ton-mile)	2.515	2.241	2.115	1.646
EEDI/Reference line (%)	112 %	99.4 %	94.0 %	73.0 %

*** LFS ; LNG Fueled Ship**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Energy Saving Devices

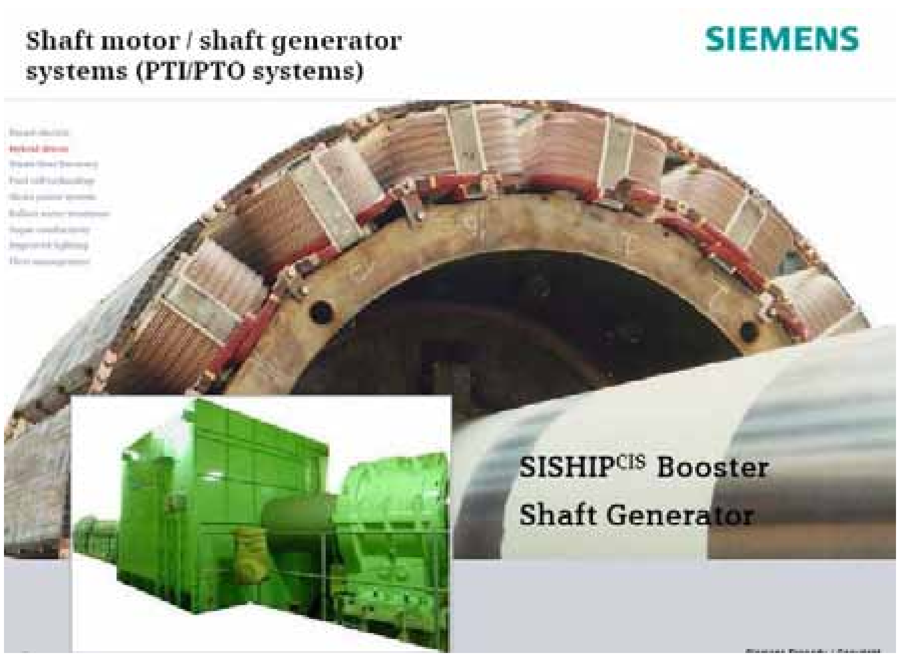
Shaft Generator	1%
Pre-Swirl Stator (PSS) Ducted PSS Rudder Bulb Fin	3~6%
Waste Heat Recovery System (WHRS)	3~4%
Air Cavity System, Micro Bubble	7~10%

Choice is dependent on ship type, cost, available space, etc.

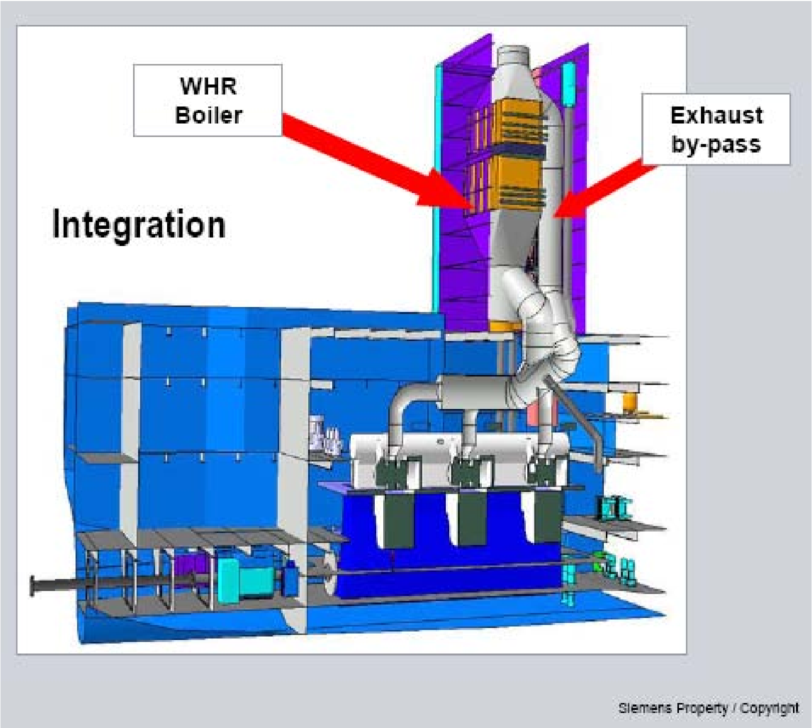
Performance is dependent on ship type, operation condition, device type, etc.

