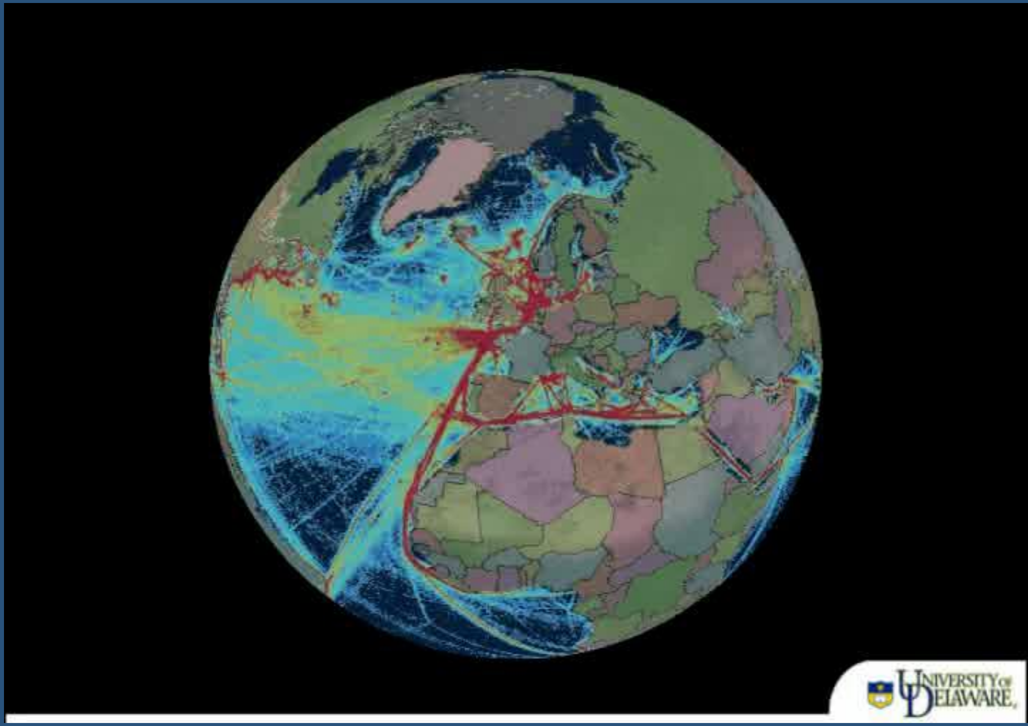
Emissions From Maritime Shipping Sector In A Freight Context



James Corbett, P.E., Ph.D.

Presentation to OECD/ECMT JTRC WG on Transport GHG Reduction Strategies
21-22 May 2007

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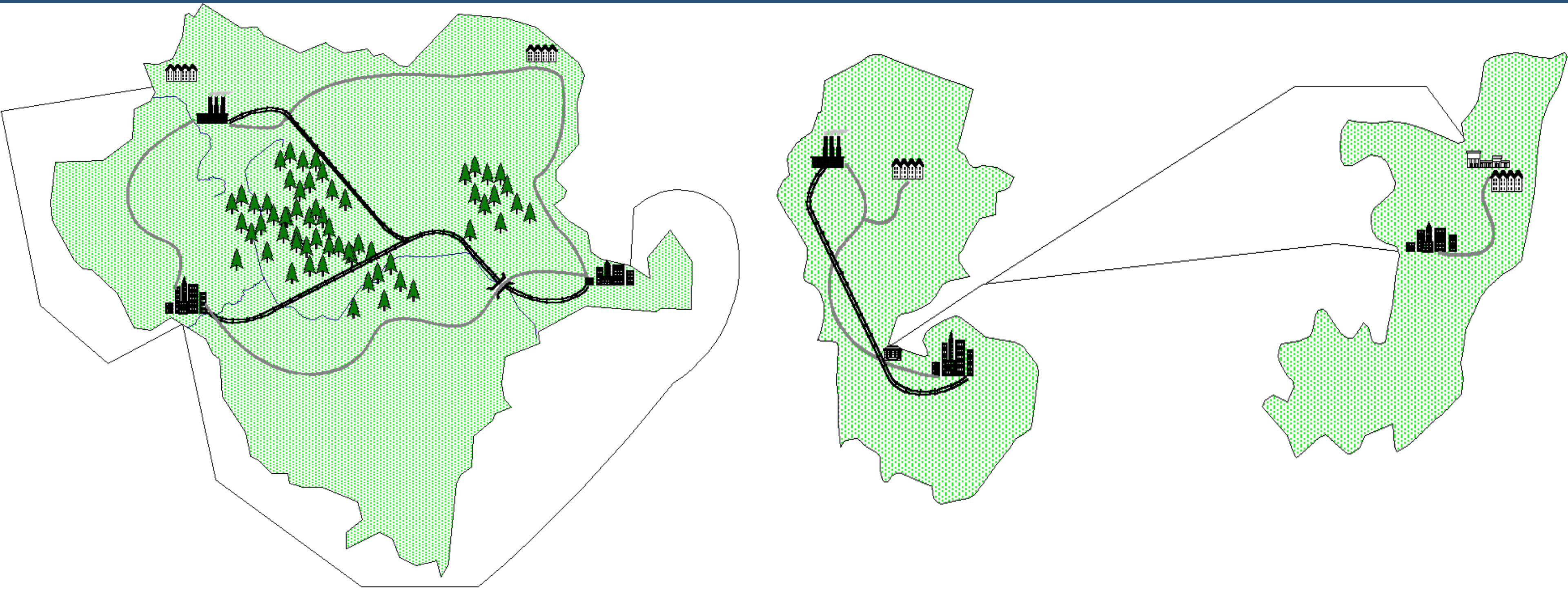
Freight is an important multimodal transport function



Shipping is an integral part of global trade

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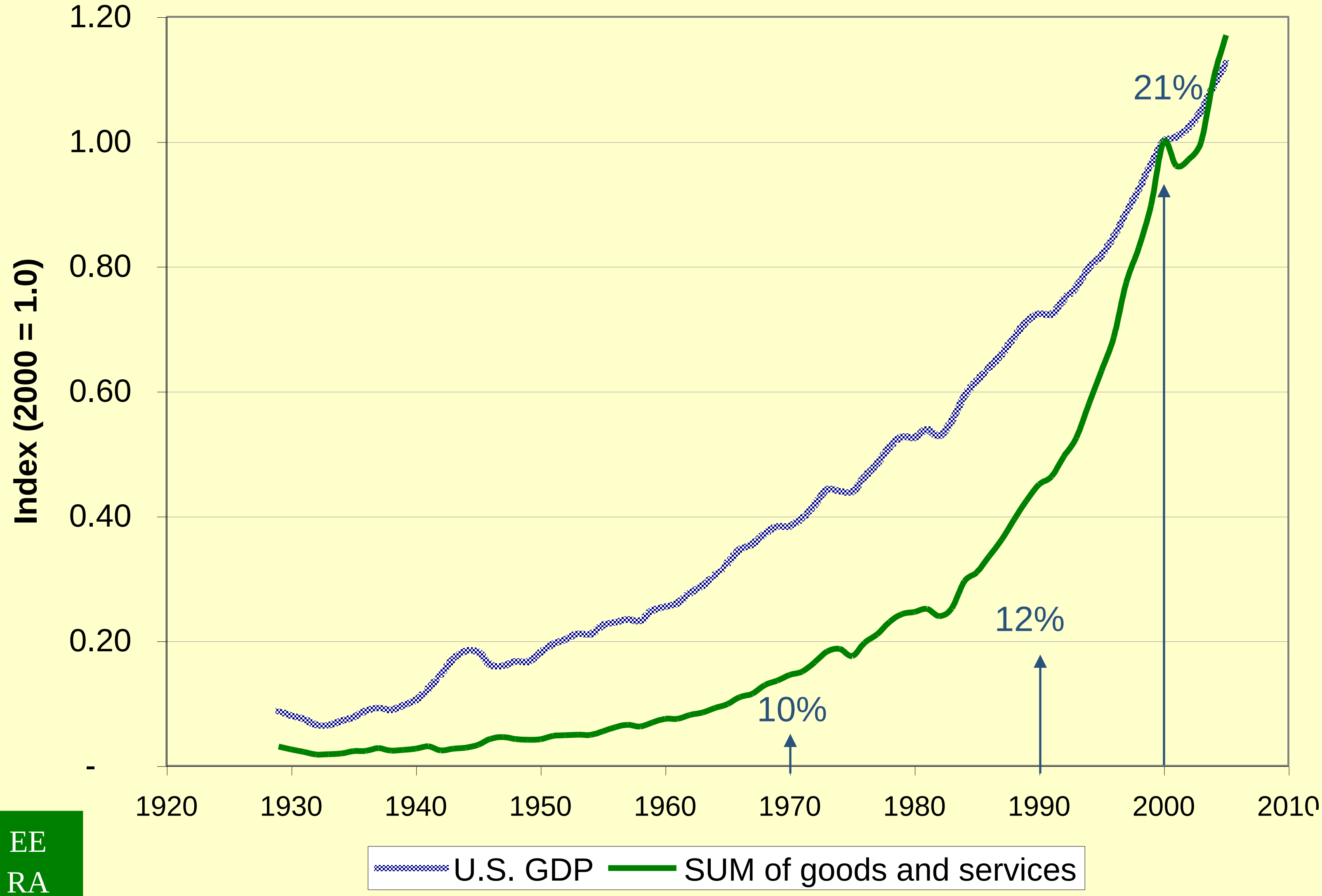
Freight is an increasing contributor to the economy



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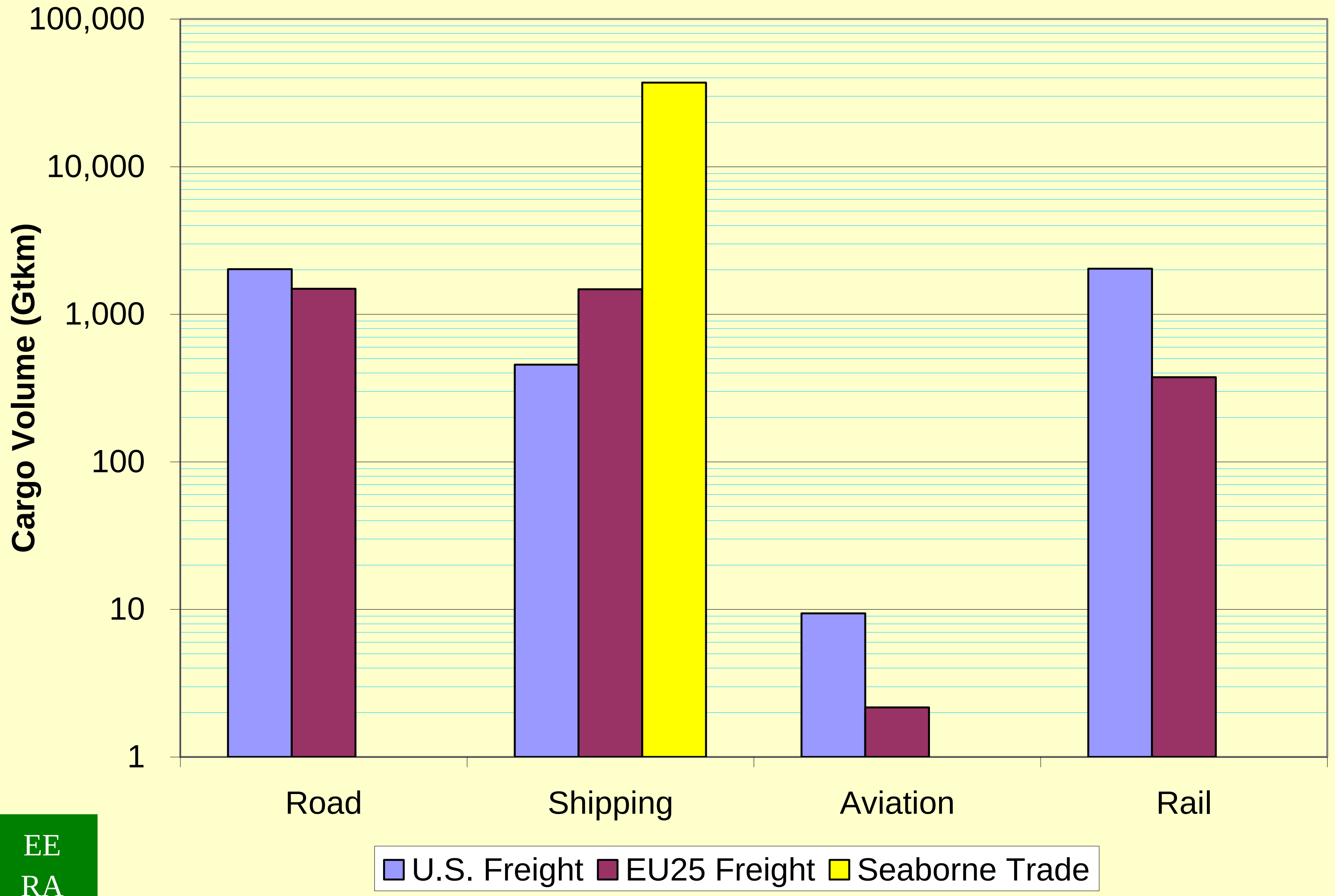
Air pollution and Climate Impacts from Ships

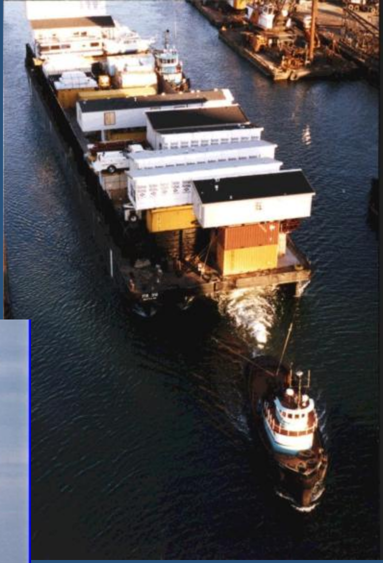
- Two reasons to reduce ship emissions:
  - Ships contribute to problems TODAY
  - Growth in shipping makes problems worse TOMORROW

