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# **Decision Support Model for the Management of Ballast Water in the Delaware Bay and Other Port Ecosystems**

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# Motivations, Objectives, Key Questions

- IMO/BWC (2004): **Performance Standards** for all ships
  - Right of nations to establish more stringent prevention standards
  - 2004 IMO resolution calls for “suitable decision-making tool” to analyze BW management protocols
- **Model objective**: Tool to better understand the complexities, uncertainties, and support the best management actions

Are current standards feasible?

Could technologies meet stricter standards?

What might these standards cost the industry?

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## What have we learned from the model so far?

- Range of technology efficiencies meet IMO standards
  - A key factor in technology choice is voyage duration
  - Port protection may cost ~\$150 to \$240 Million/yr
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## Ballast Water Discharge Decision Support Model

$$\min \sum TC_{k,v} \cdot X_{k,v}$$

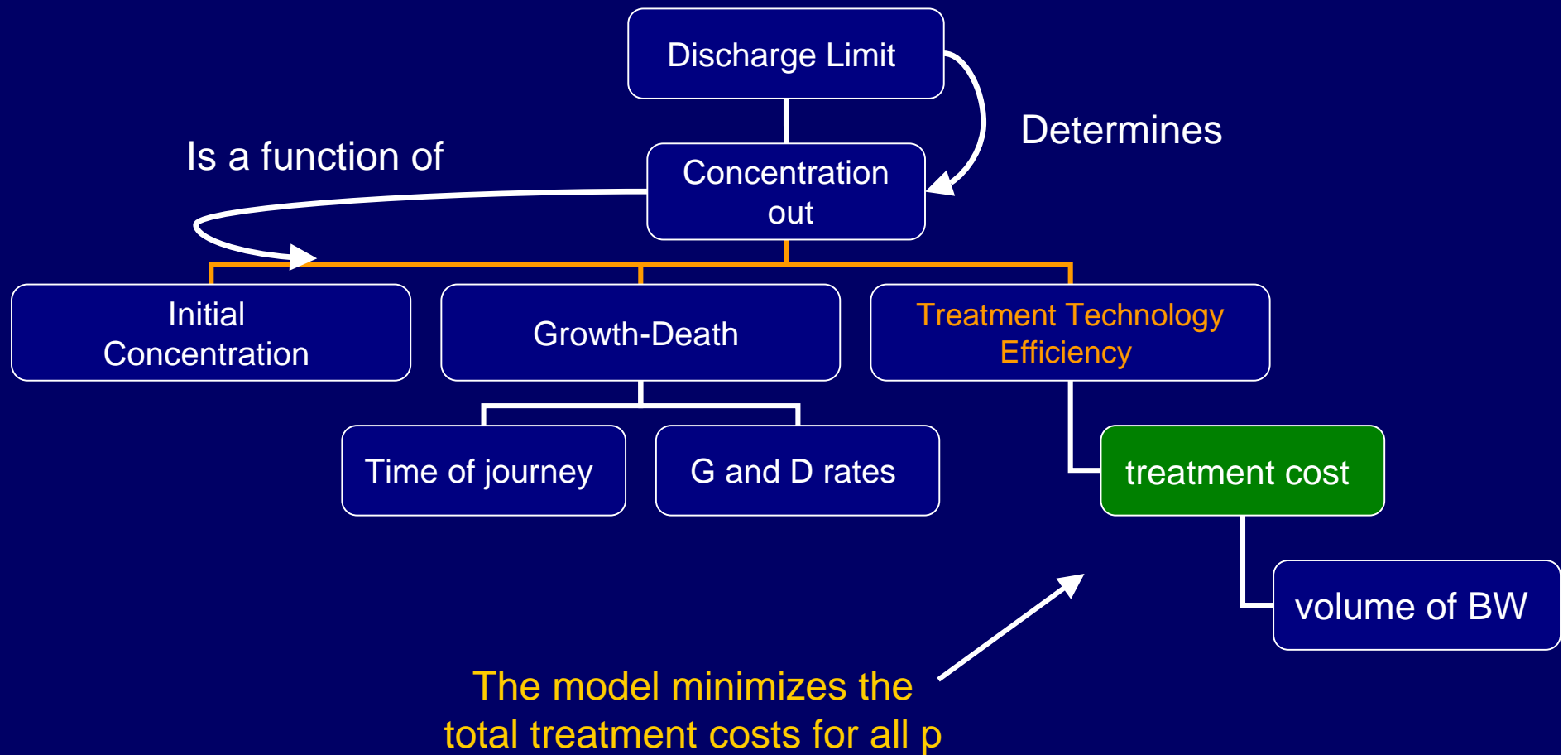
Subject to

$$CVOUT_{p,v} \leq LIMOUT_p$$

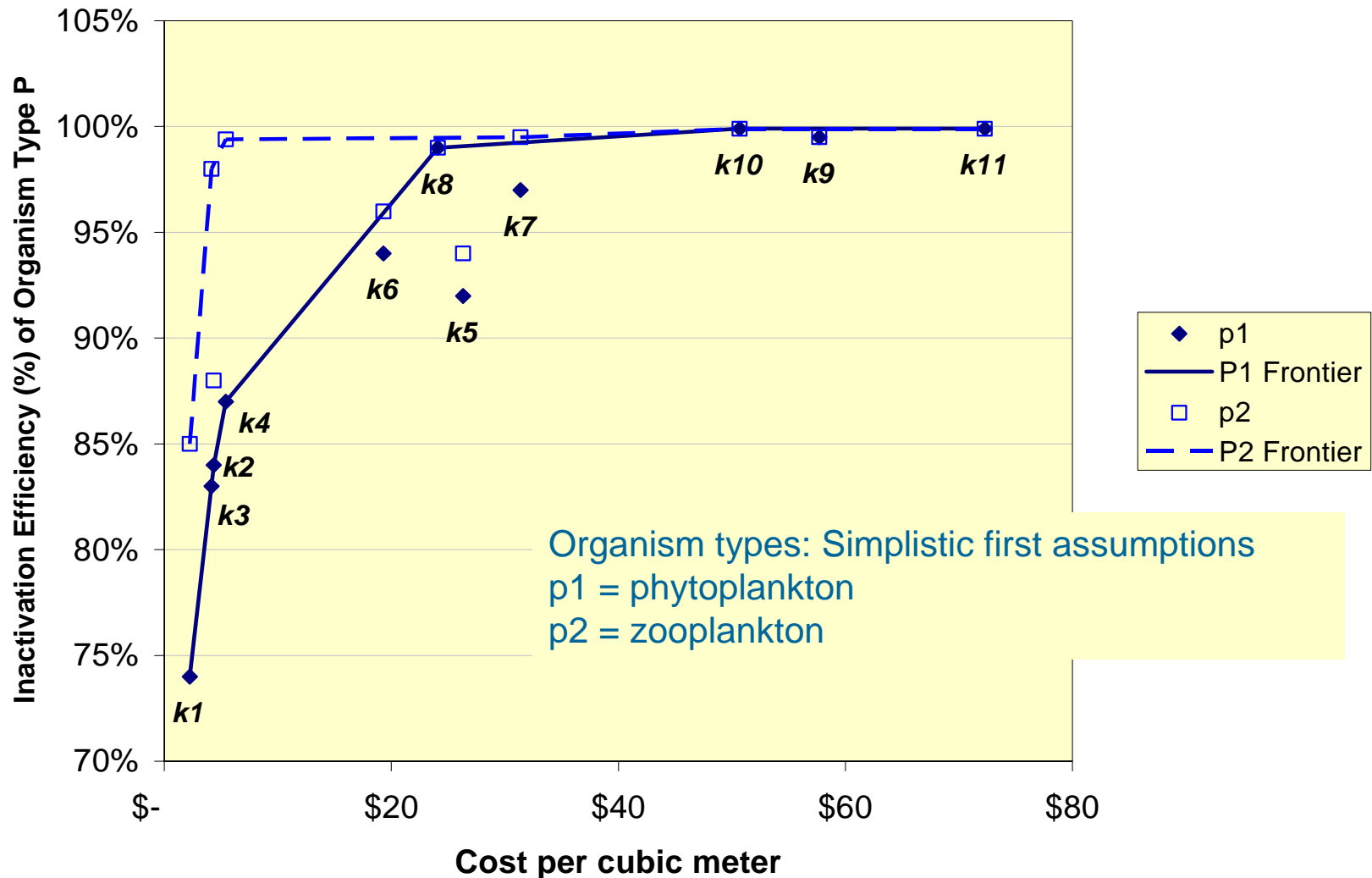
$$X_{k,v} = bin \ 1/0$$

Objective function **minimizes total costs for a vessel or fleet** by choosing the cheapest technology or technology combinations that meet regulatory limits

# Parameters and Calculations



# Emerging Technology Frontier



Derived from Taylor et al, 2002; Matheickal & Raaymakers, 2004

# Ongoing Case Study: **Delaware Bay**

We model 1,142 international journeys, all "IMPORTING" ballast water



- 5th largest port complex in the US in total waterborne commerce
- 2nd largest oil port in the US
- ~70 million tons of cargo/yr
- Major Ports: Philadelphia, PA; Camden, Gloucester City, and Salem, NJ; Wilmington, DE

# Concentration of Organisms IN:

- C IN varies with geographical location, season of the year, depth, time of the day, nutrients, etc.