Higher FOC Performance, but Higher Ship Cost

Shaft Generator

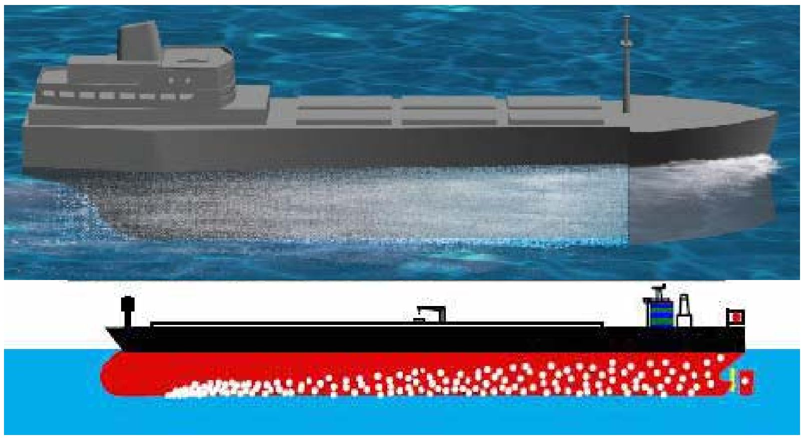


WHRS

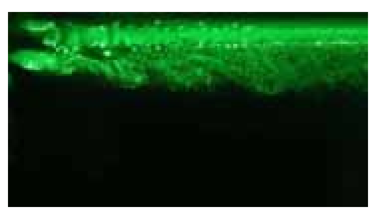


Shaft generator and WHRS of Siemens

Micro Bubble Injection



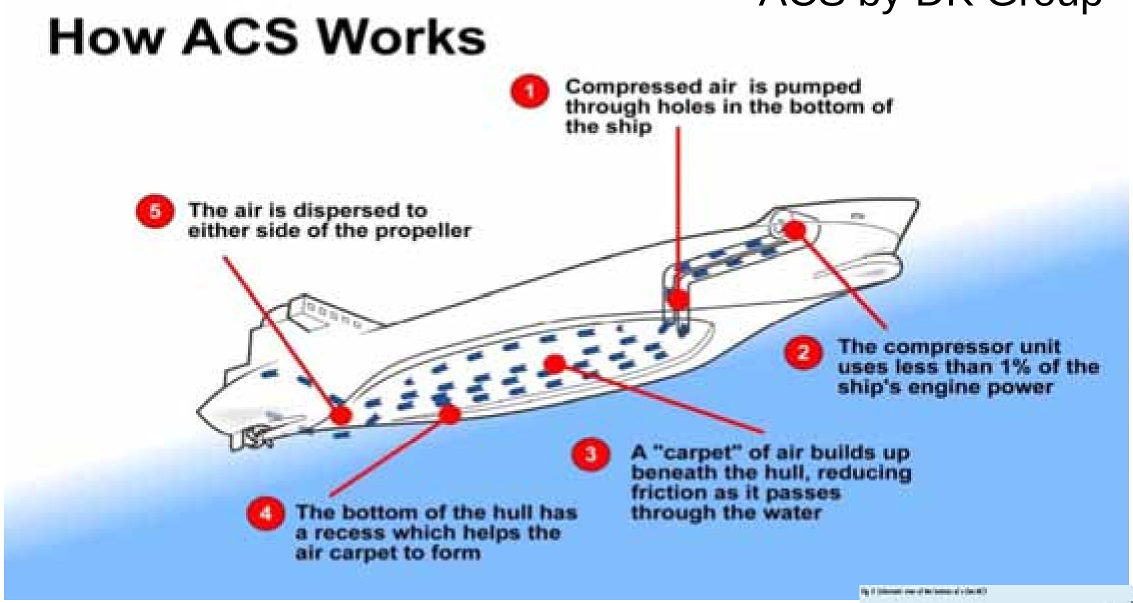
- Producing thin layer of bubbles
- Drag reduction by air bubbles
- The film of air generated by air injection on ship surface covered with very water repellent layer

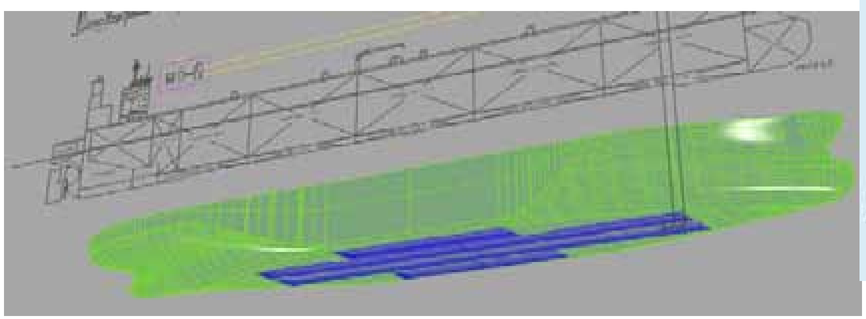


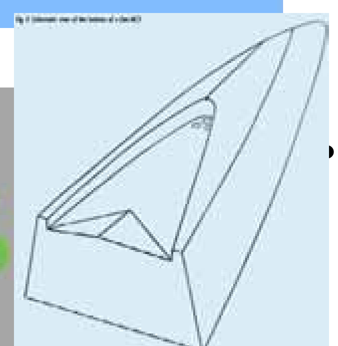
Reduction of viscous frictional drag

Air Cavity System

ACS by DK Group





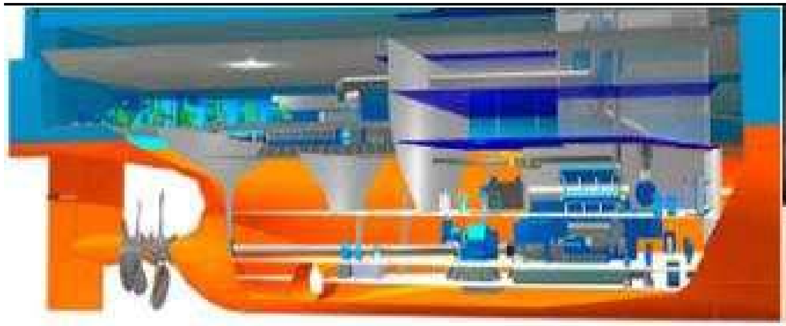


Potential up to 15 % CO2 reduction

- Pressured air injection on ship bottom
- Air pressure injection requires some additional power (1~3%), but significant drag reduction is expected.
- Pay-back time 2-4 years

Energy Saving Devices

Contra/Counter Rotating Propeller (CRP)



© KAMOME PROPELLER

© Mitsubishi Heavy Industry

- Recovery of rotating energy loss originated by a propeller through the use of a contra rotating propeller
- Improves propulsion efficiency by10% to15%
- Reduces cavitation
- Benefits mainly at cruising speeds
- Complicated design and higher costs

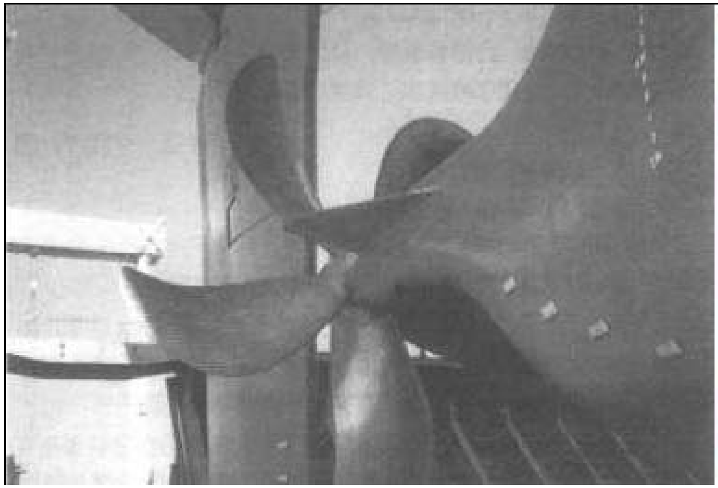
Hull appendages

- Typical concepts to increase propulsion efficiency
  - *Making uniform stern flow*
  - *Reducing rotating energy loss*
  - *Generating more thrust by appendage*
- Improves propulsion efficiency by 3% to 5%