- Other reasons (depending on perspective)
  - Controls more cost-effective than other modes
  - Impacts mitigation may be asymmetric

Mode share comparison



Ships are more heterogeneous than onroad transport



- Tug and towboats
  - 1-30 barges: 0.5 - 4 MW
- High speed ferries
  - 150-350 passengers: 2-4 MW
- Roll-on\Roll-off
  - 200-600 vehicles: 15-25 MW
- Tankers
  - 250,000 tons of oil: 25-35 MW
  - LNG fleet: 20-30 MW
- Container
  - 1750 TEU: 20-25 MW
  - 4300TEU: 35-45 MW
  - 6000 TEU: 55-65 MW

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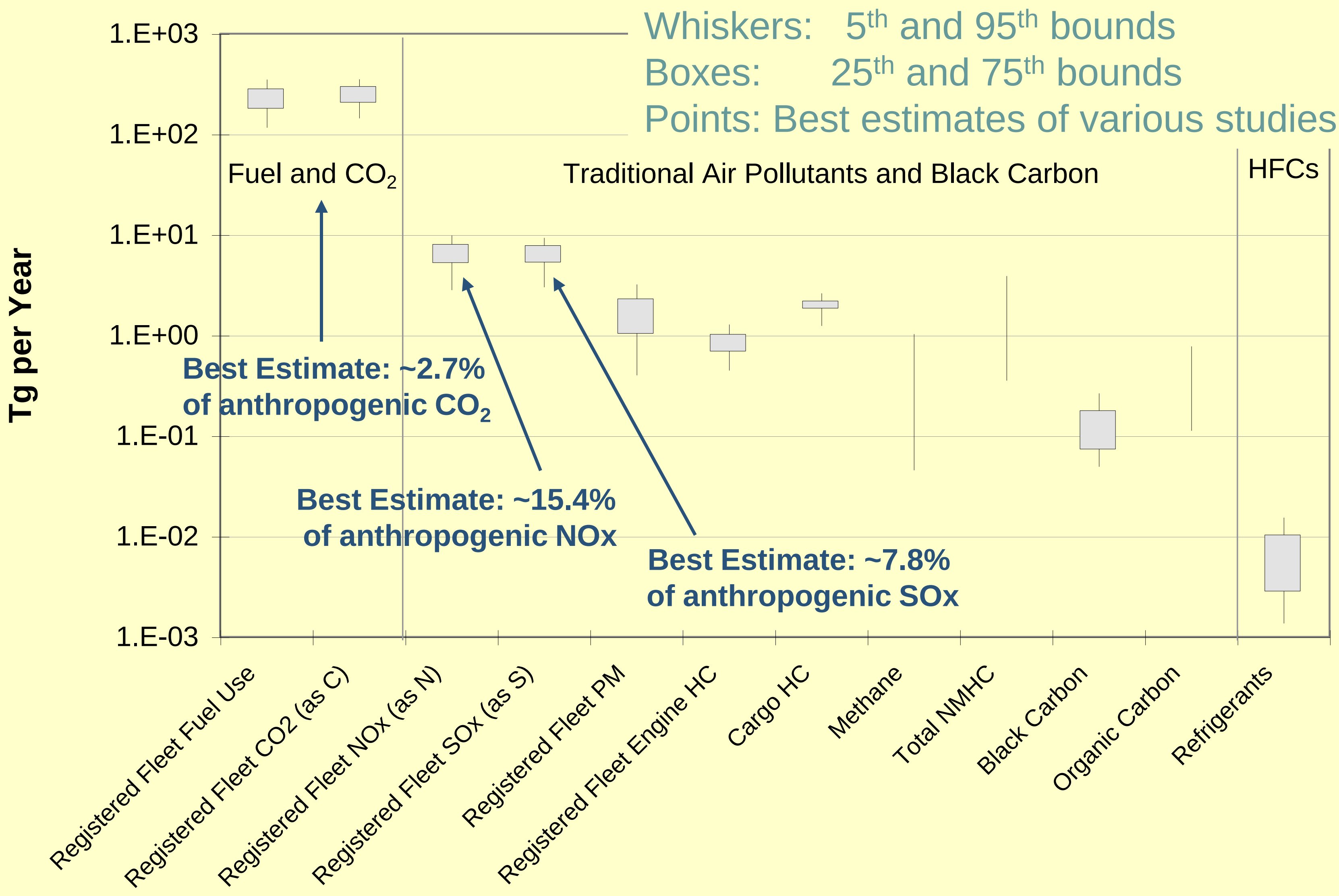
Ship emissions estimates bounded



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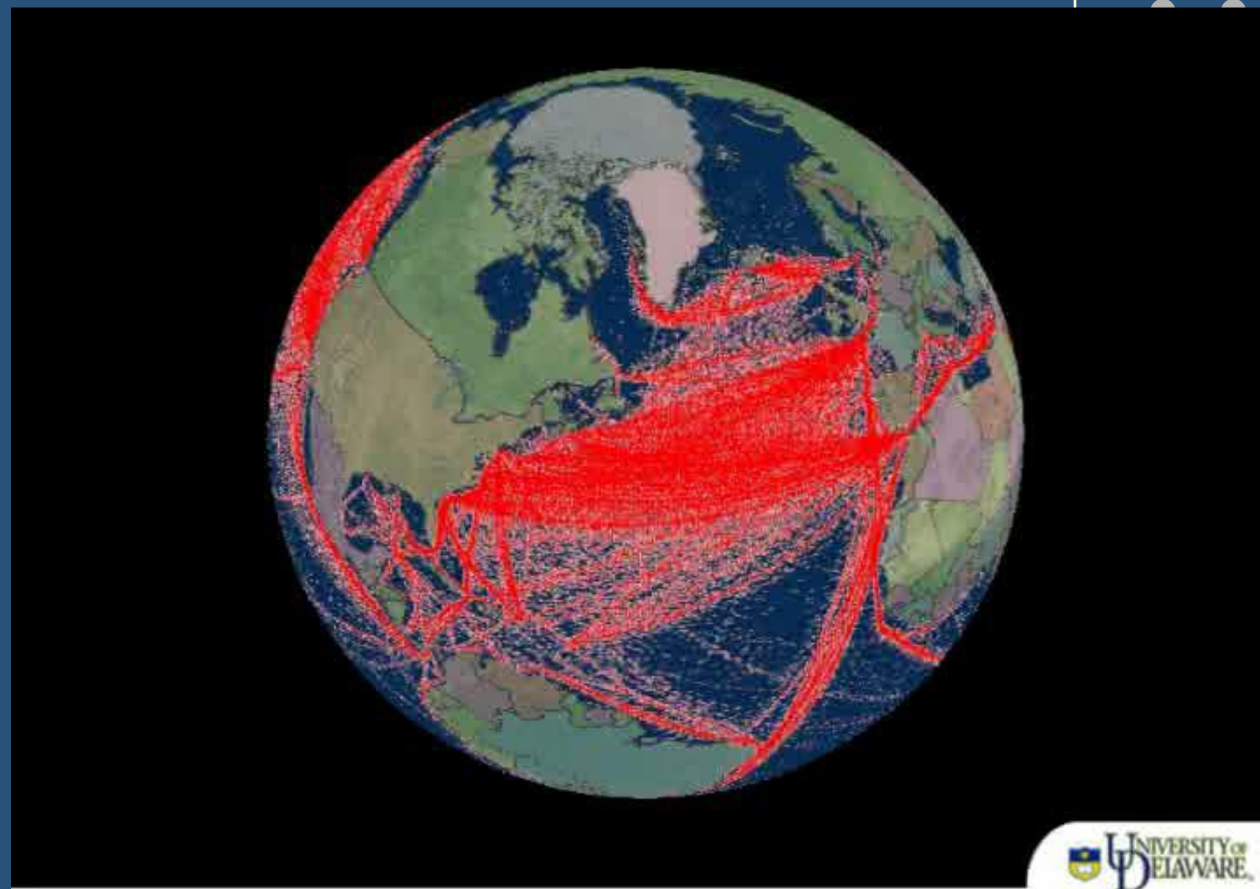
Ship traffic differs by vessel type

- Containership
- Tanker
- Bulk Carrier
- General Cargo
- Refrigerated Cargo
- Ro-Ro
- Passenger



Trade driven by commodity demand & resource supply

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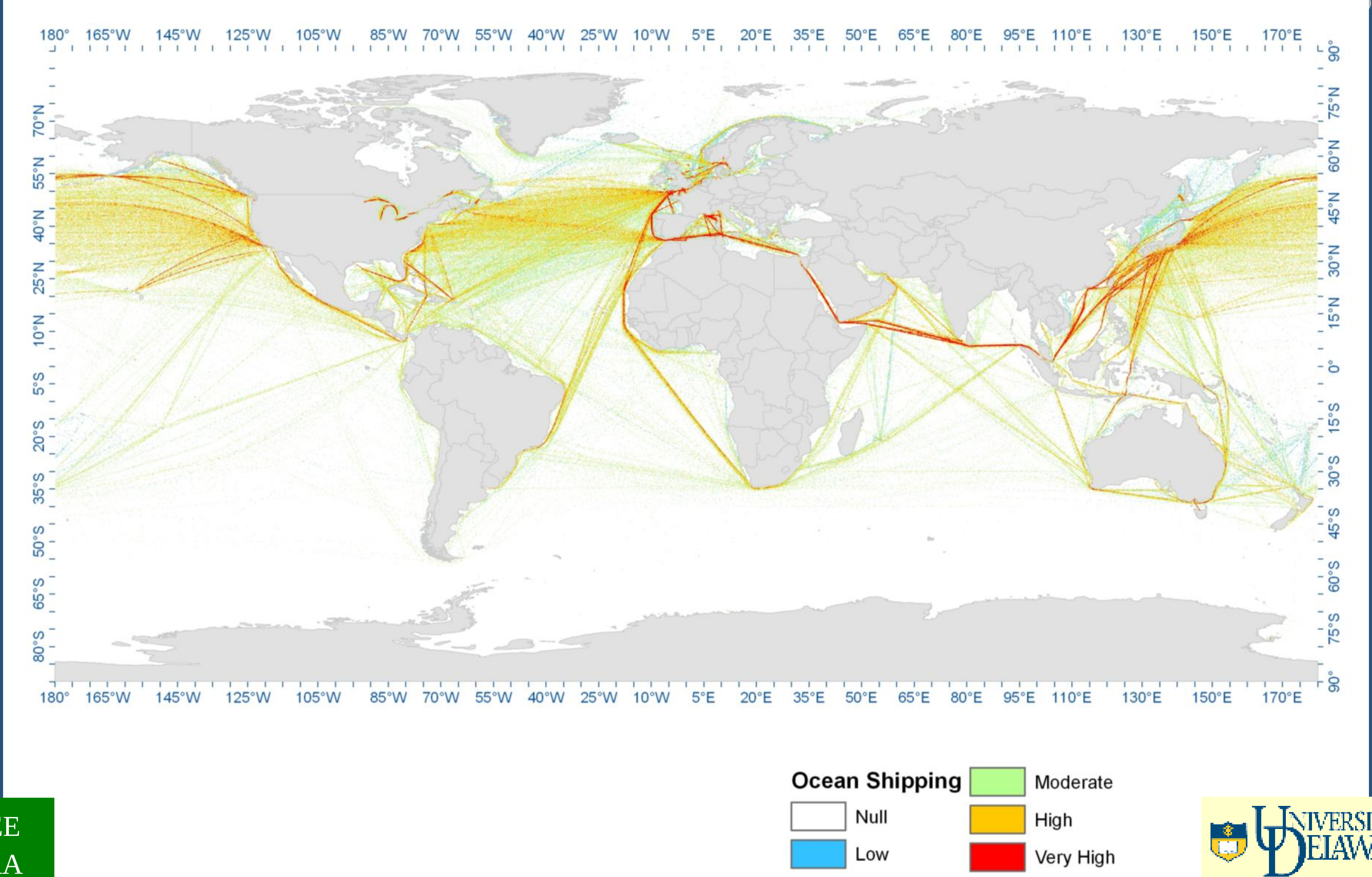
Trade import patterns are clear …
… connected to domestic freight system