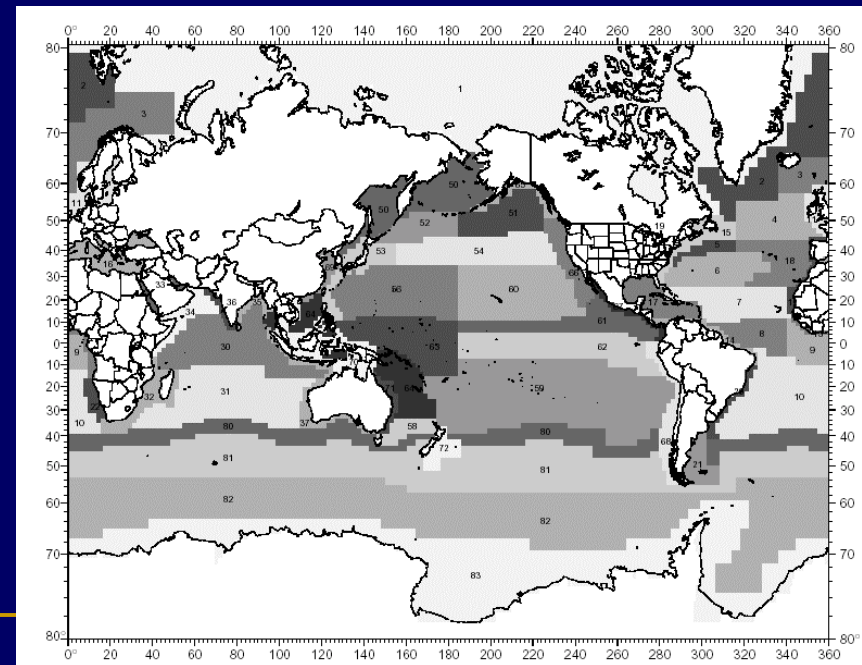
Assumption:

C IN randomly assigned

$$1 \cdot 10^6 \text{ m}^{-3} < p1 < 1 \cdot 10^{10} \text{ m}^{-3}$$

$$1 \cdot 10^2 \text{ m}^{-3} < p2 < 2 \cdot 10^4 \text{ m}^{-3}$$

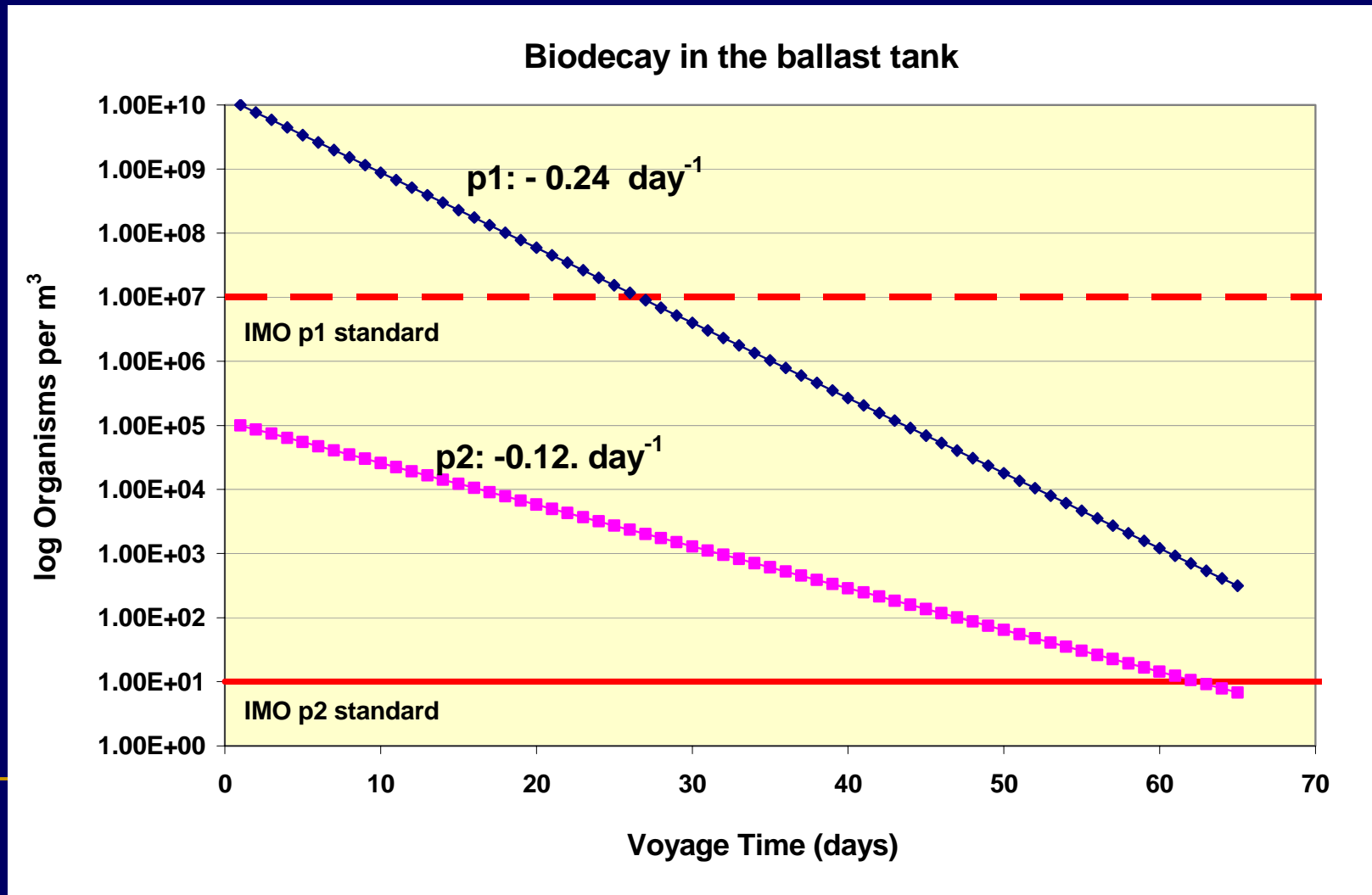
## Biogeochemical provinces



(Longhurst, 1998)

# Growth and Death in the BW Tank:

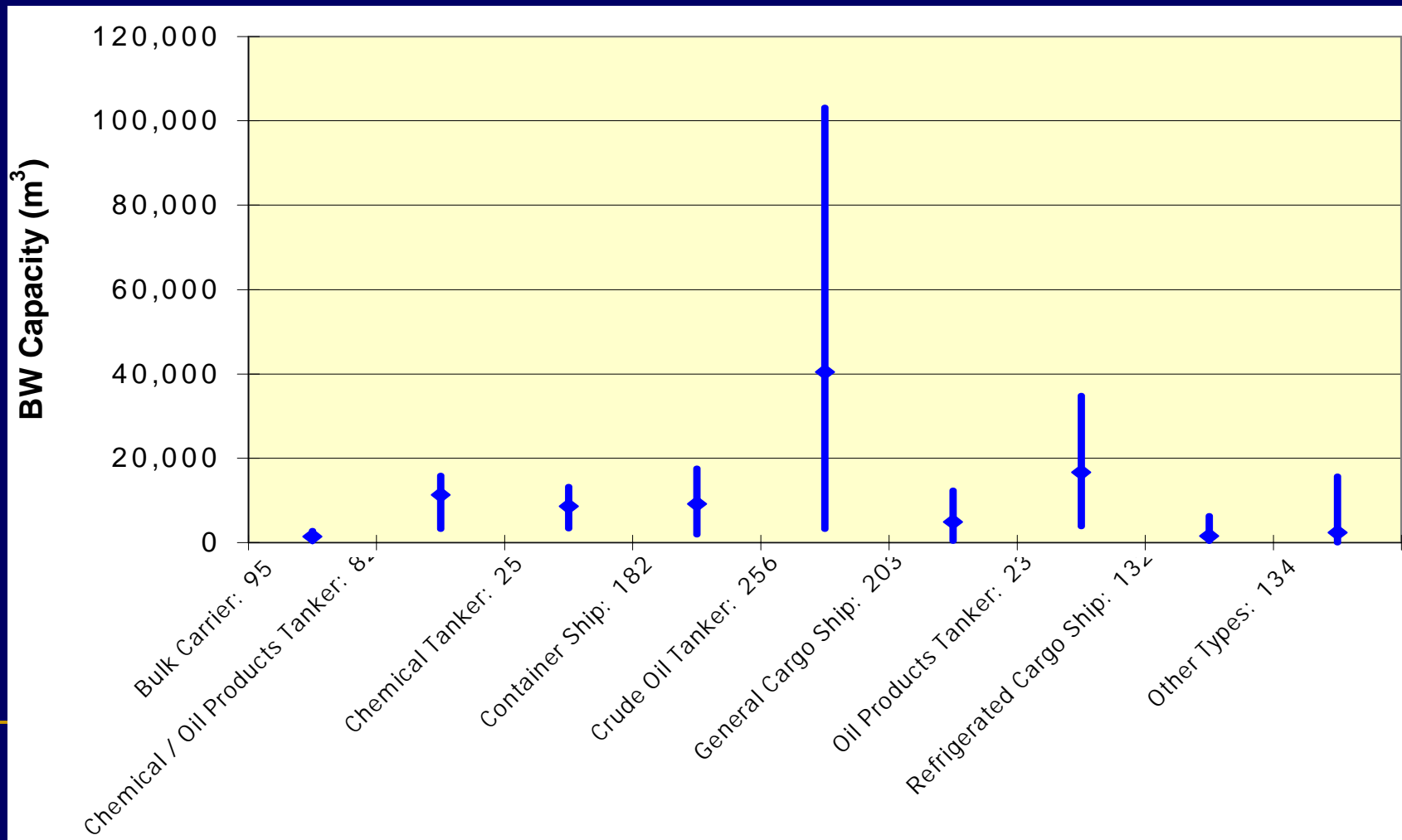
Assumption: all p grow according to  $N_{t+1} = N_t \cdot e^{(G-D)t}$