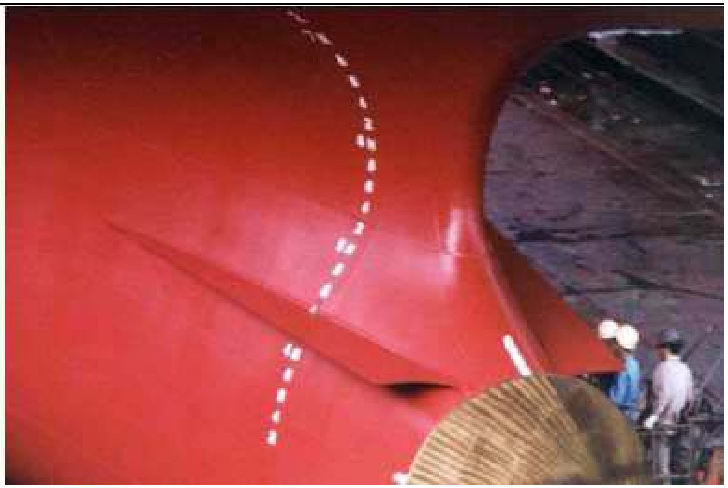
Pre-Swirl Stator (Daewoo Shipbuilding & Marine Engineering)

SAVER Fin (Samsung Heavy Industry)

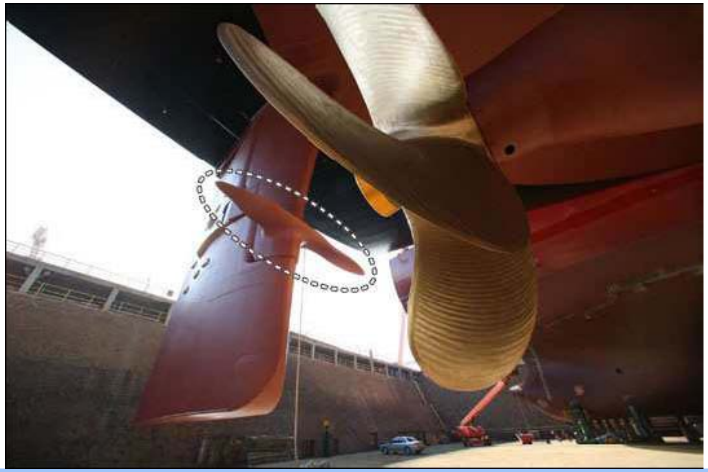
Hull appendages



Sumitomo's Fin



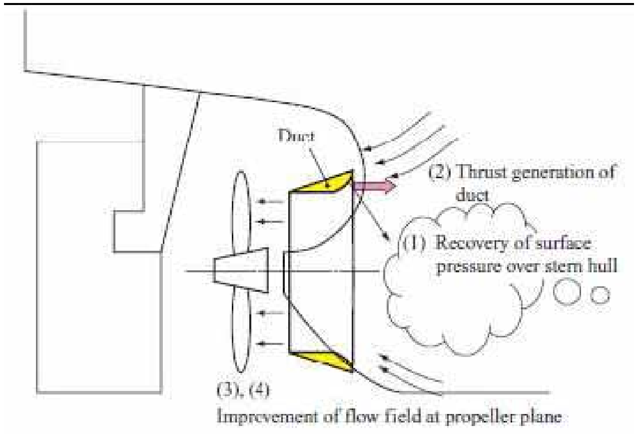
IHI's Fin



Thrust fin (Hyundai Heavy Industry)

Energy Saving Devices

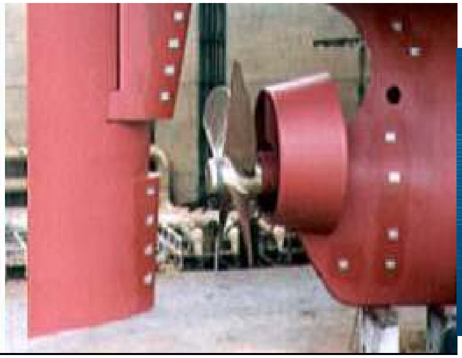
Duct Propeller



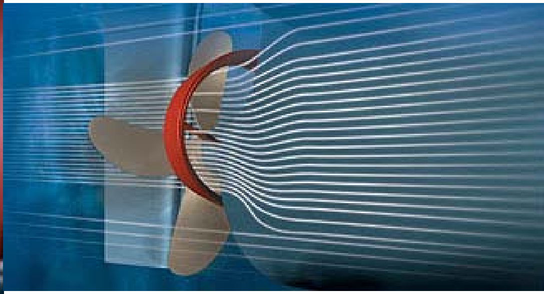
- Thrust gain by duct
- Increase propeller efficiency by making stern flow uniform
- Many variations in application
- Improves propulsion efficiency by 3% to 8%

SSD
(Super Stream Duct)

SDS
(Semi-circular Duct System)