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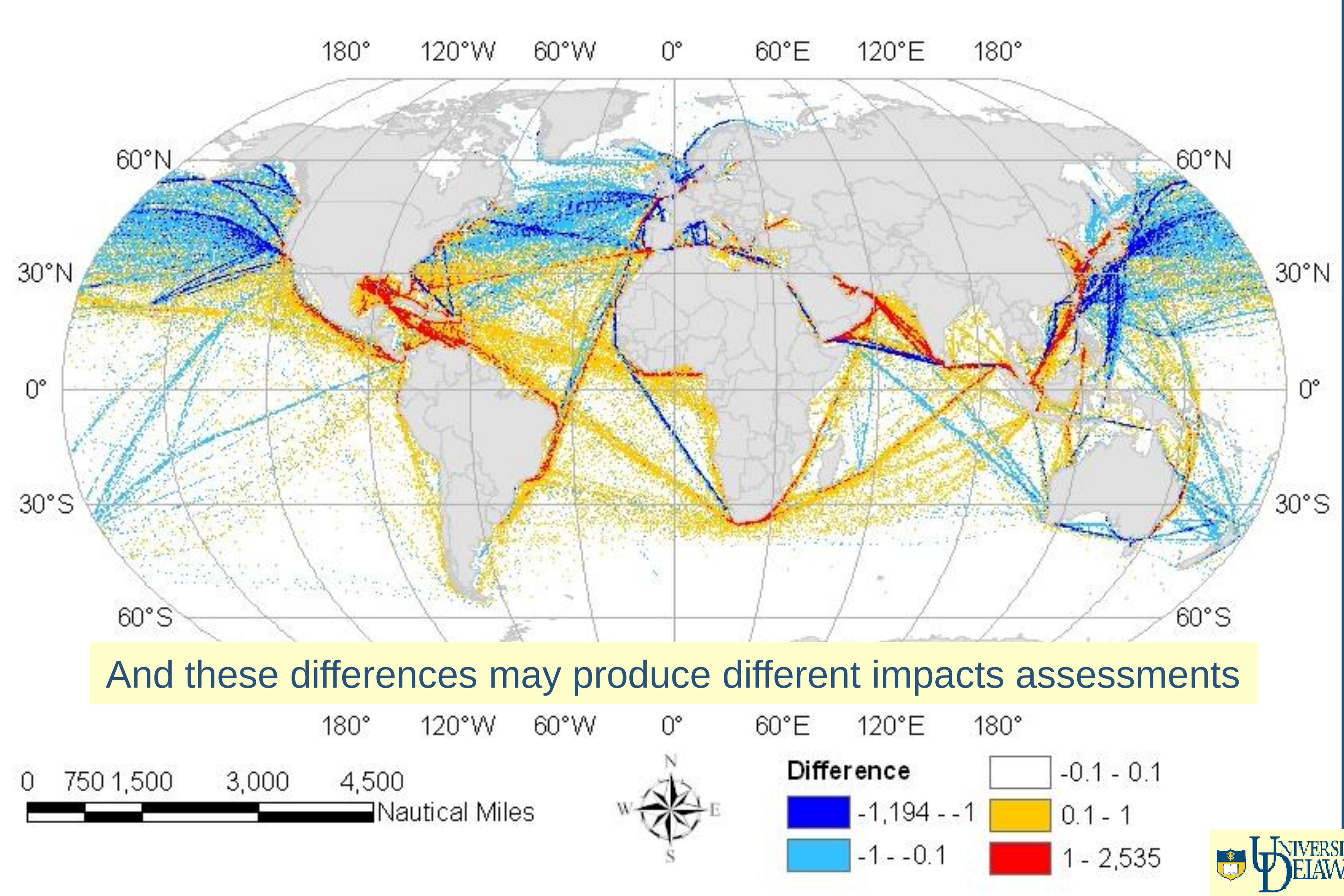
Different top-down proxies provide different regional pictures



And these differences may produce different impacts assessments

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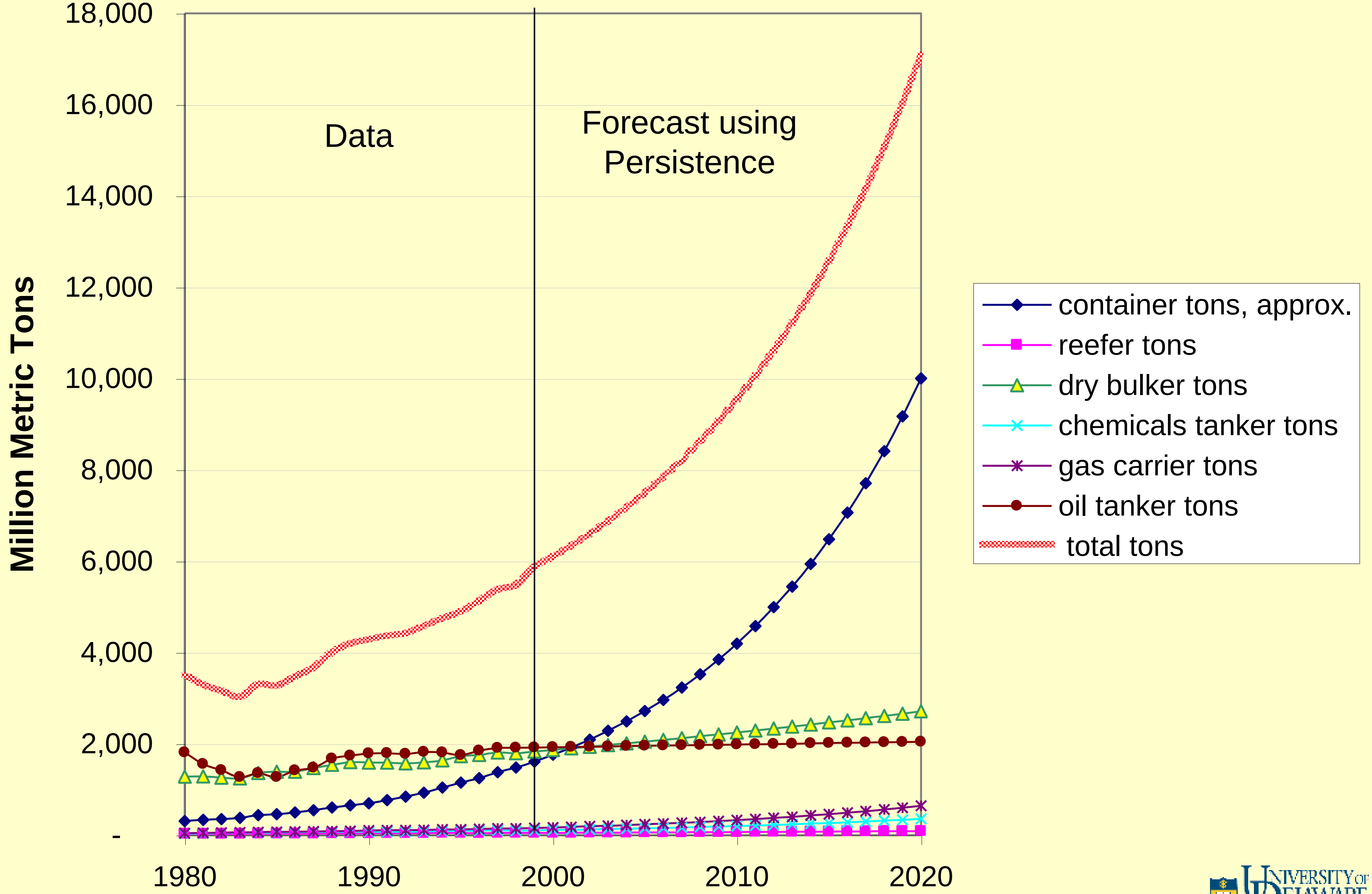
Forecasting Summary

- Power-based trends used for forecasting
  - First-order indicator of proportional change in emissions, adjusted for control measures
- Forecasts are primarily extrapolations of BAU that can be bounded and/or adjusted
  - North American trends validated by comparison with other modal trends and ship trade-energy models, at multiple scales

- *Ship emissions growth rates are faster than GDP*
- *Future emissions with IMO-compliant SECA will be greater than base year emissions in 2002.*

Fast-growing sectors can dominate forecast



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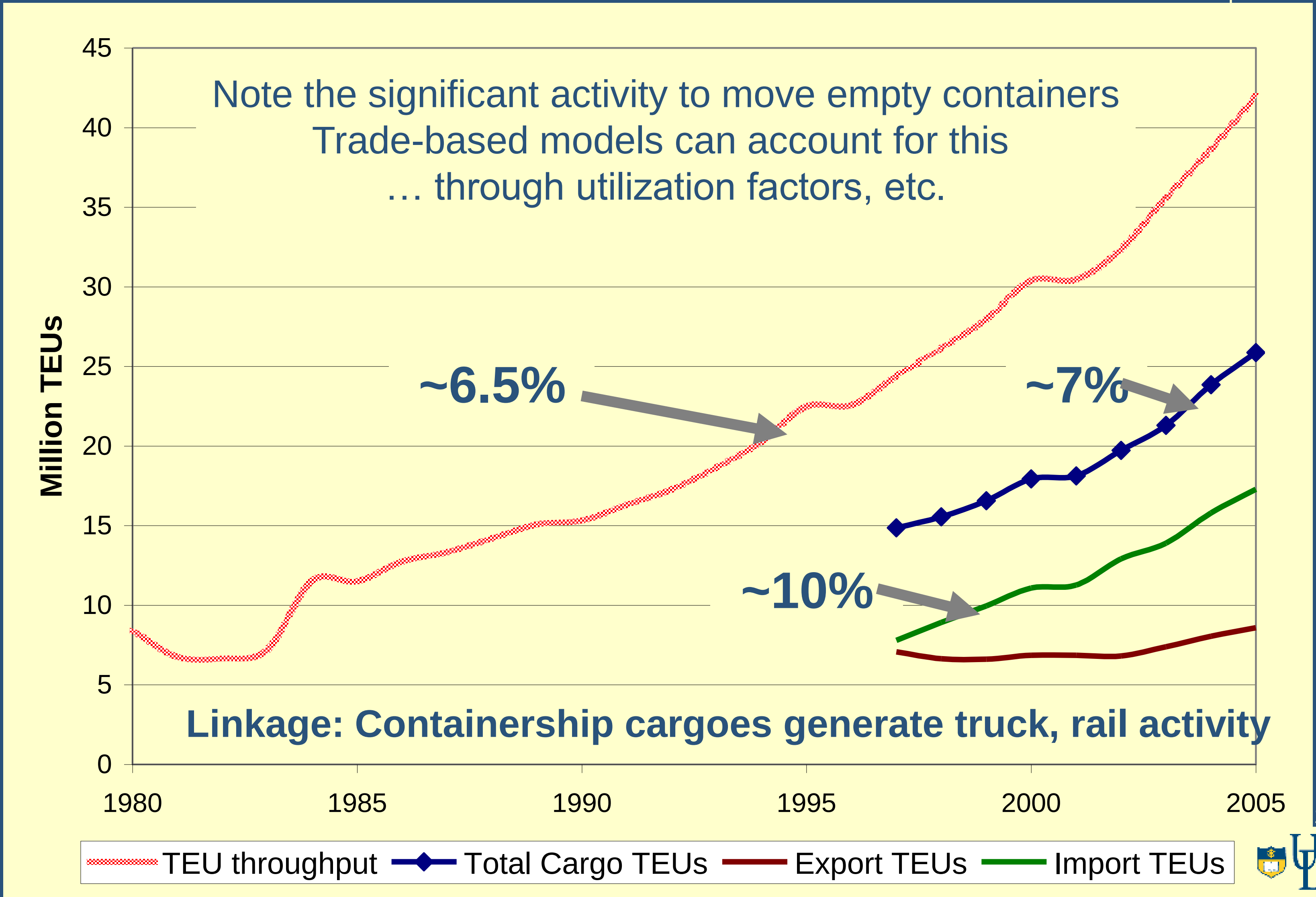
U.S. Containership energy use driven by strong growth in "heavy-leg" activity