# Ballast Water Volume

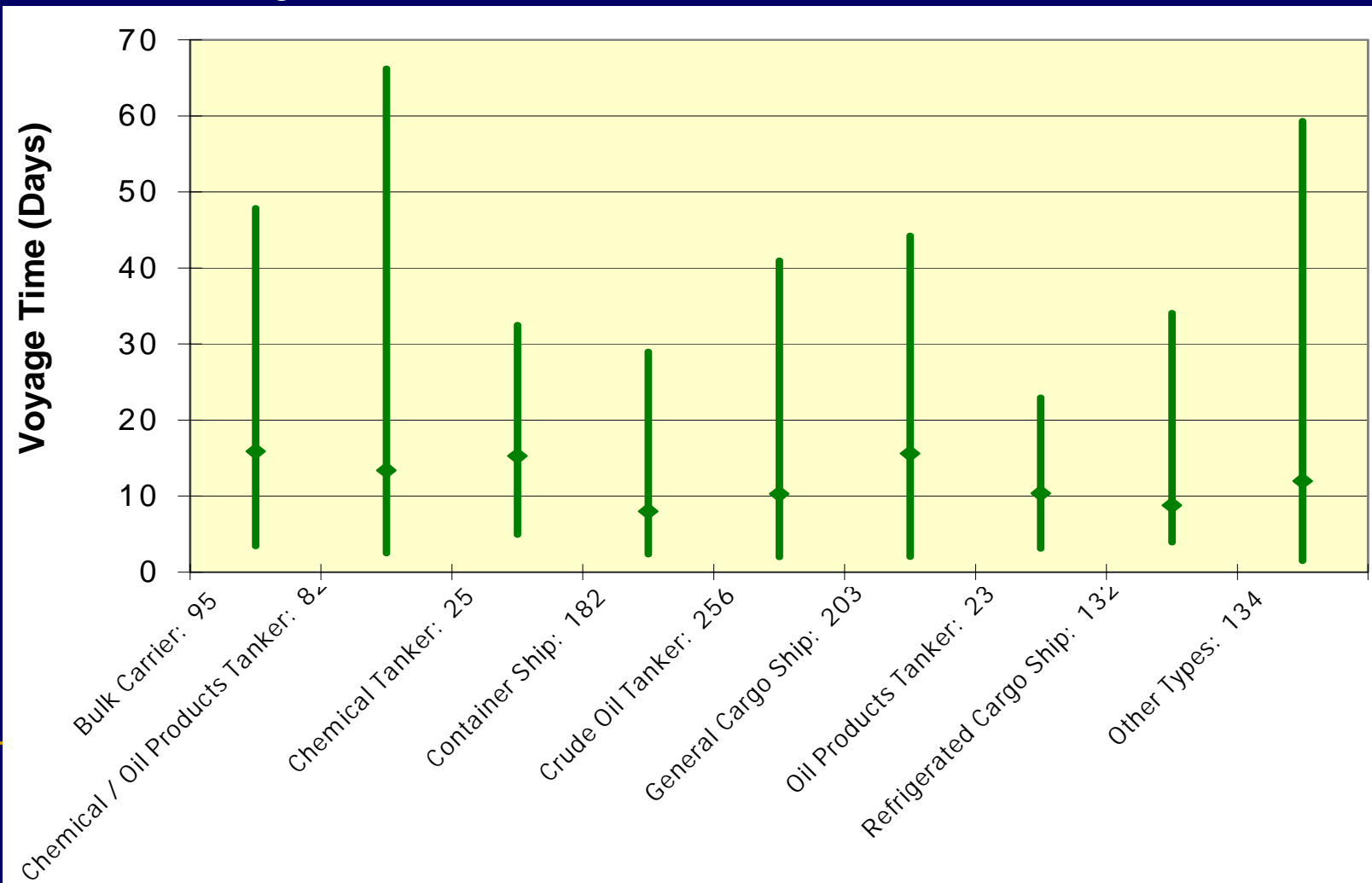
Assumptions: BWV = max. BW capacity of the ship