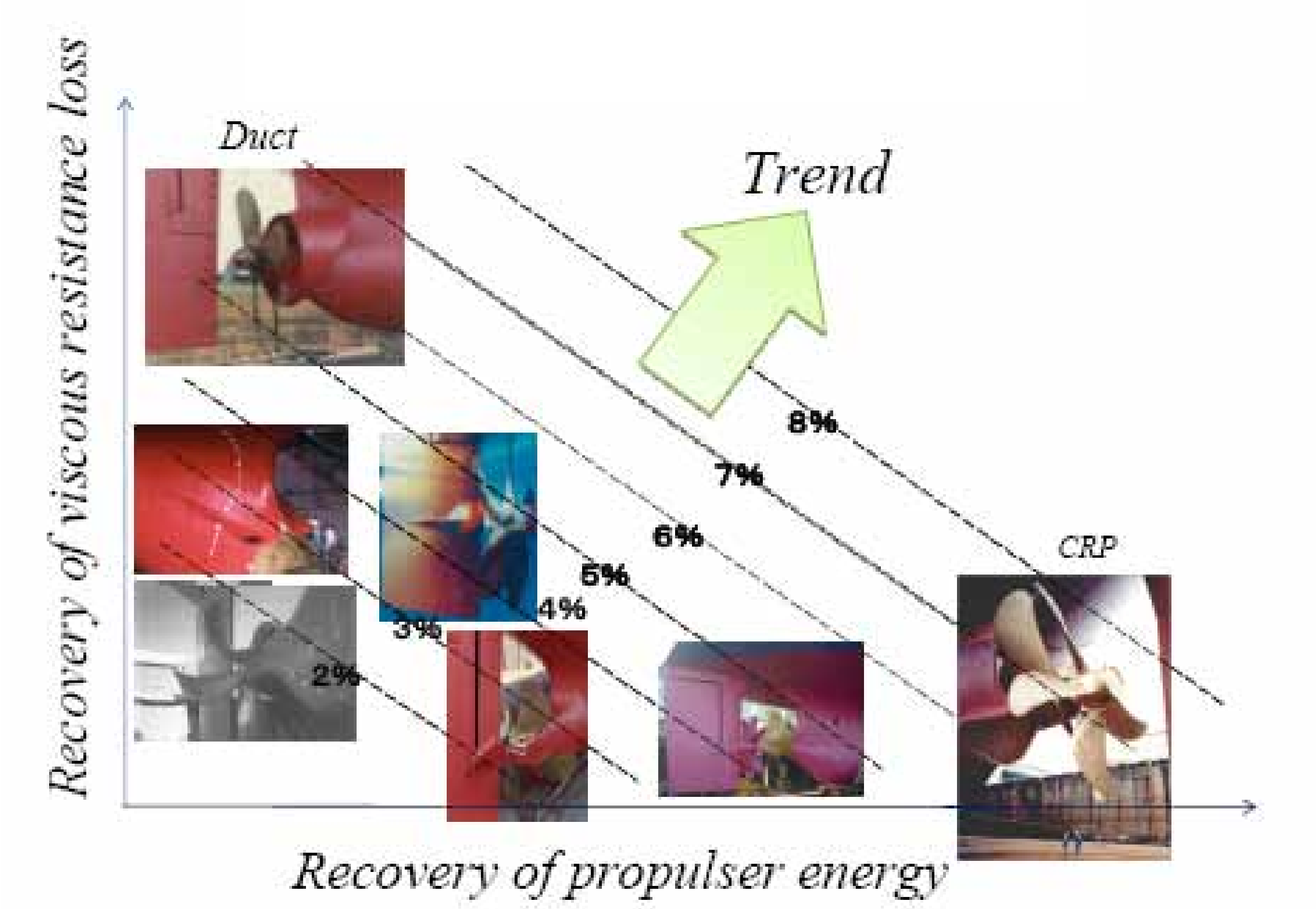


SILD
(Sumitomo Integrated Lammeneren Duct)



Mewis duct

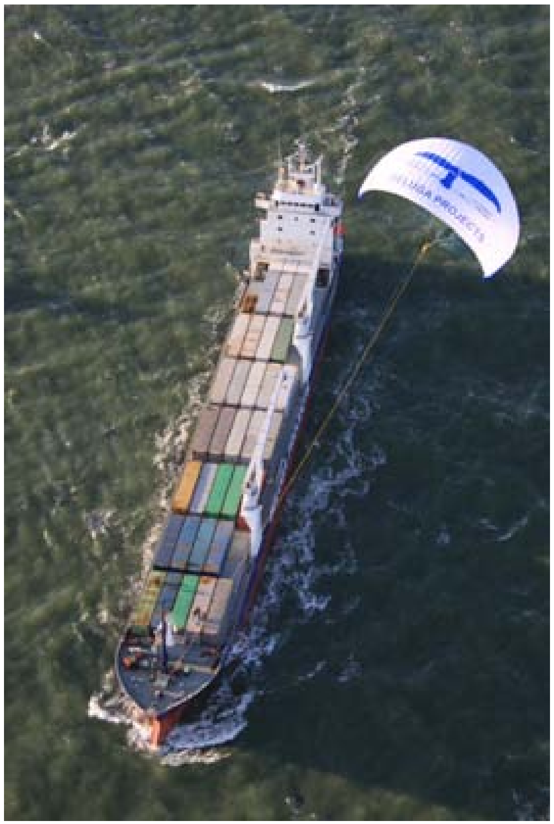
Typical Energy Saving Devices: Their Efficiency

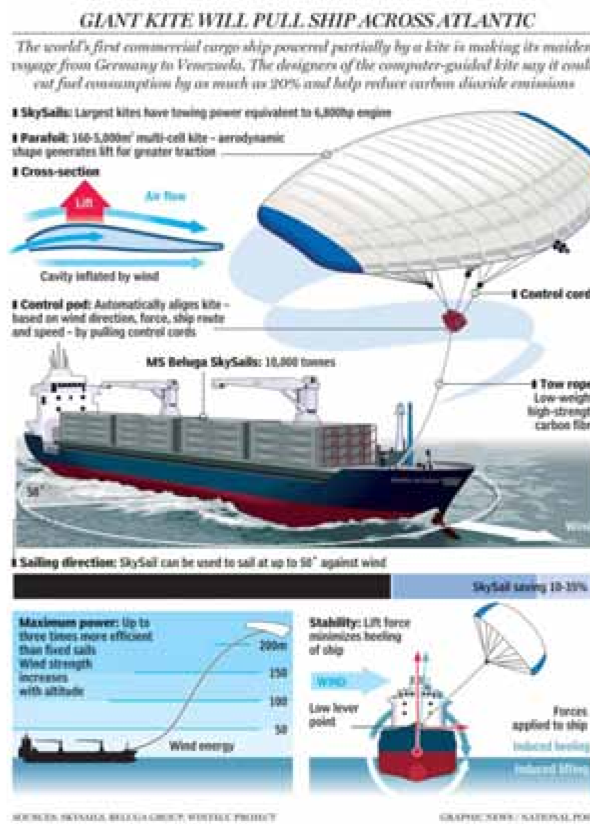


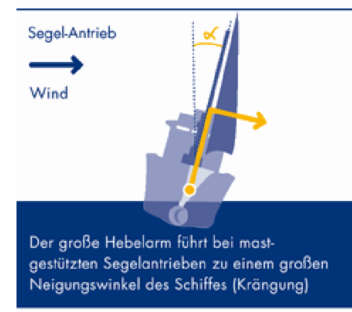
Source :N. Sasaki (NMRI)