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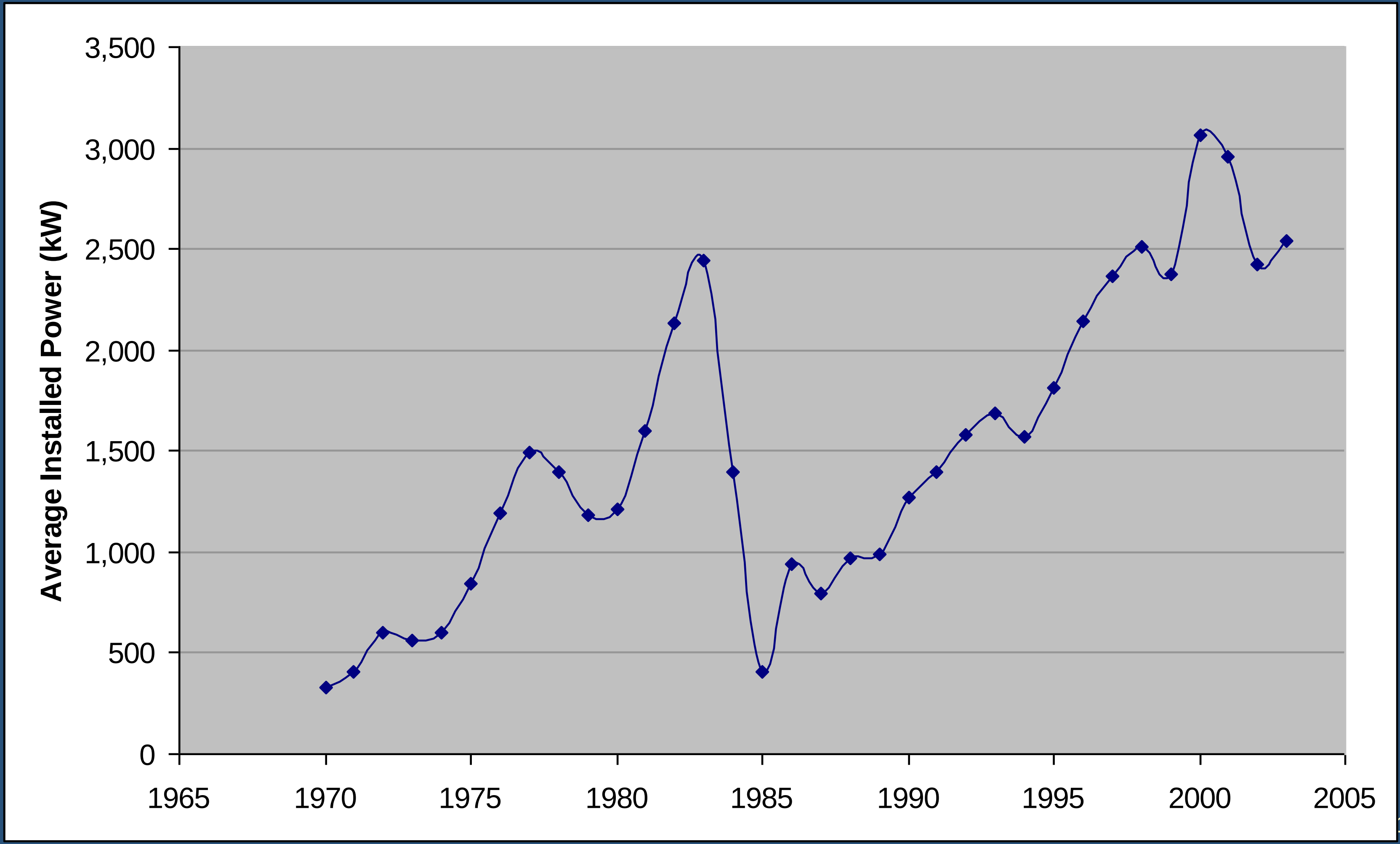
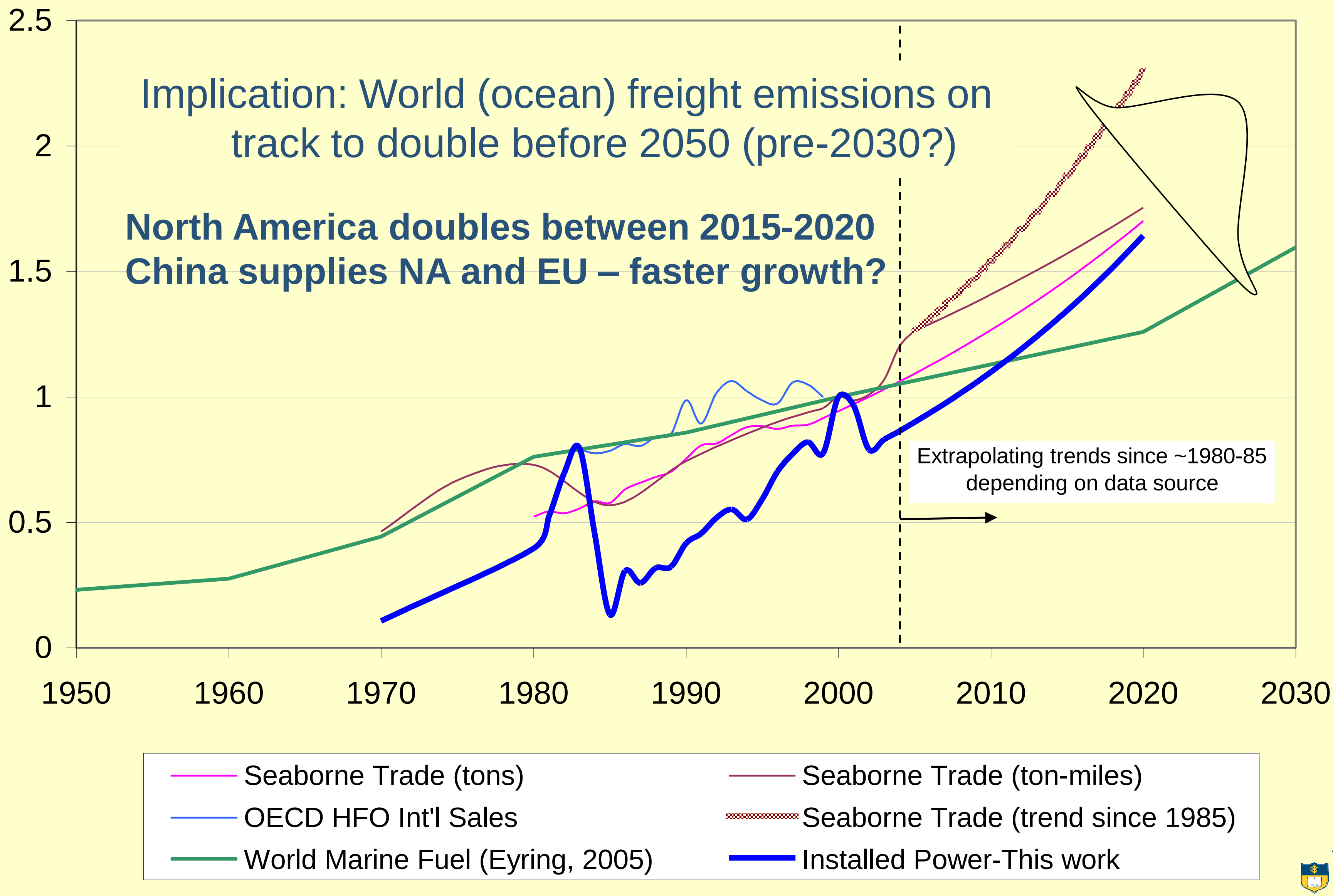
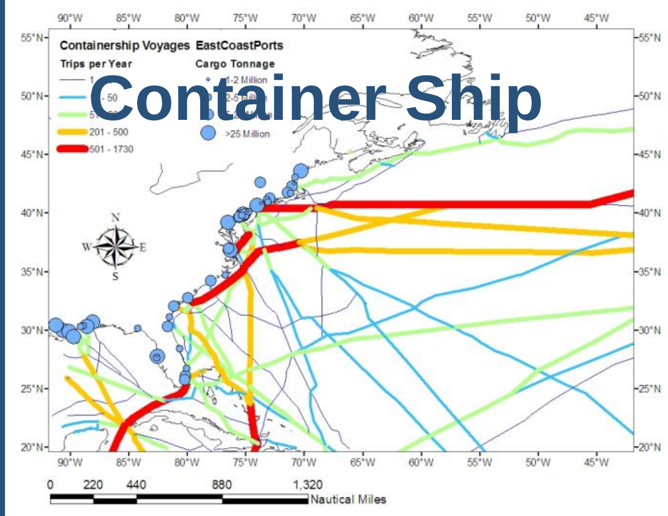
Shipboard power trends indicate strong growth in energy demand



Building a valid range of world forecasts … starting with trade and energy

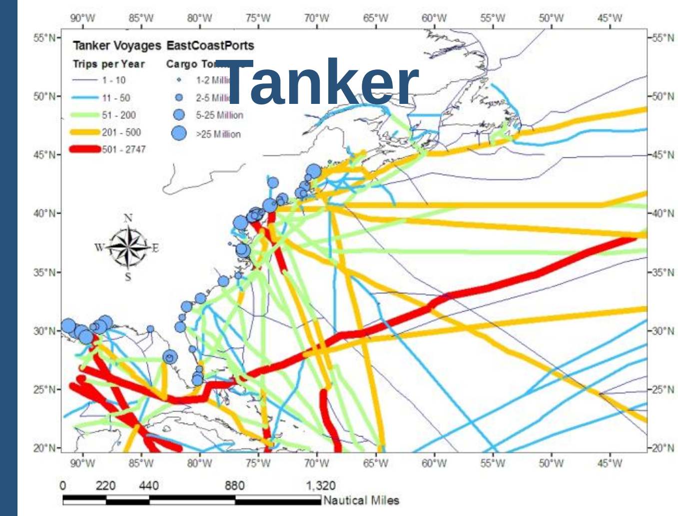


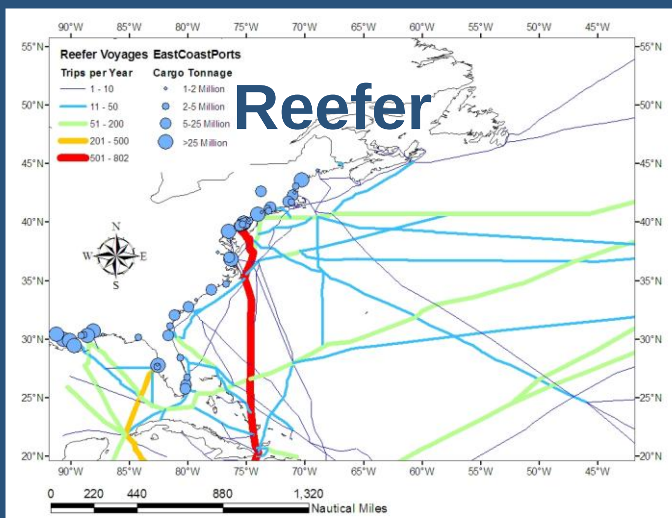
Concept illustration credited to discussions with M. Granger Morgan, Carnegie Mellon University

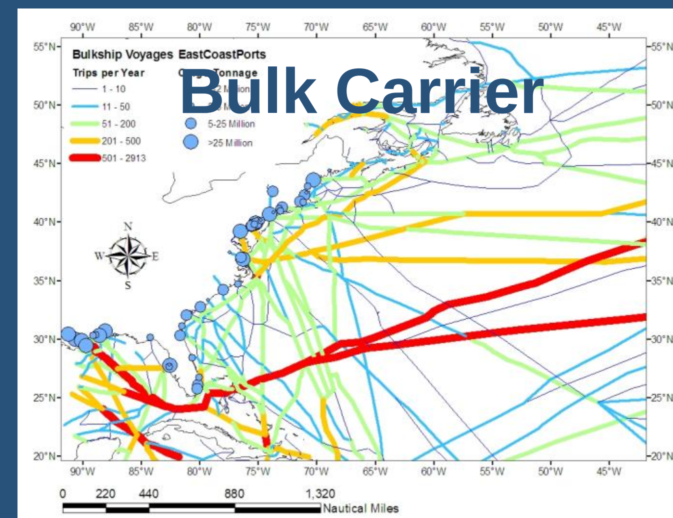


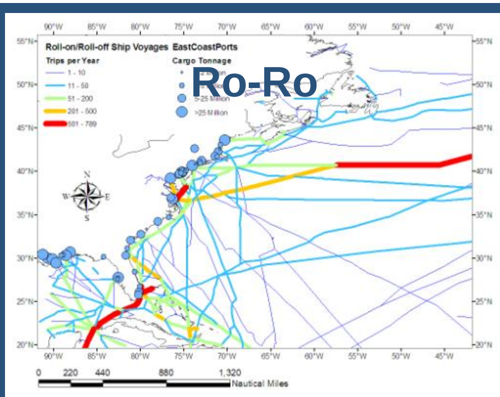
Next Steps

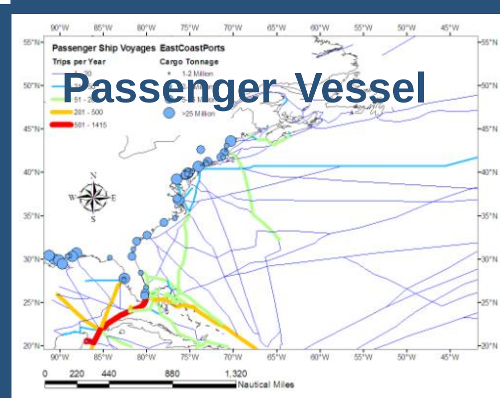
- Recognize different growth rates and re-forecast spatially
- Consider policy and technology interventions
- Couple better with economics trends
- **Go multimodal**
- **Expand globally**

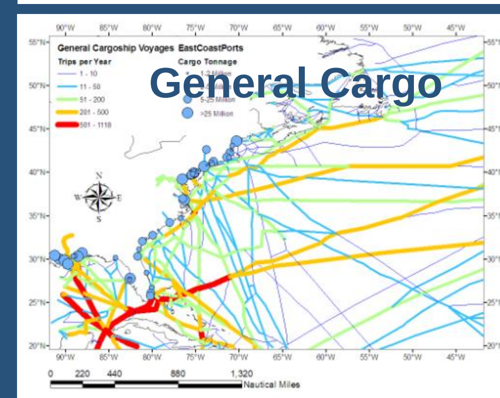












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Approaches to setting ship targets

1. Reduce emissions to improve performance, irrespective of growth. *DO SOMETHING SOON*

2. Reduce emissions to hold current exposure (impacts?) constant at some base year, offsetting trade-driven growth in emissions. *HOLD THE LINE*

3. Reduce emissions by X amount, maintaining emissions reductions (impacts?) from some base year, despite trade growth. *MITIGATE IMPACTS*

Menu of options to be matched with strategies and fleet

- Environmental control technologies
  - Pre-combustion: e.g., water emulsions
  - In-engine: e.g., humidification
  - Post-combustion: e.g., SCR, scrubbers, PM controls

  Only technology (and cost) combos get multiple pollutants

  Nearly all carry CO2 penalties of 1-3% for retrofits

- Alternative marine fuels and energy systems

  Could double fuel price (freight rate ↑), and may require phase in

- Operational (behavior) changes

  Possible in short term, possible multimodal logistics effects

  Achieves reductions in CO2 and all pollutants (win-win)

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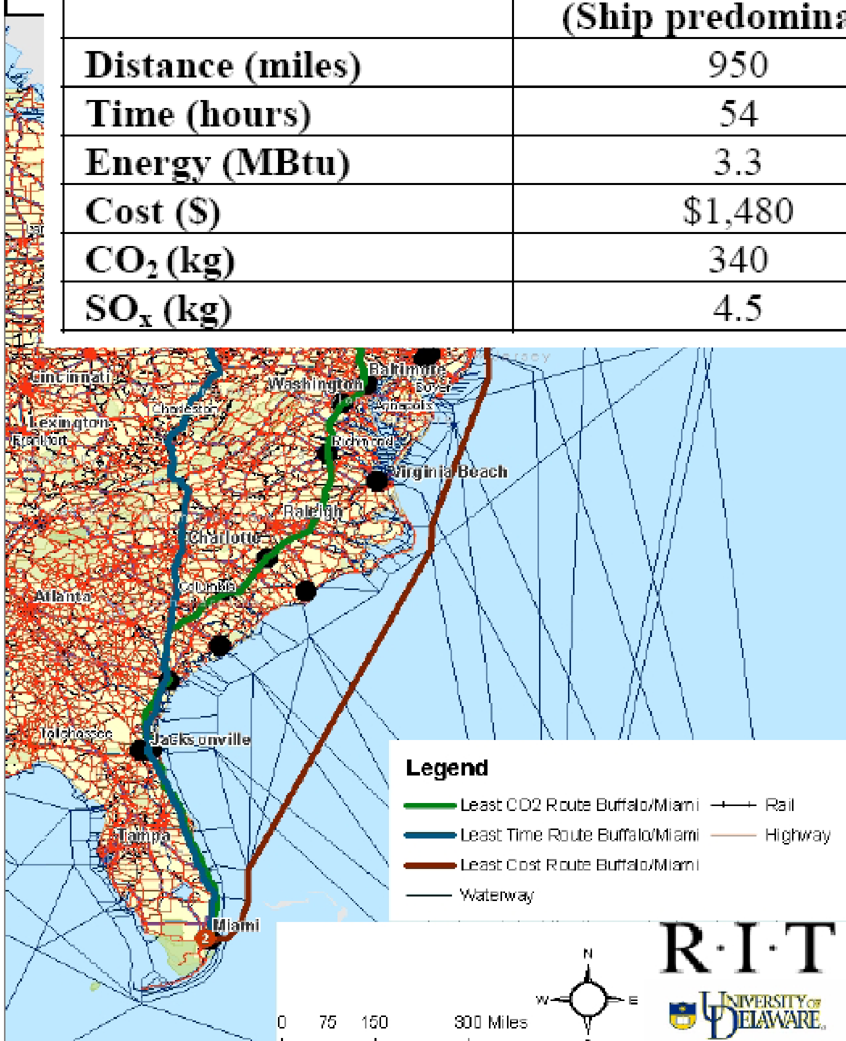
(Marine) Freight Transport insights