No residual BW/ no carry over/ no sediments/no cysts in the BW tank



# Journey Time

Assumption: No time lags for techs to reach max. efficiency



# Technology Costs and Efficiencies

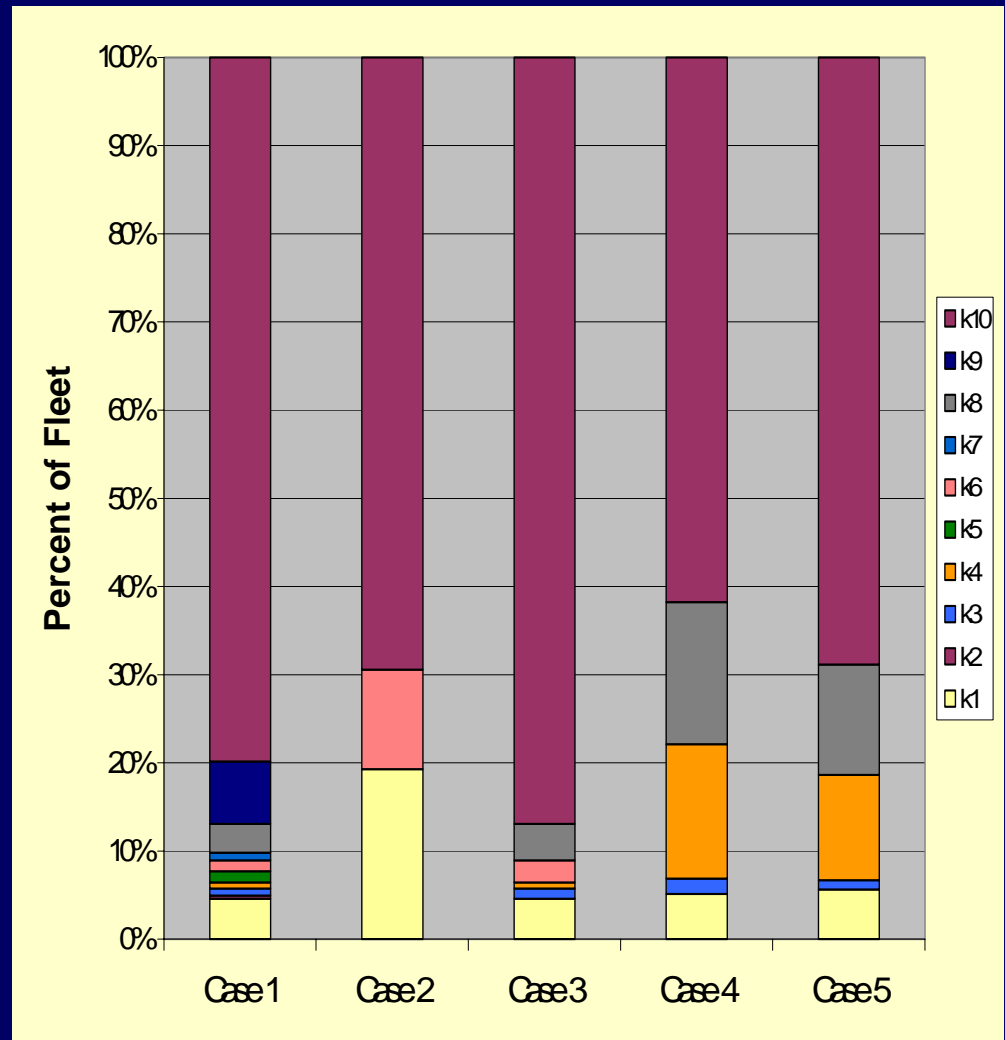
Assumption: any technology can be used in any ship

Techn.	Total Cost US\$/ m <sup>3</sup>		Efficiency (% eliminated)	
	Low Est.	High Est.	p1	p2
k1	\$ 1.45	\$ 2.25	74 %	85 %
k2	3.35	4.35	84	88
k3	4.16	4.16	83	90
k4	5.42	5.42	87	92
k5	6.49	26.33	92	94
k6	7.07	19.31	94	96
k7	9.80	31.39	97	97
k8	14.46	24.10	99	99
k9	16.28	57.71	99.5	99.5
k10	16.87	50.69	99.9	99.9

(Taylor et al. 2002)

# We are running a variety of cases

Case	Cost	Org. Conc. variability	Limit
1	Low	Low	Vessel
2	Low	Low	Port
3	High	Low	Vessel
4	High	Low	Port
5	High	High	Port