Clean Energy Devices: Skysail

- Kite operated in 100~500m height
- Expect 10~30% fuel reduction


Ship with Skysails





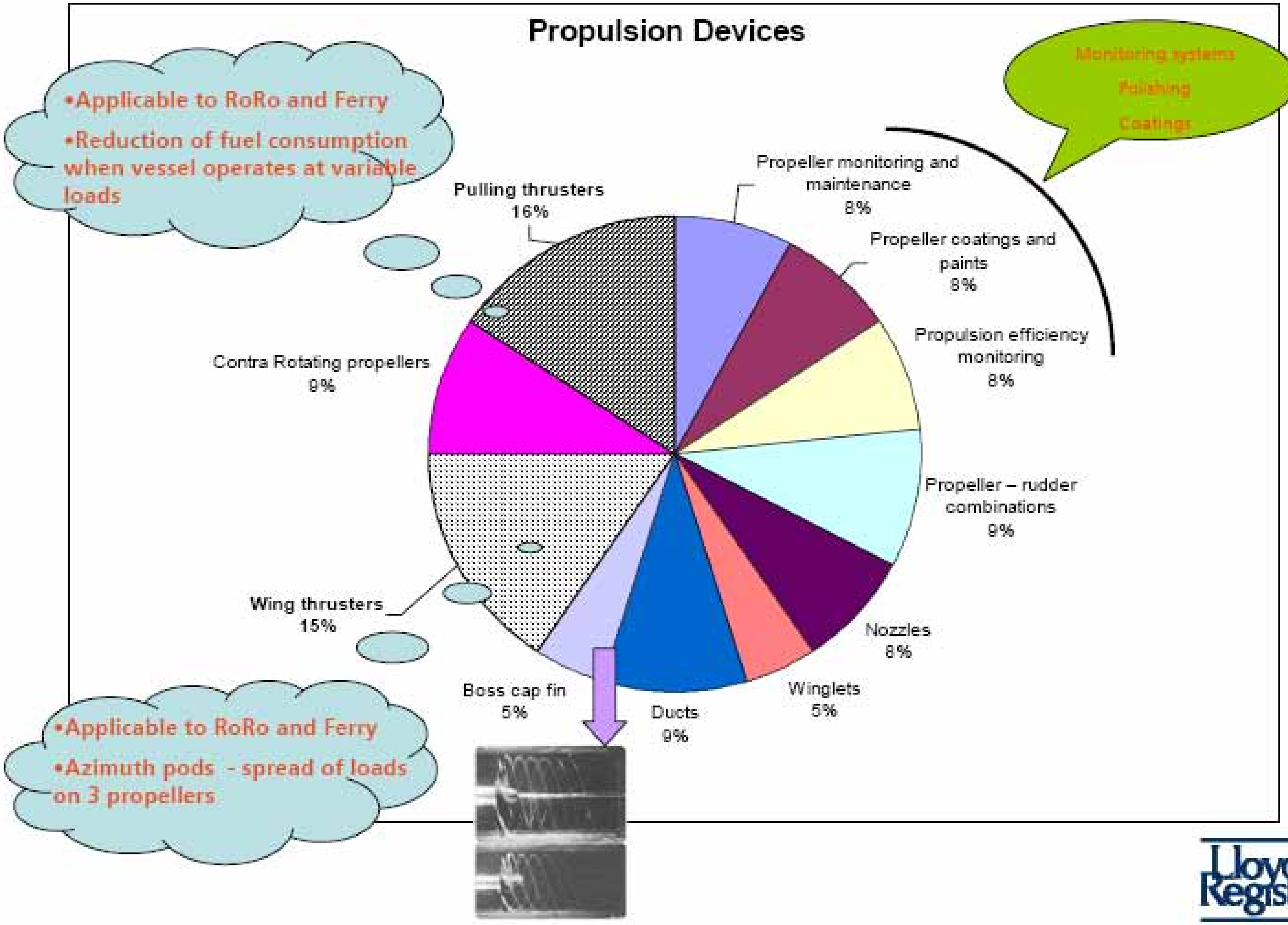
Clean Energy Devices: Solar Power

NYK Ship with solar cell

Concept design of AquaSailor with solar sail

Energy Saving Devices

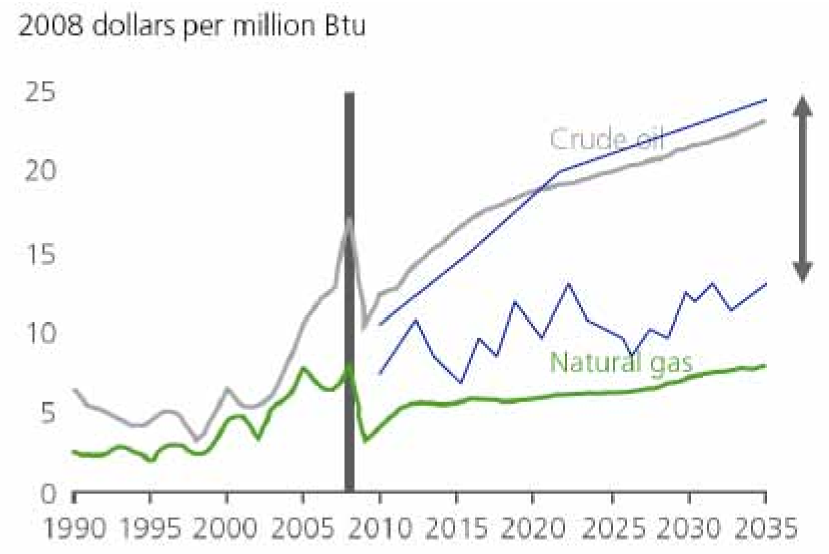
Strategy: e.g. Lloyd's Register



Lloyd's Register
LIFE MATTERS

Alternative Fuel/Energy for Ships: LNG as fuel

- Strong candidate for future propulsion engine
- Duel fuel: Diesel + LNG (ME-GI)
- Relatively cheap cost
- 15~25% Reduction of CO2
- Dramatic reduction of Nox, Sox, and air dust pollution
- e.g. 14,000TEU containership => 14M$/year reduction of fuel cost (DSME)



Ref. U.S. Energy Information Administration (EIA)