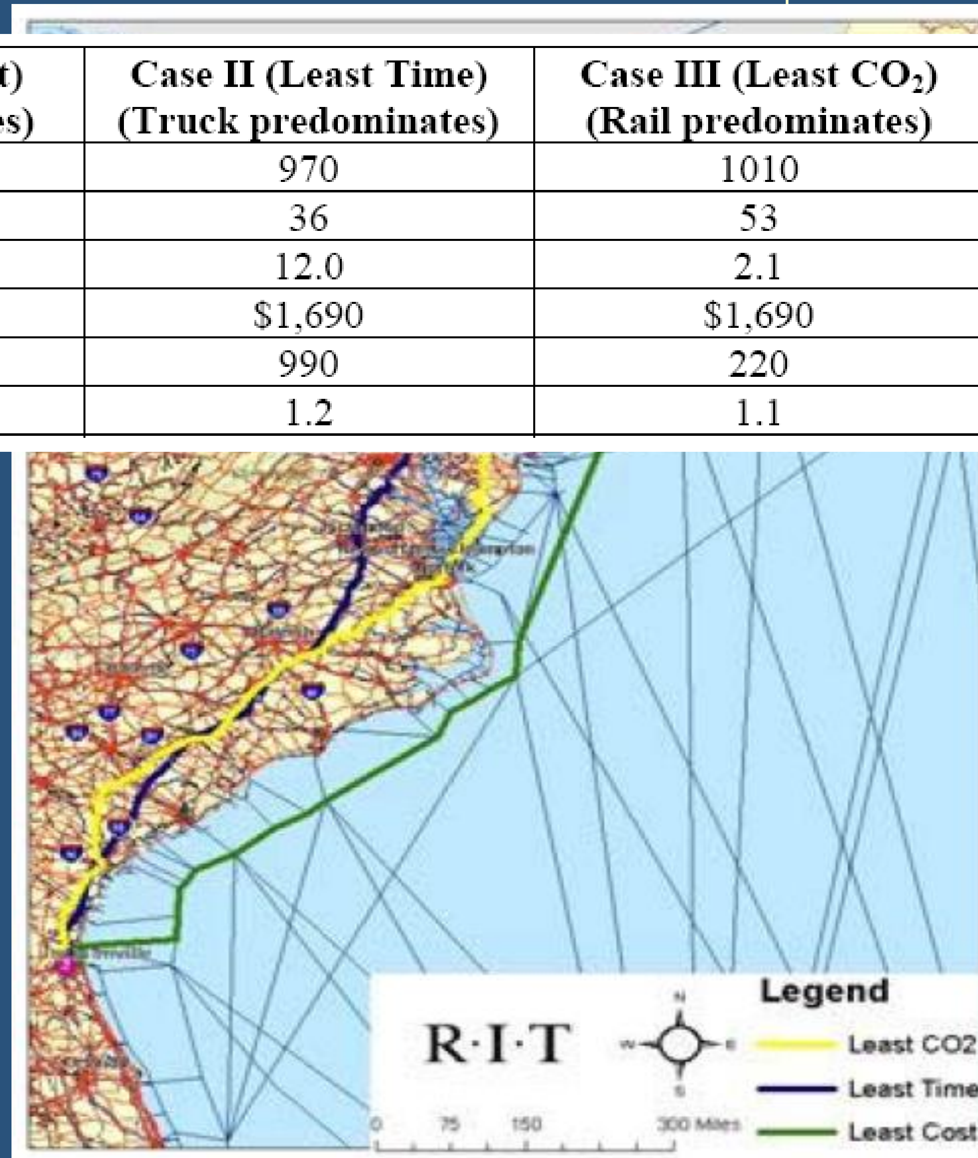
- Technology will involve fleet retrofits and new-builds
- Economics determines role of alternative fuels
- 0.5% SECA *or lower* may be justified in large regions
  - Health effects work ongoing, but SOx control benefits appear greater than control costs
  - Reducing SOx and NOx will modify climate assessments
    - Most abatements increases CO2; reduced emissions change ozone and indirect aerosol forcing
- Market incentives promising at several scales
- Operational logistics changes may involve all modes
- Decades required to completely achieve change

GIFT Network Model
(under development)

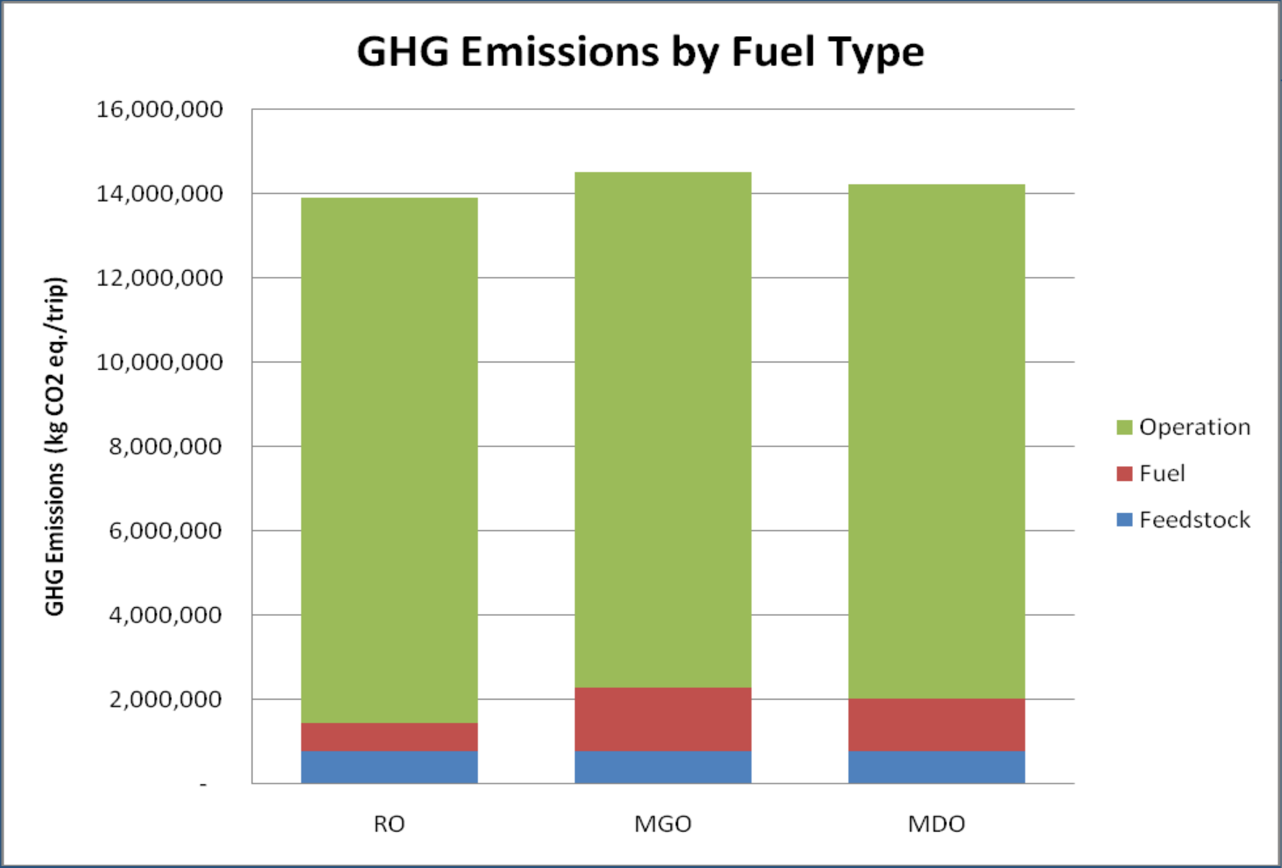
Figure 1. Intermodal Freight Transport Model

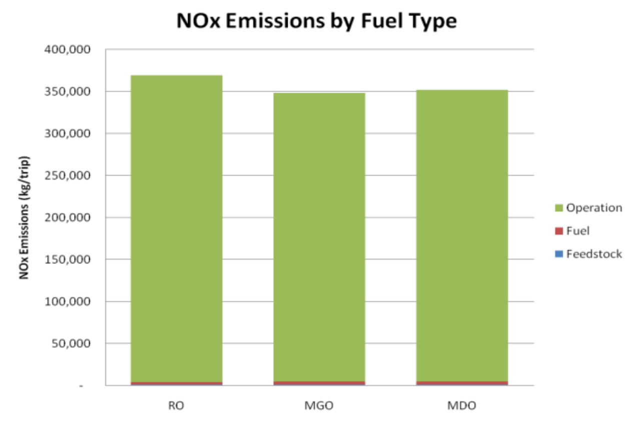
	Case I (Least Cost) (Ship predominates)	Case II (Least Time) (Truck predominates)	Case III (Least CO_2) (Rail predominates)
Distance (miles)	950	970	1010
Time (hours)	54	36	53
Energy (MBtu)	3.3	12.0	2.1
Cost ($)	$1,480	$1,690	$1,690
CO_2 (kg)	340	990	220
SO_x (kg)	4.5	1.2	1.1

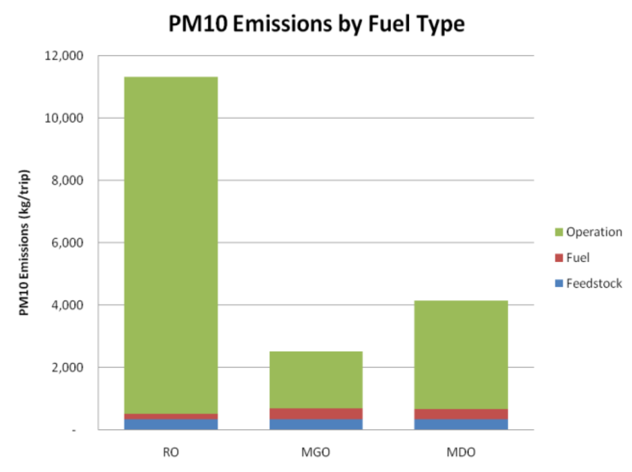


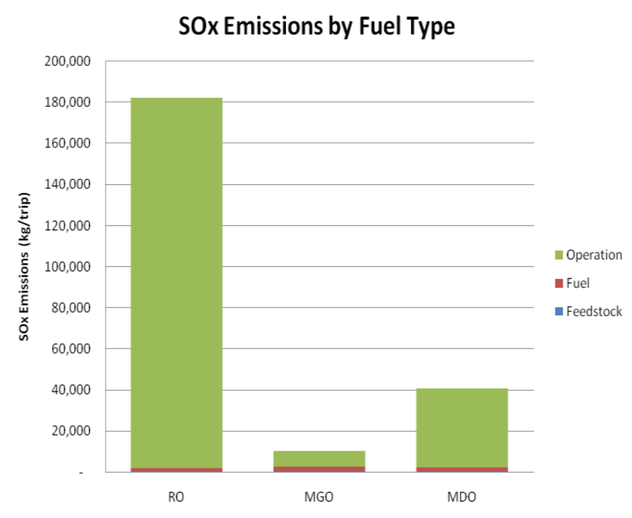


Total fuel cycle comparisons









Winebrake, J.J., J.J. Corbett, and P.E. Meyer, A Total Fuel Life-Cycle Analysis Of Energy And Emissions From Marine Vessels, Paper No. 07-0817, in *Transportation Research Board 86th Annual Meeting*, Transportation Research Board, Washington, DC, 2007

A modern fleet of ships does not so much make use of the sea as exploit a highway. -- Joseph Conrad, The Mirror of the Sea, Ch. 22, 1906

Courtesy: National Maritime Museum, Britain

Discussion welcome

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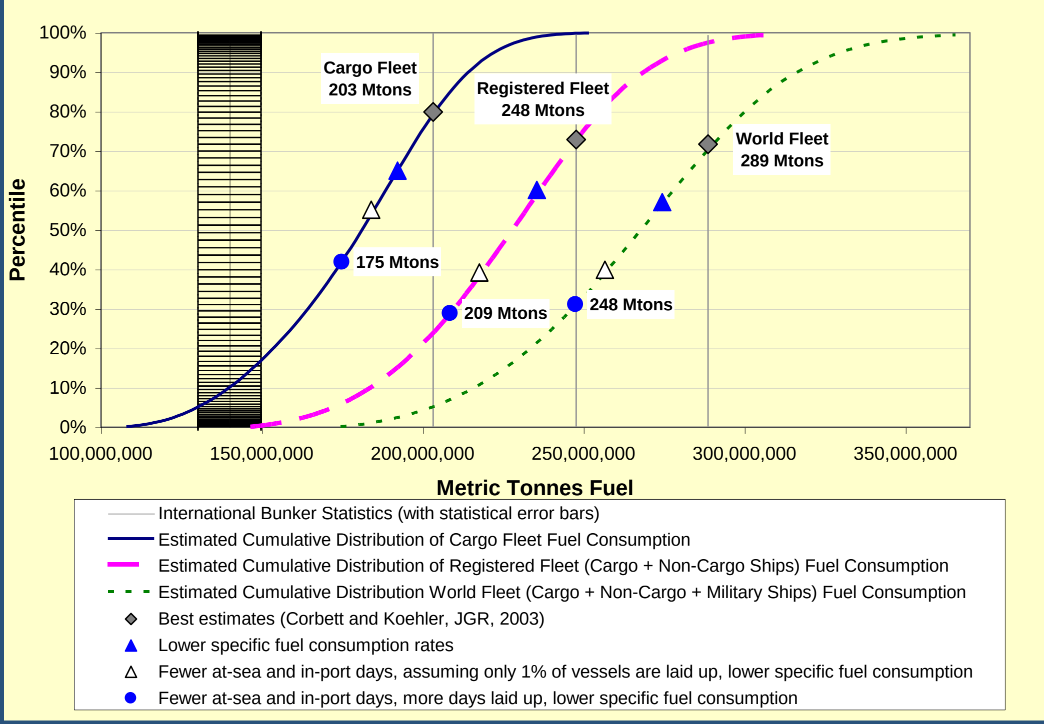
Best practices for CMV inventories