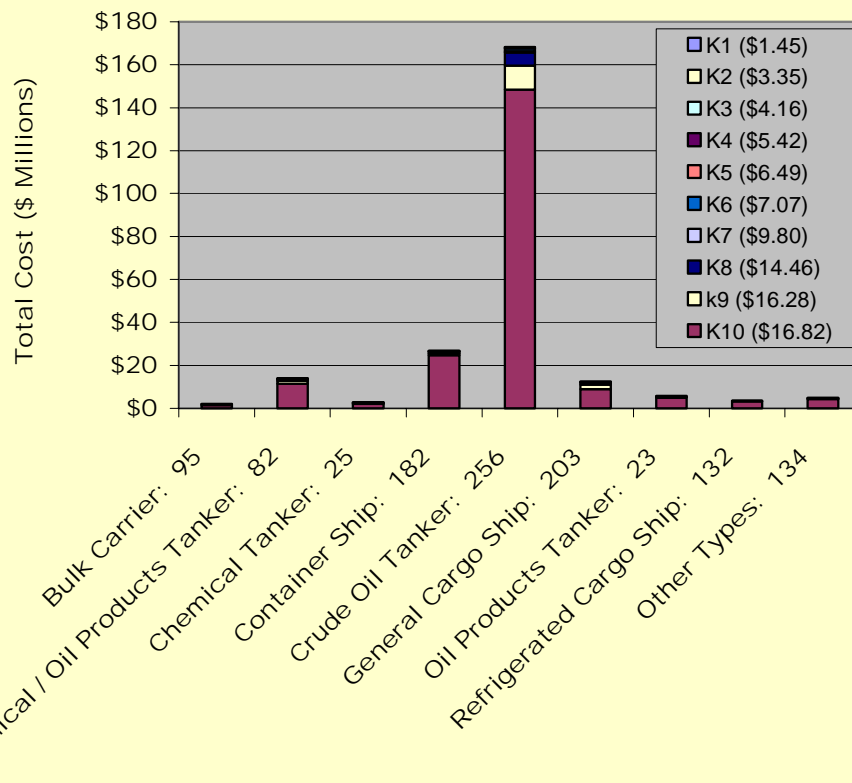


# Vessel-by-Vessel and Port-wide Scenarios

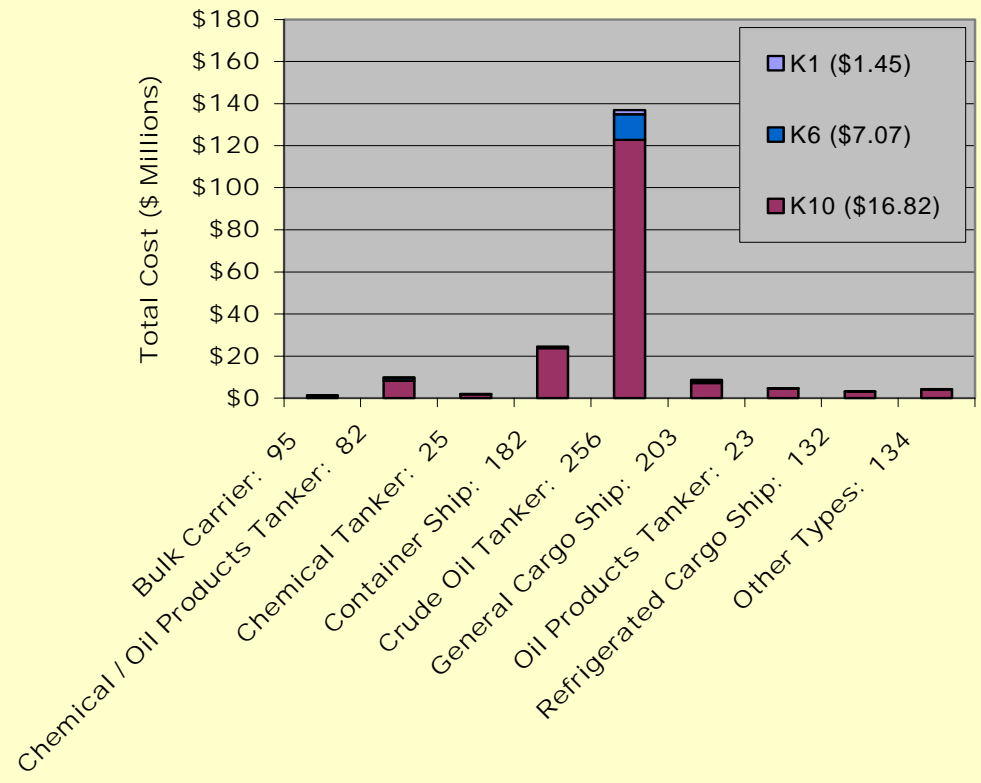
Both comply with IMO, but port scenario applies standard across all discharges

- High-end technology choice dominates total cost
- Meeting IMO standard on port-wide basis less costly