Energy Saving Devices

Alternative Fuel/Energy for Ships: Electric & Nuclear

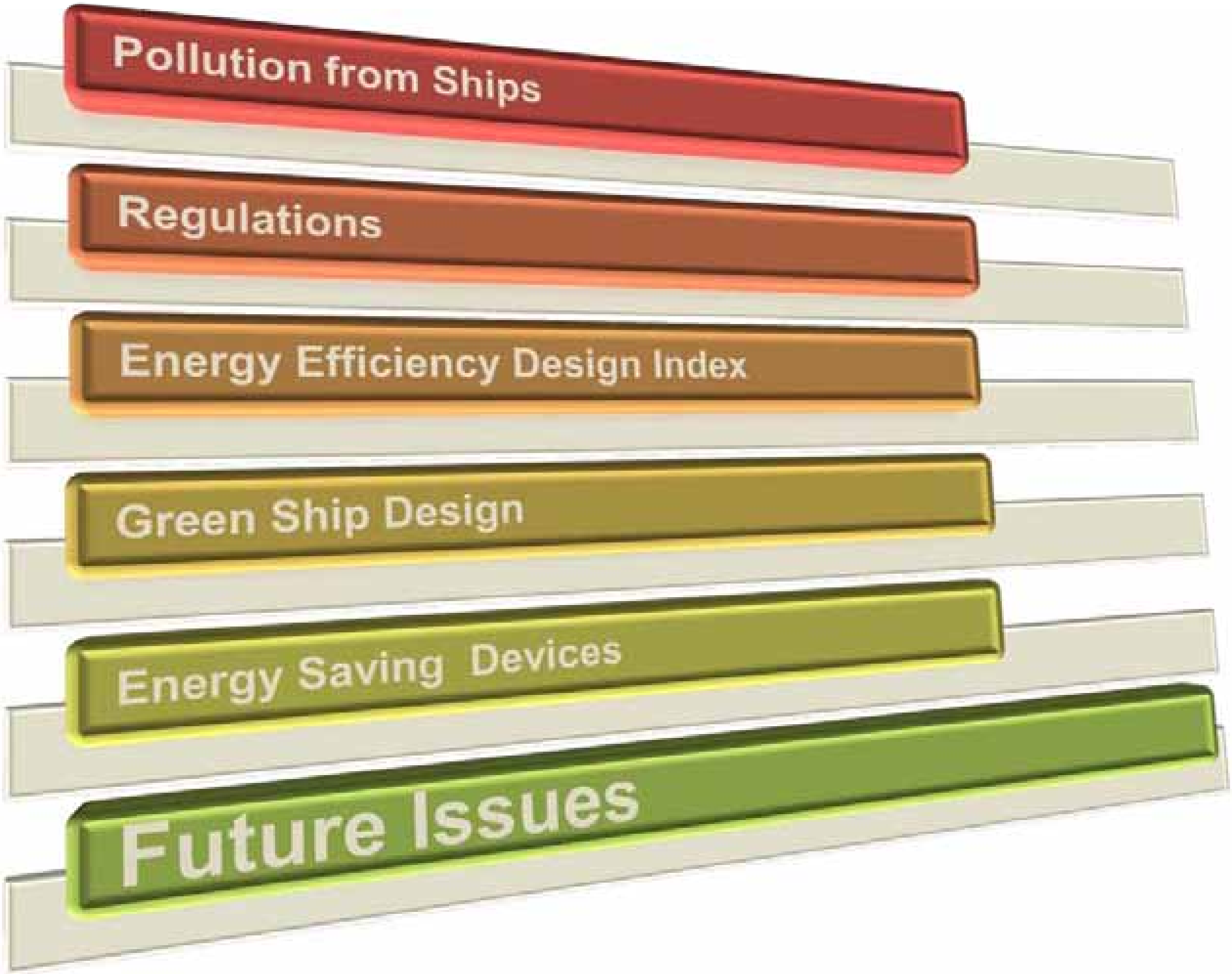
- Hybrid electric-diesel system, fuel cell, pod propulsion system
- Excellent performance for noise and vibration
- Good performance for constant thrust power and controllability
- Flexible arrangement
- Heavy machinery system
- Lower shaft transmission efficiency (about 7~8% less than other system)

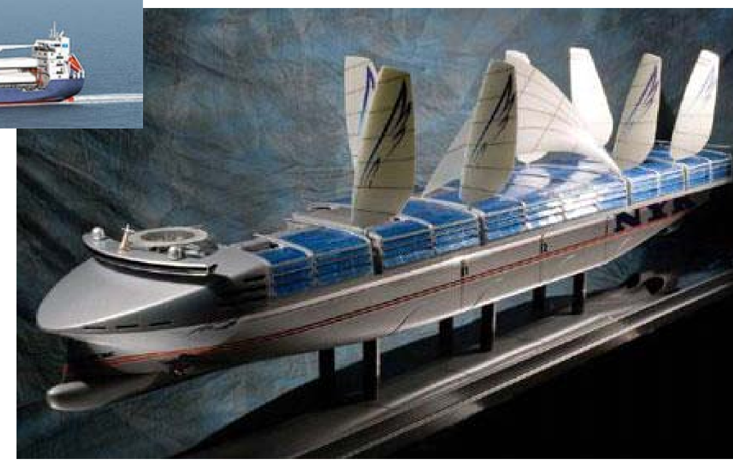
- No air pollution
- 3-4 year operation with one supply
- Low fuel cost
  (1g uranium = 2 ton crude oil)
- No heavy duct system or large space for fuel
- Critical environmental problem in failure case
- Heavy safety system
- Very high ship cost
- Complicated system and many operators

More Emerging Technology

- **Hull Painting and Ultrasonic Hull-Surface Coating**
- **Bio-diesel**
- **FOC Reduction by Path Optimization**
- **Fuel Machinery System Optimization**
- **Structural Material**
- **Optimum Ship Structural Design**

…… (many more)


Pollution from Ships
Regulations
Energy Efficiency Design Index
Green Ship Design
Energy Saving Devices
Future Issues



Ship price ↑ **Operation Cost** ↓

Which will be more ?