- Step 1: Identify the vessel(s) to be modeled, and engines in service
- Step 2: Estimate the engine service hours for the voyage or voyage segment
- Step 3: Determine the engine load profiles, including power and duty cycle
- Step 4: Apply emissions or fuel consumption rates for specific engine/fuel combinations
- Step 5: Estimate emissions or fuel consumption for the voyage or voyage segment

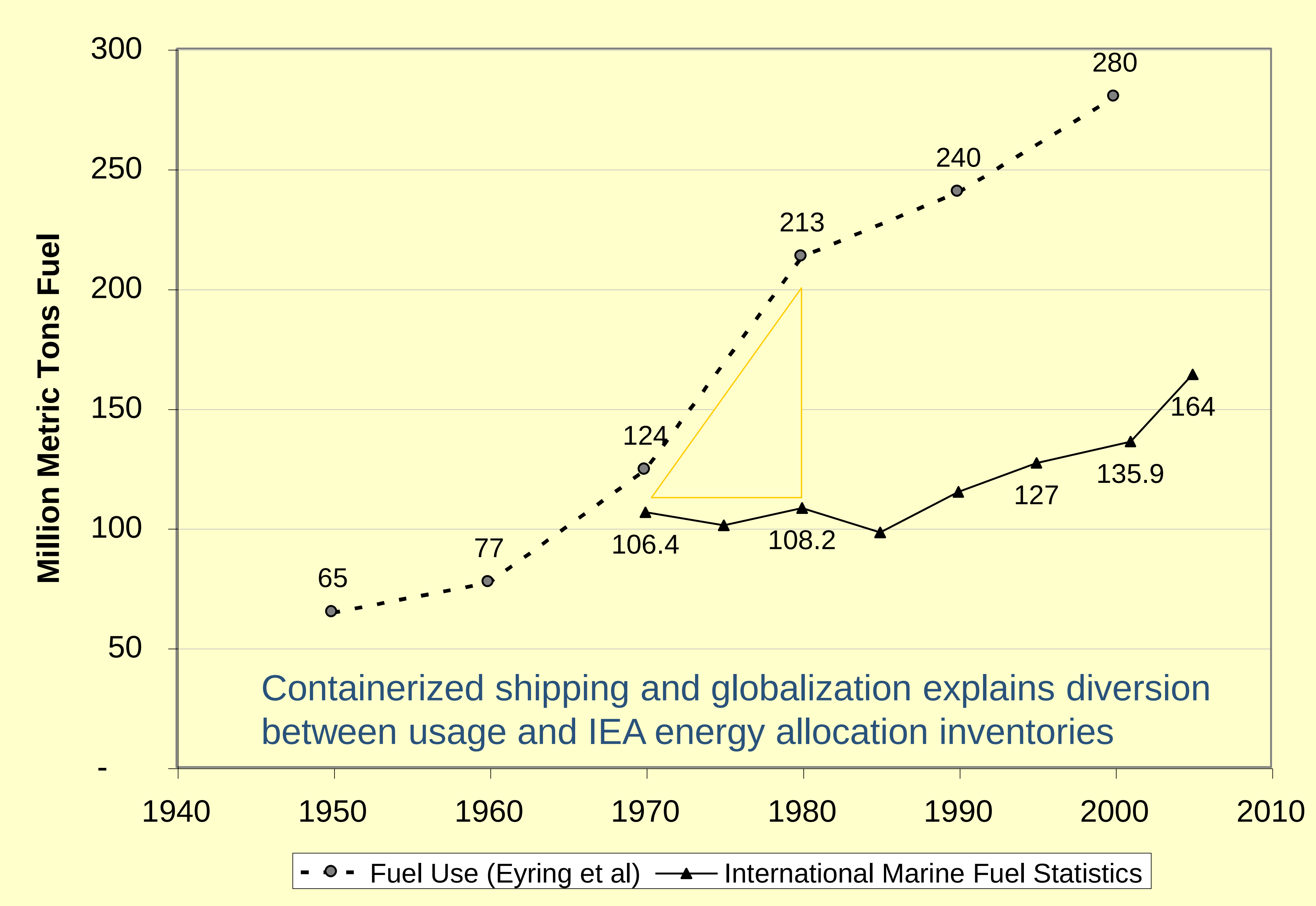
Steps 6+: Assign emissions spatially and temporally both in and out of port regions

Uncertainty remains, but bounding is improving



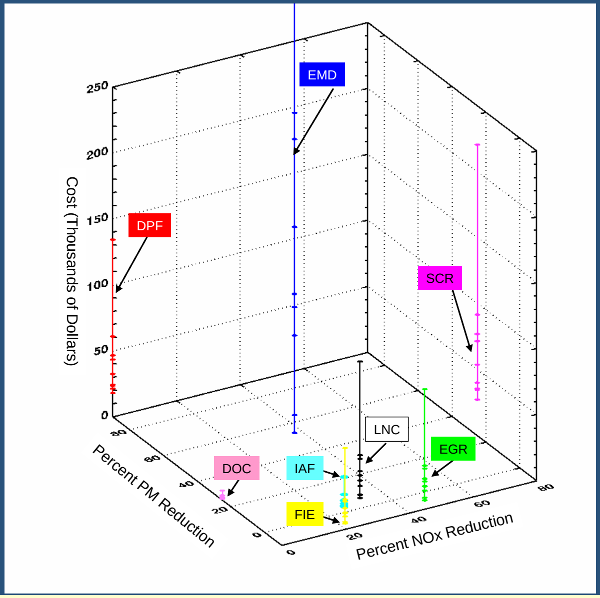
[Corbett and Koehler, 2003; Corbett and Koehler, 2004]

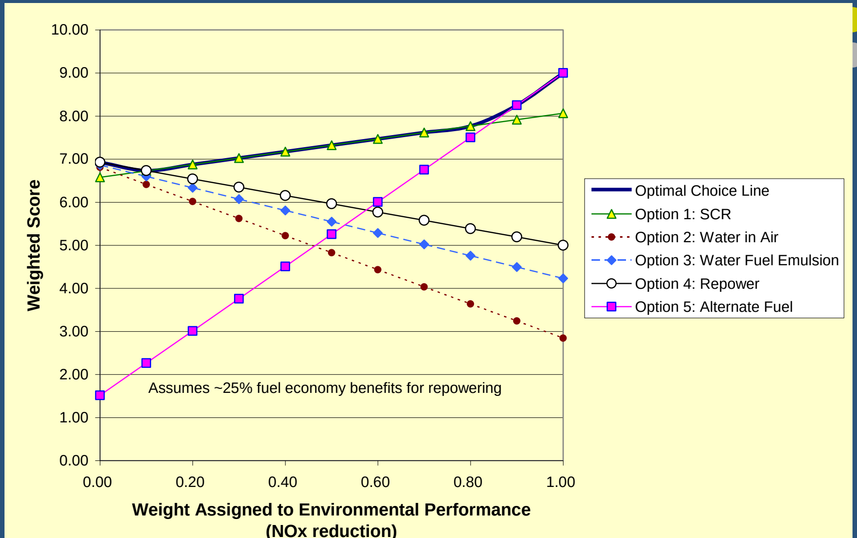
Fuel consumption over past 50 years



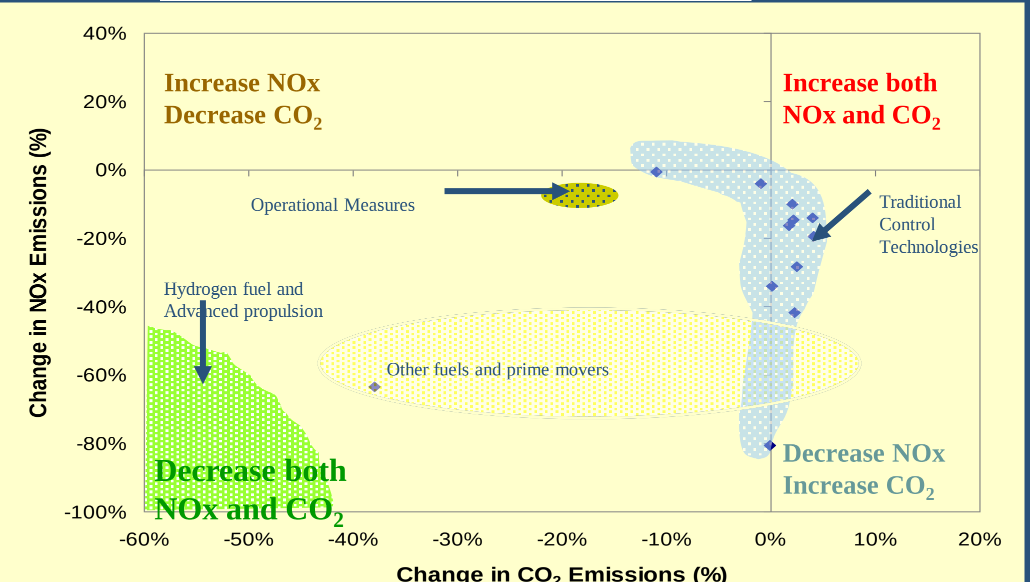
From Eyring et al., Part 1, *JGR*, 2005

Looking for preferred technology frontiers among uncertain, variable alternatives

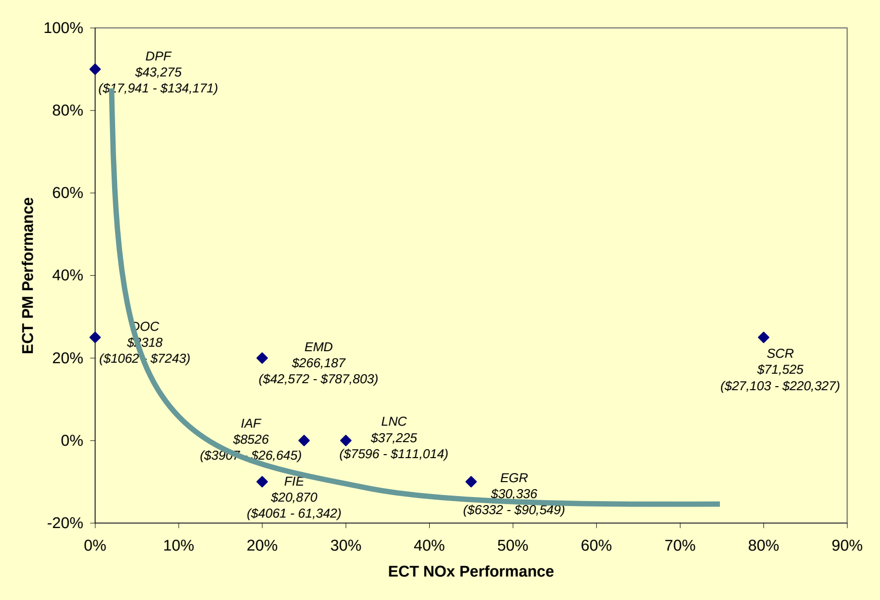




Corbett, J.J., and D.S. Chapman, Decision Framework for Emission Control Technology Selection, *Decision Analysis*, *Manuscript number AW-05-00171, Version 1*, under revision, 2006.

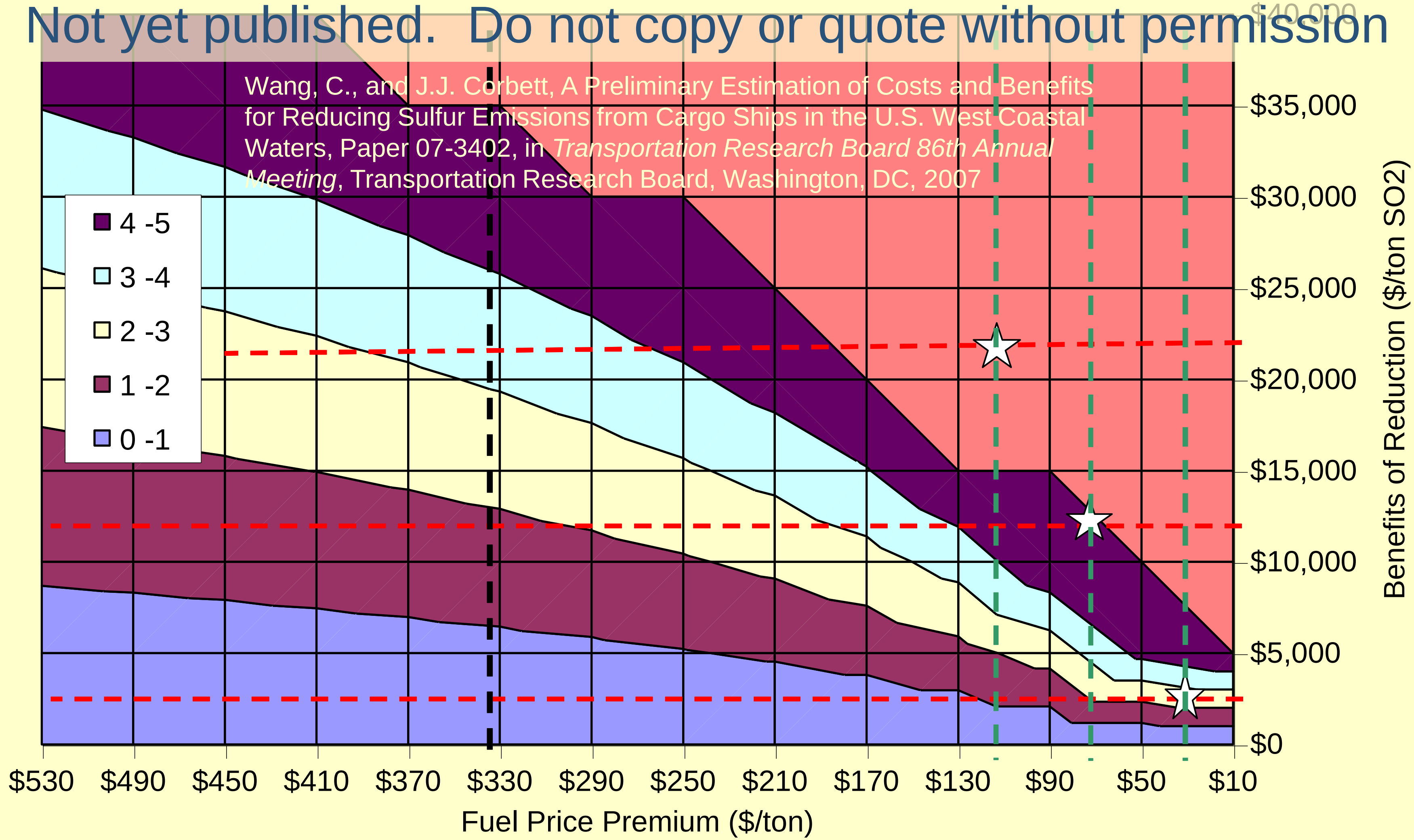


Source: Corbett, *Marine Transportation and Energy Use*, Encyclopedia of Energy, 2004.