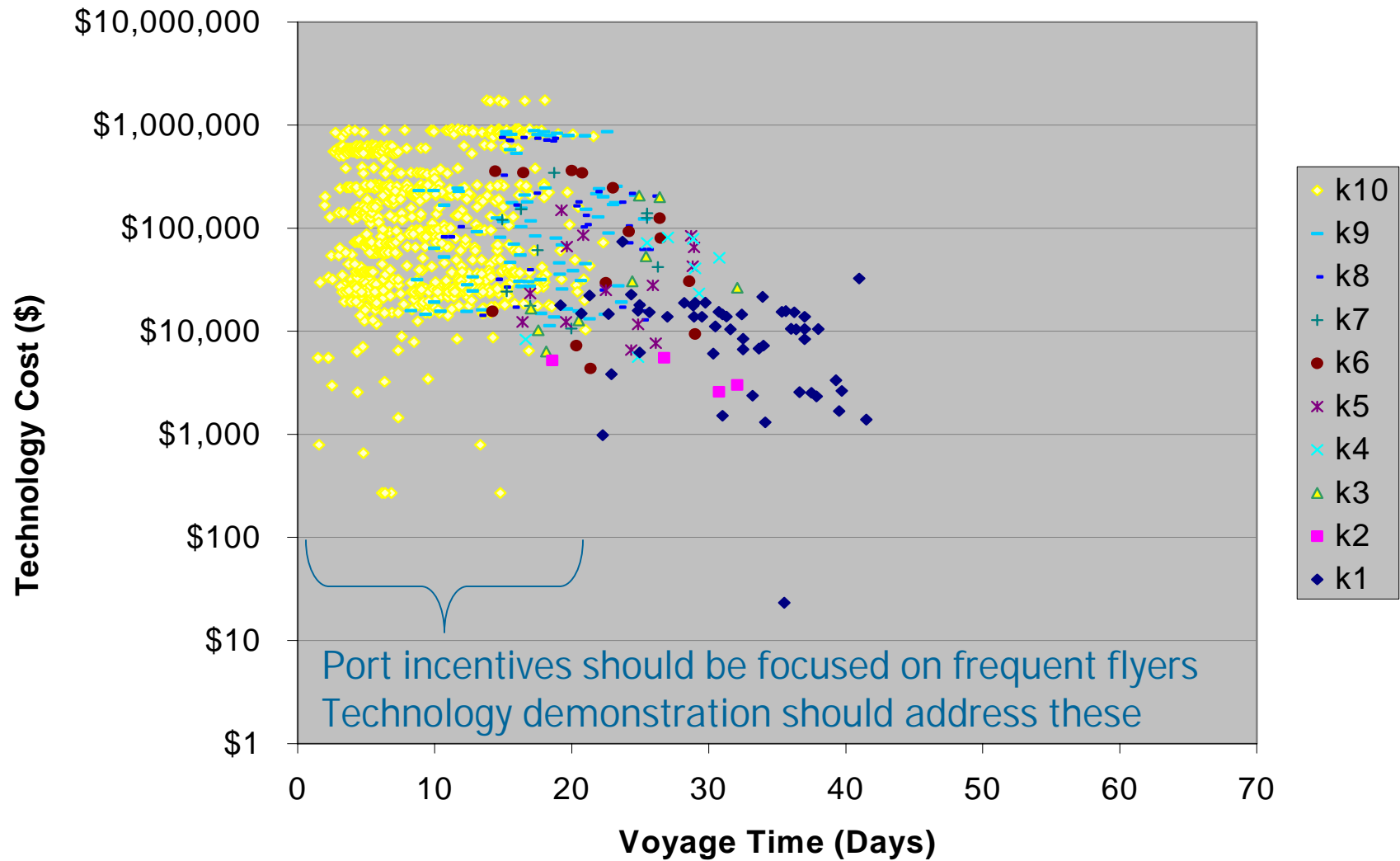
### Vessel-by-vessel limit



### Port-wide limit



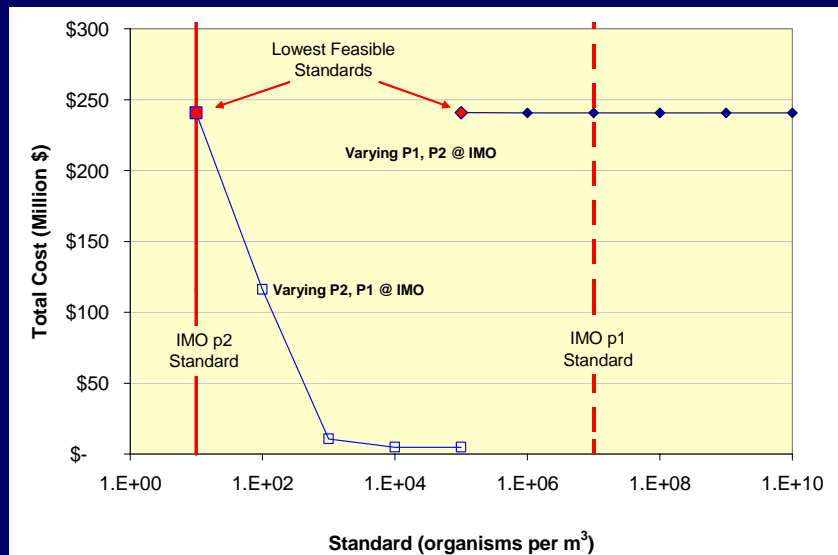
# Shorter voyages need stricter technology



# Sensitivity to IMO discharge standard

Varied discharge standard  $\pm$  two orders of magnitude

- The model reveals feasibility limits
- Varying p2 standards affects costs
- Stricter p1 standard costs the same as the IMO
- p1 limits could be reduced by two orders of magnitude for same fleetwide treatment costs



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## What have we learned from the model so far?

- Range of technology efficiencies meet IMO standards but dominant technology (ies) must be very effective
  - A key factor in technology choice is voyage duration organisms decay makes compliance less costly, assuming they are not growing as in Gollasch et al (2000)
  - Port protection may cost ~\$150 to \$240 Million/yr
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*Questions and comments  
are welcome!*

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