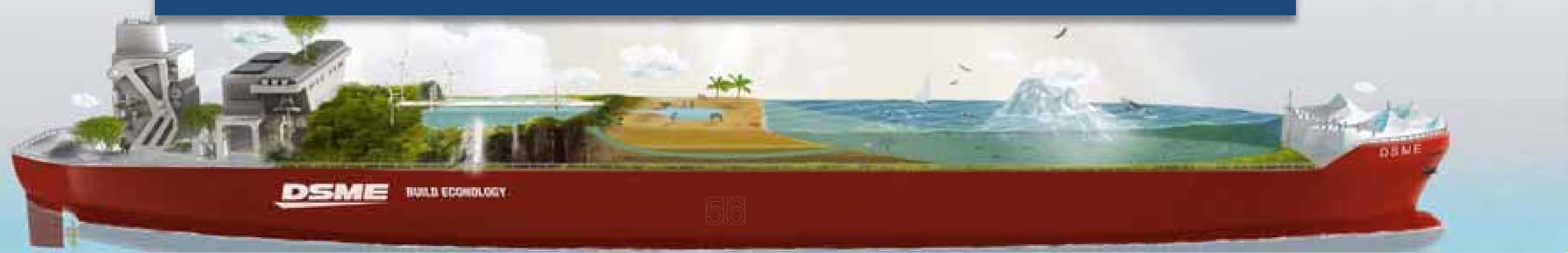
DSME Econology Plan

Econology = Ecology + Economy + Technology

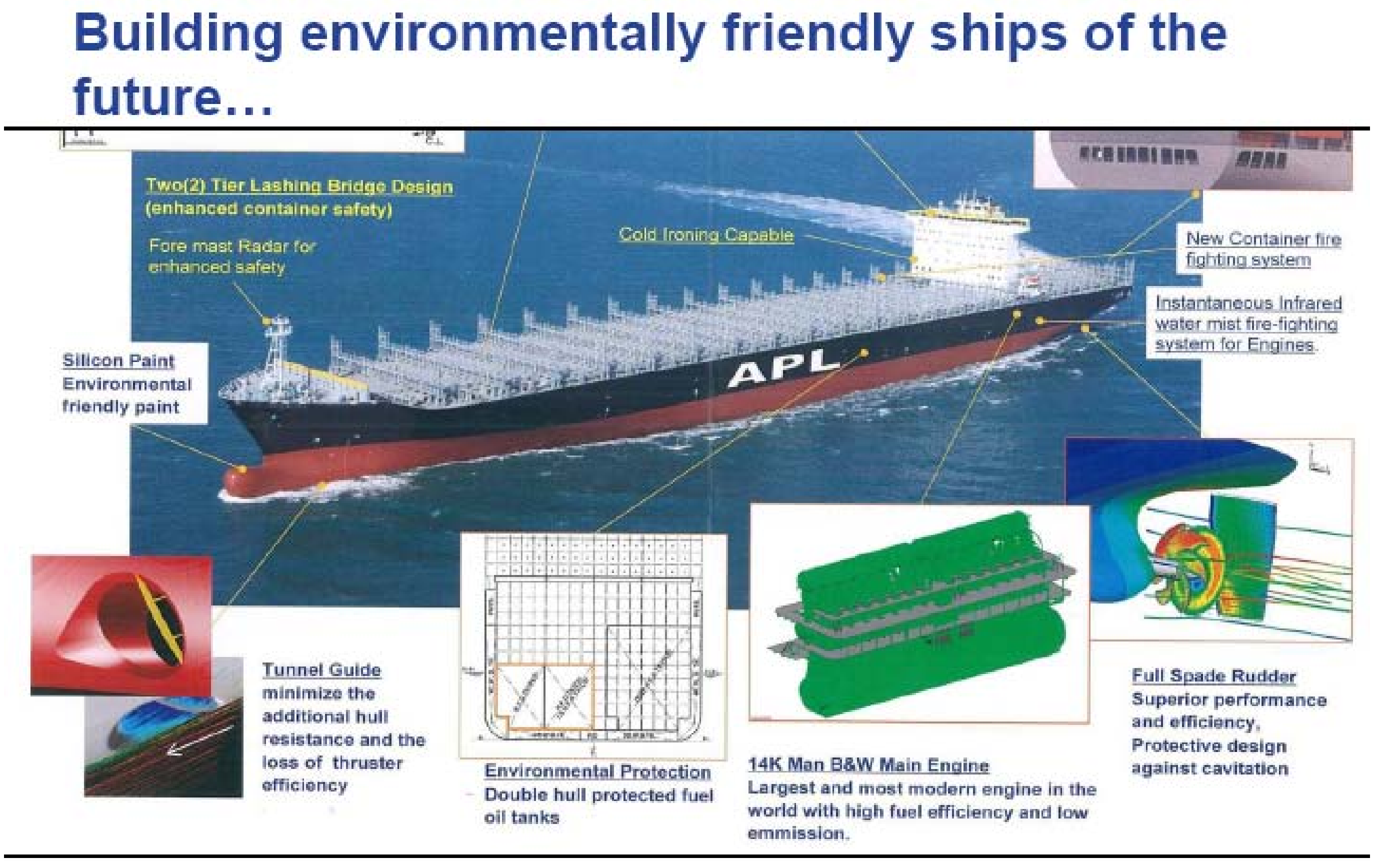
High Performance Ship Design	Green Enhanced Design
▪ Optimum Dimensions ▪ Excellent Speed Performance ▪ Maximum Capacity (DWT, VOL) ▪ Competitive FOC ▪ Safety	**F**uel(= CO_2) Saving Max. (EEDI) **E**fficient Operation (EEOI) **E**mission Reduction **L**ess Maintenance
Conventional Design Goals	New Requirements of Environmental Associations & Shipping Industry