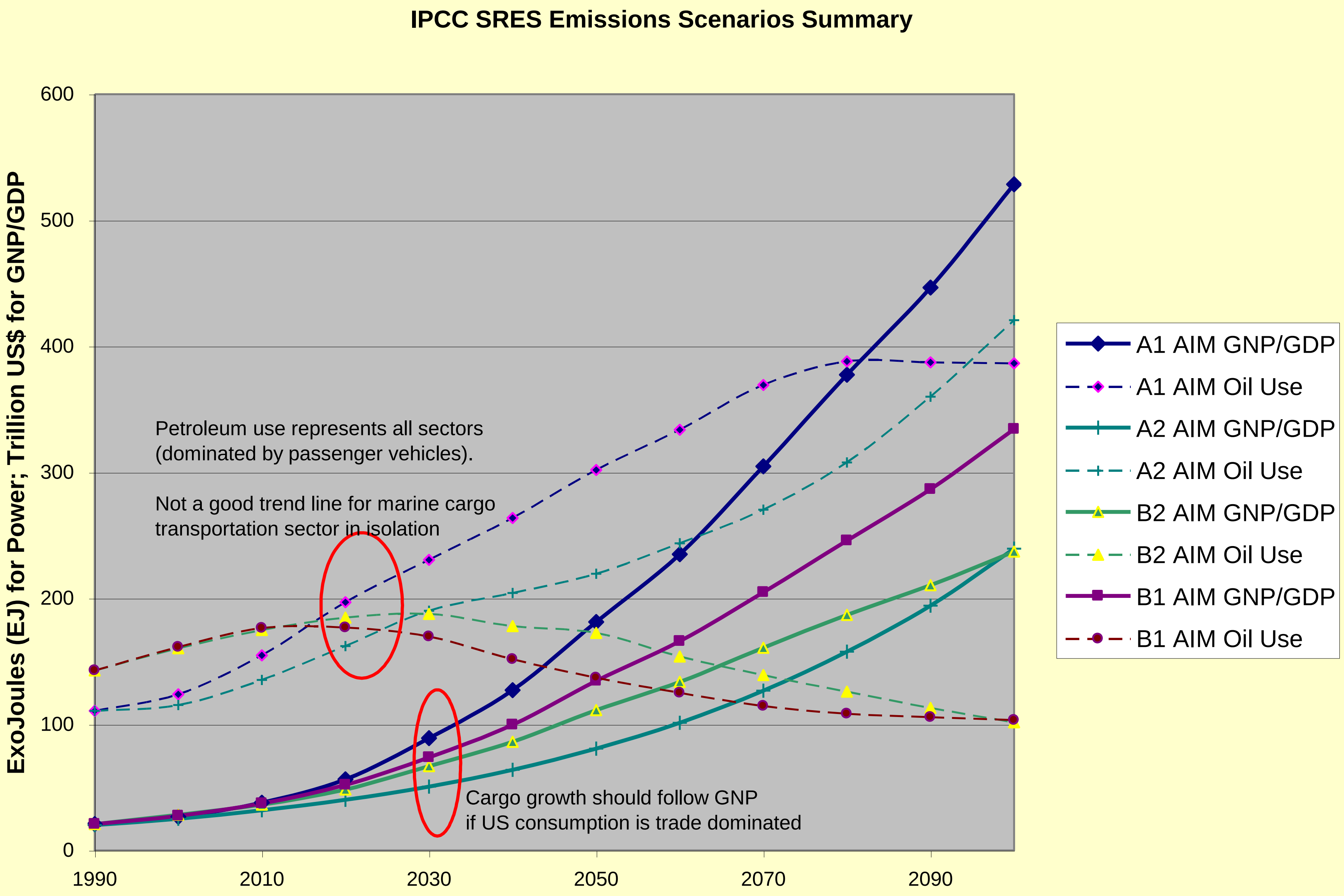


Benefit-cost ratio of fuel switching … and scrubbing

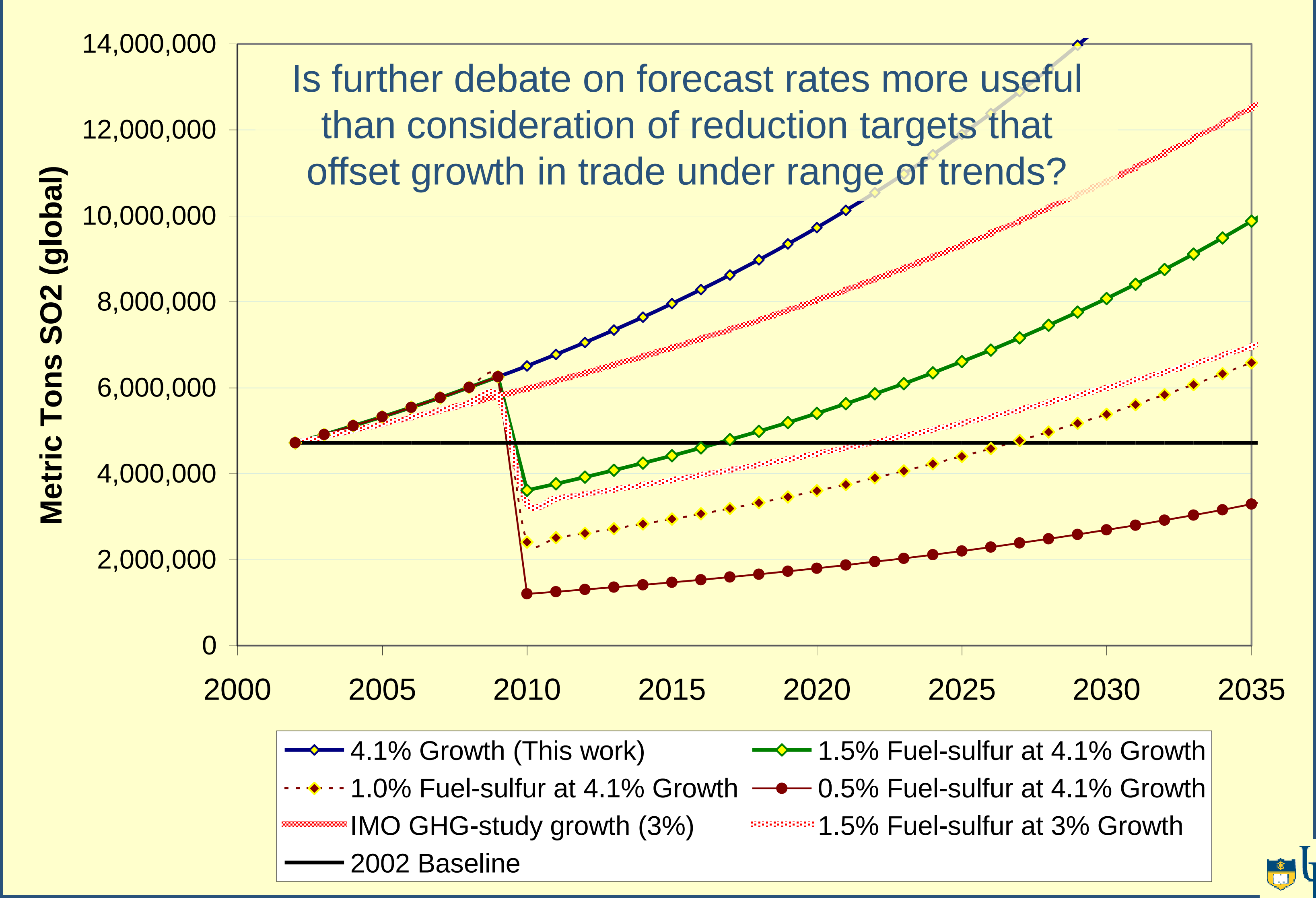
Not yet published. Do not copy or quote without permission



Summary of IPCC forecast trends



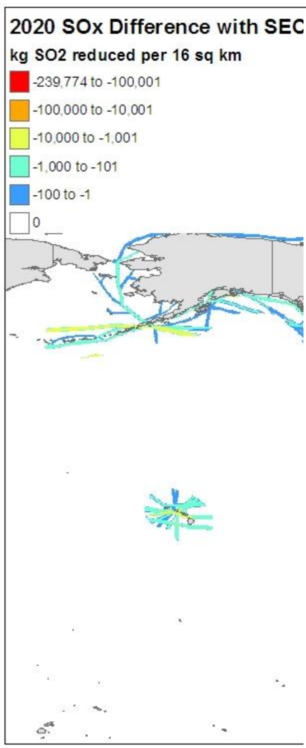
Bounding insights to transform policy debate, focus dialogue

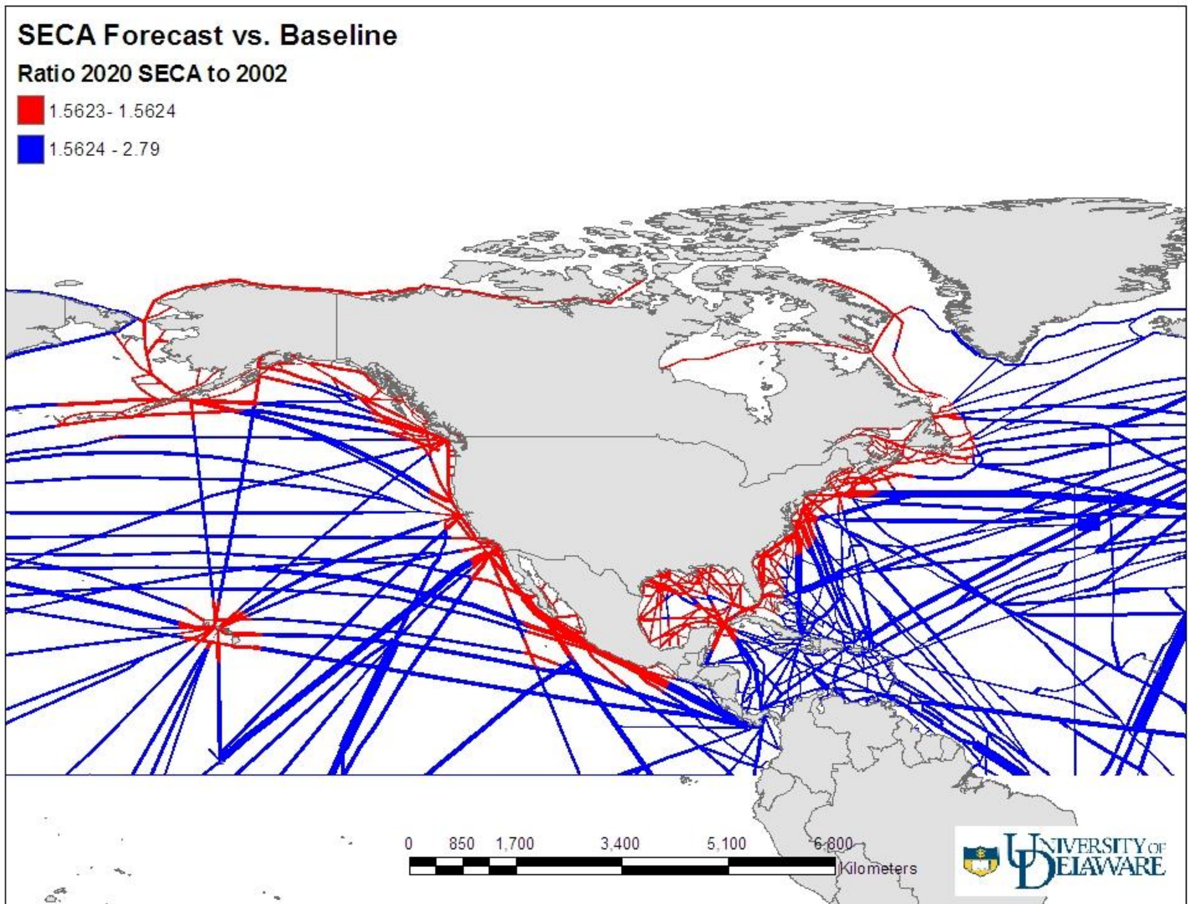


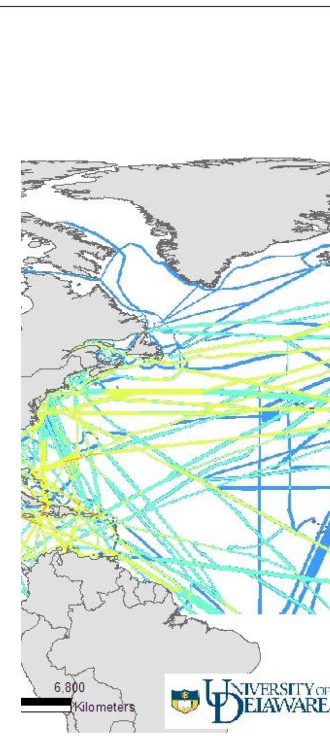
North American Results:

Hypothetical IMO-compliant SECA (1.5% S) reduces future emissions from BAU

… but not compared to base year







- Redu … ion tons … se-year

Freight transport and environment:
multi-scale, multimodal challenge bigger than ships

More sustainable freight logistics, inventory, production, and consumption

Evaluation of economic drivers/barriers to innovation and diffusion of sustainable concepts, regulatory jurisdiction and standards

Design of transportation strategies to achieve economic, energy, and environmental goals that improve stewardship faster than growth

Forecasting trends and alternative mitigation pathways

Intergrated measures of sustainable transportation beyond air pollution

Impacts analysis: Environmental and health effects

Multi-scale characterization: Emissions inventories, fate-transport modeling

Emissions and discharges: Air pollution formation and control technologies

System attributes: Vessel or vehicle, engine, and propulsion design

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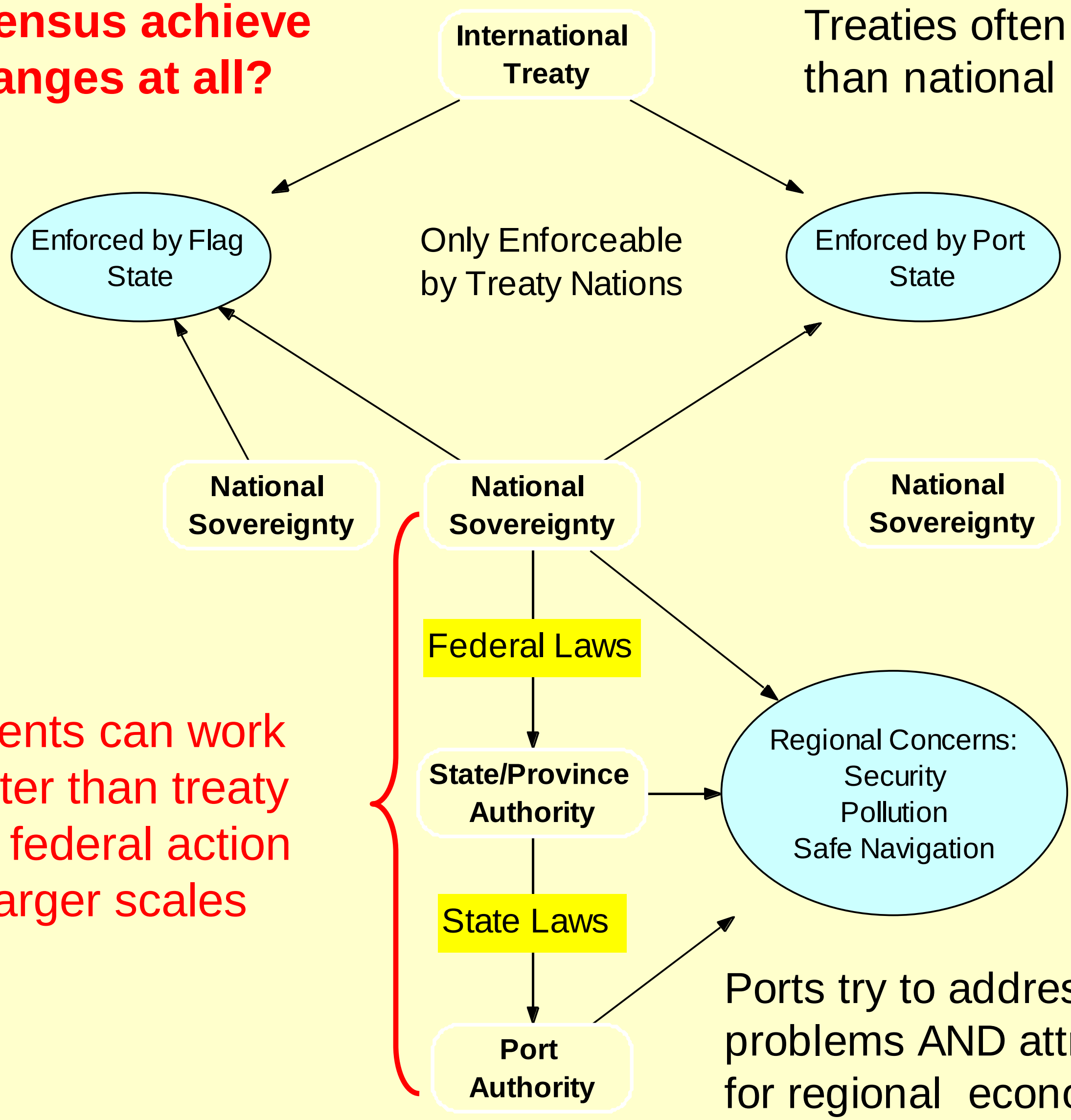
Jurisdictional constraints

Can treaty consensus achieve these target ranges at all?

Treaties often are weaker than national laws



Some nations don't participate, even though their ships sail globally

Economic instruments can work at these levels faster than treaty or multinational or federal action - if compatible at larger scales

Ports try to address policy problems AND attract cargoes for regional economy

Intermodal Comparisons: Infrastructure Factors

	Emissions (g/kg fuel)[2] NO$_x$	CO	Carbon intensity[3] ($/tC)	Fraction of CO_2 (%)	Size of fueling stations (power)	No. of fueling stations
Marine	71	16	950	6	175 MW	28-40[4]
Autos[1]	14	130	2300	56	2.7 MW	180,000
Aircraft	3	17	2100	8.7	240 MW	72[5]
Heavy trucks	30	17	2800	16	20 MW	5,500
Rail	76	9	3500	2.3		

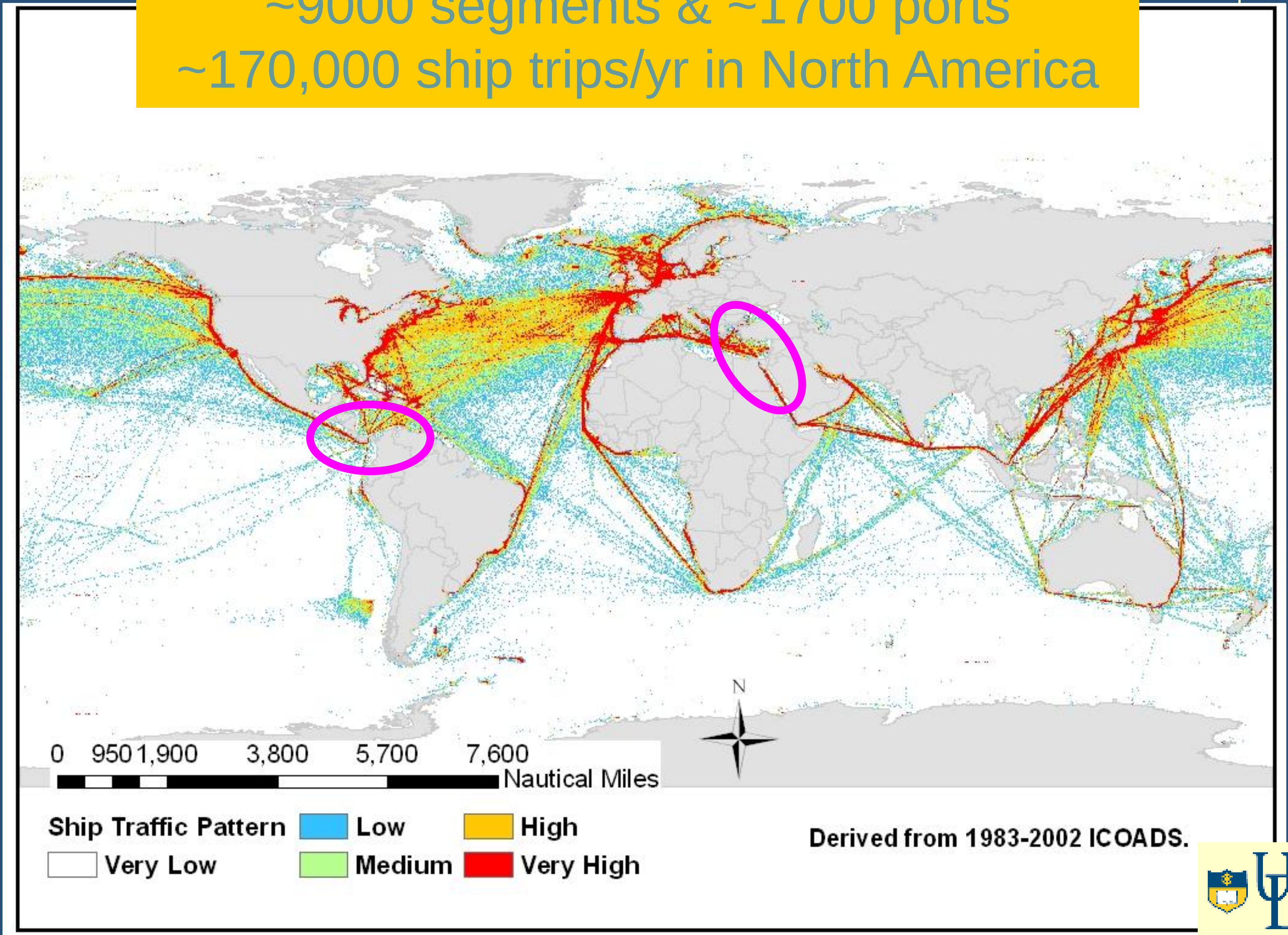
All figures for the United States. All figures rounded to two significant digits. (1) Includes both automobiles and light trucks. (2) Computed using estimated actual emissions and fuel use. (3) End user expenditures divided by carbon emissions. (4) Total of companies in the large U.S. ports providing international marine fuels (@ 4-10 per port). (5) Large hub airports

Source: Farrell, A.E., D.W. Keith, and J.J. Corbett, A strategy for introducing hydrogen into transportation, *Energy Policy*, 31 (13), 1357-1367, 2003

Ships may be preferred niche market for new technology innovation

Building Empirical Network

~9000 segments & ~1700 ports
~170,000 ship trips/yr in North America



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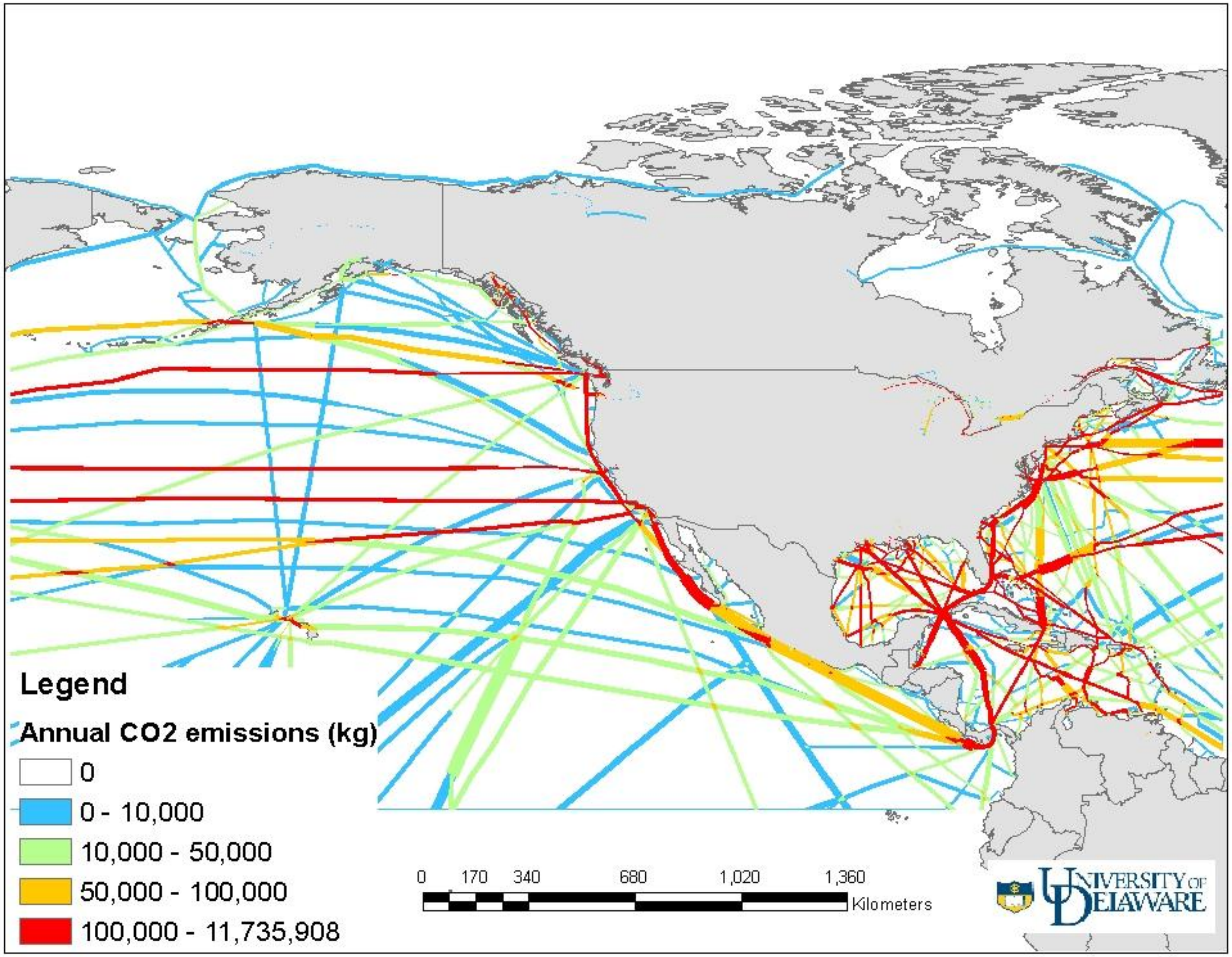
Spatial Distribution in Multimodal Context



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