+

Hi-Performance & Environment Friendly Ship

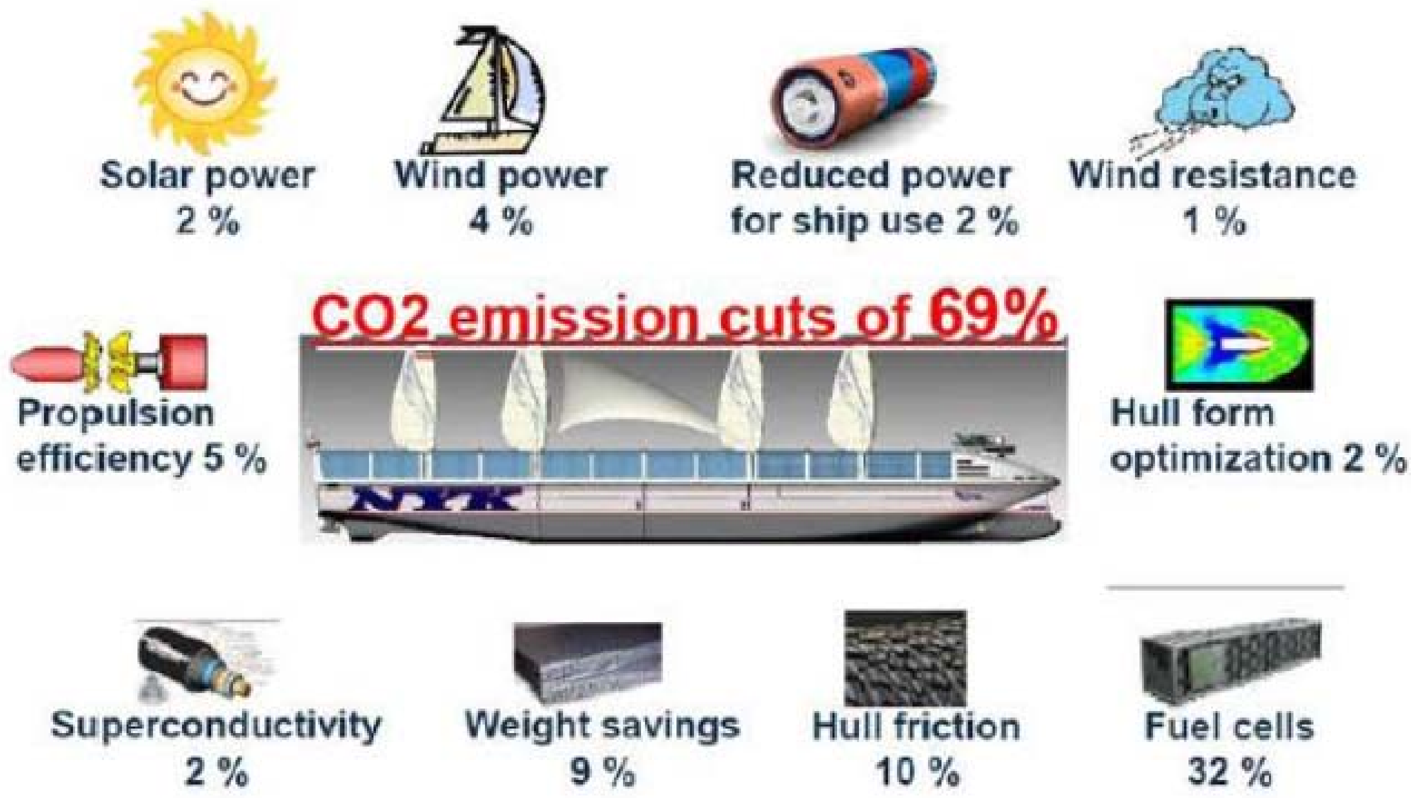


APL's Concept for Environmental Friendly Ship



Source :Poh (MTEC 2011)

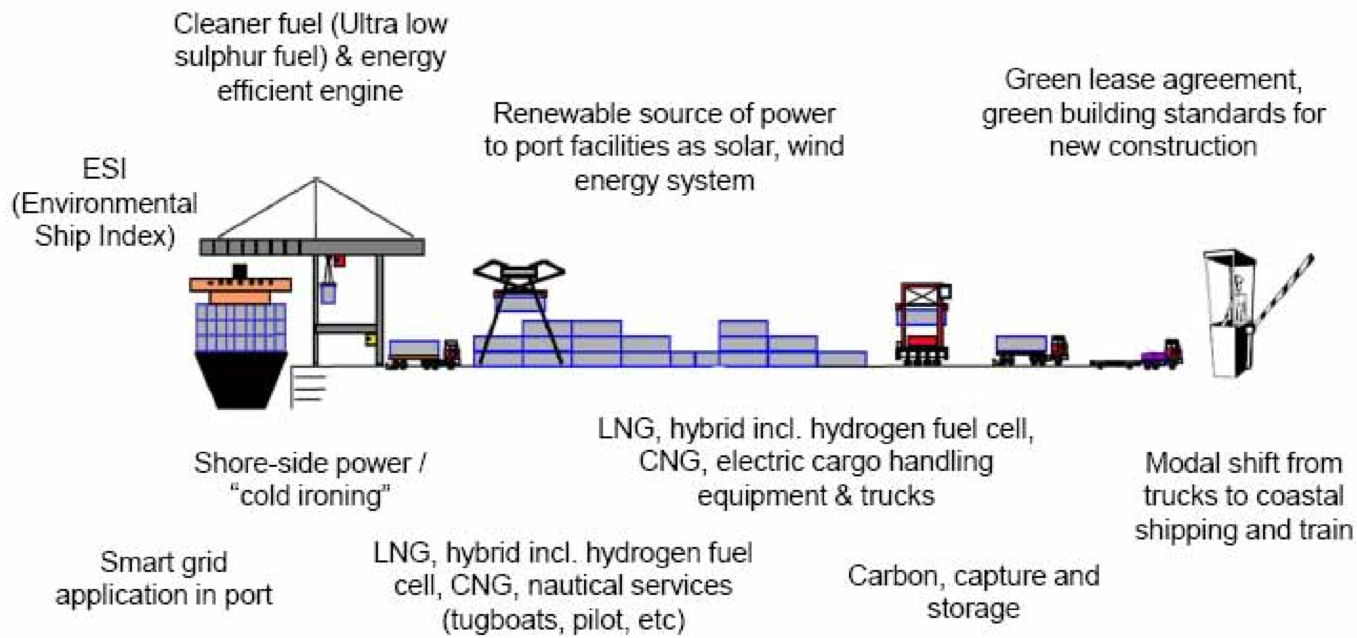
Super Eco Ship 2030 (NYK, Japan)



We need to consider all the aspects for green ship.

Global Maritime Activity for GHS Reduction

Some green innovative programs are already underway at ports around the globe to reduce their carbon footprint



The mitigation measures can be accomplished with the help of a regulatory and political framework promoting such innovation into an industry

Trends of Green Issues and Impact on Shipping and Ports
Thursday, 07 April 2011

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MANAGING RISK DNV

Source : Svensen (MTEC 2011)

Environment Friendly

Economical Operation

Through Green Ship Technologies

Acknowledgment for presentation materials

Daewoo Shipbuilding & Marine Engineering

Korean Ministry of Knowledge and Economy

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