Tidal Power

CAUSE 2003 Final Project

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Overview

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- Historical Aspects
- New Technology from an Old Idea
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- Severn Project – Will There Ever Be a Barrage?
- Long Island Sound Barrage Case Study for the Future
- Fundy Bay - Case Study
  - Environmental Impacts of Tidal Energy
  - Economics of Tidal Energy
  - Policy Concerns
  - Other Tidal Schemes
- A More Futuristic Approach –Artificial Reef Program: Offshore Rigs

Basic Science of the Tides

Lunar Tidal Dynamics

Tidal Basics

- Most locations have two tidal cycles per day: 12 hours, 25 minutes
- Essentially caused by interaction of moon, earth, and sun centrifugal forces
- Diurnal tides are generated because the maxima and minima in each daily rotation are unequal in amplitude

Newton's Law of Gravitational State

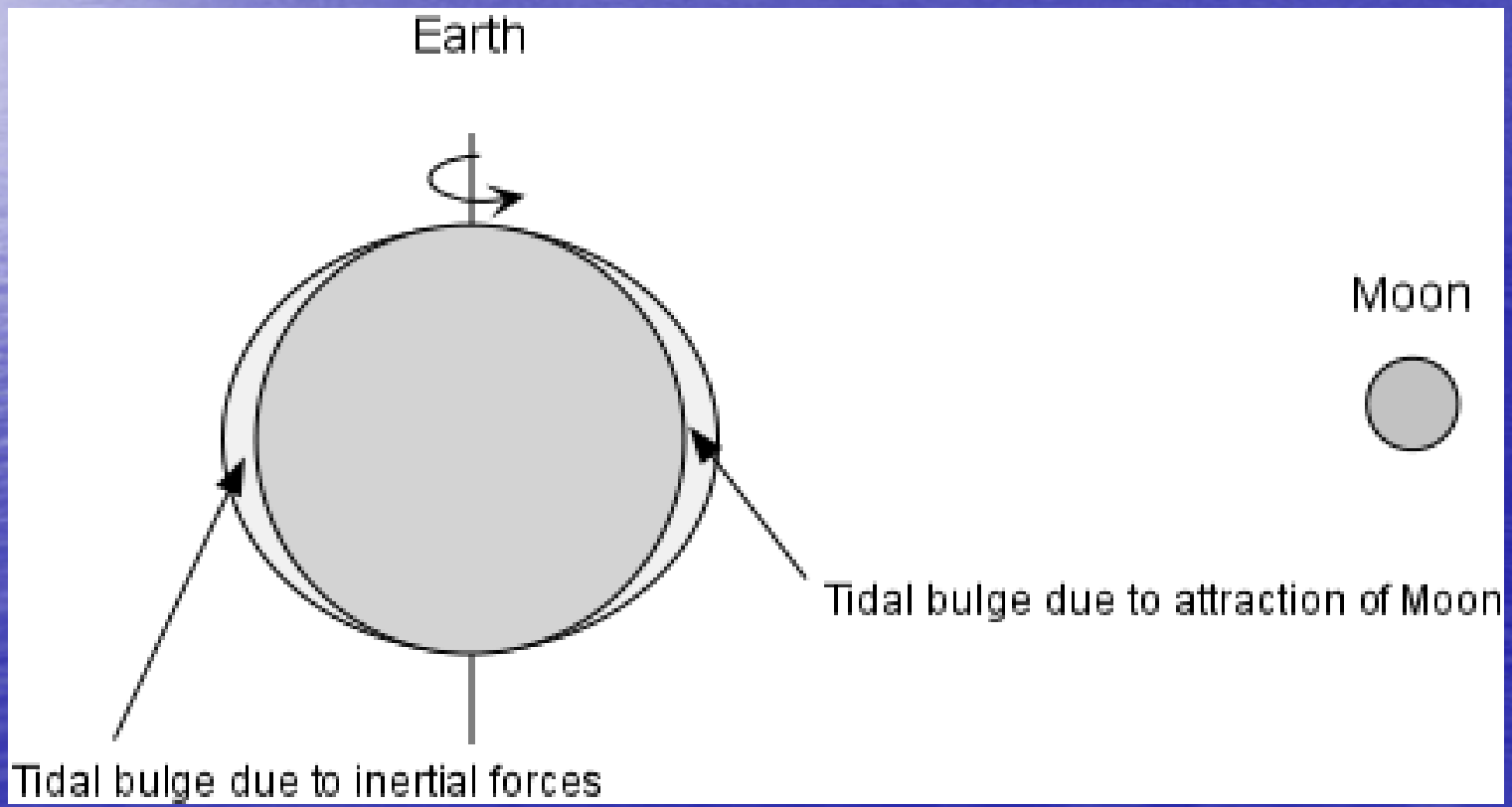
$$F = G \frac{m1m2}{R^2}$$

Particle (Water)

Radius of Earth

$$\text{Tidal Force} = \frac{2Gmm_1a}{R^3}$$

Distance between Earth and Moon



Tidal Facts

- Tidal Range = Distance between high tide mark and low tide mark
- Largest Ranges→ Coastal Regions with extreme depth gradient (Mouzel = excellent tidal range)
- Smallest Ranges→ Open Ocean (<.5 m)

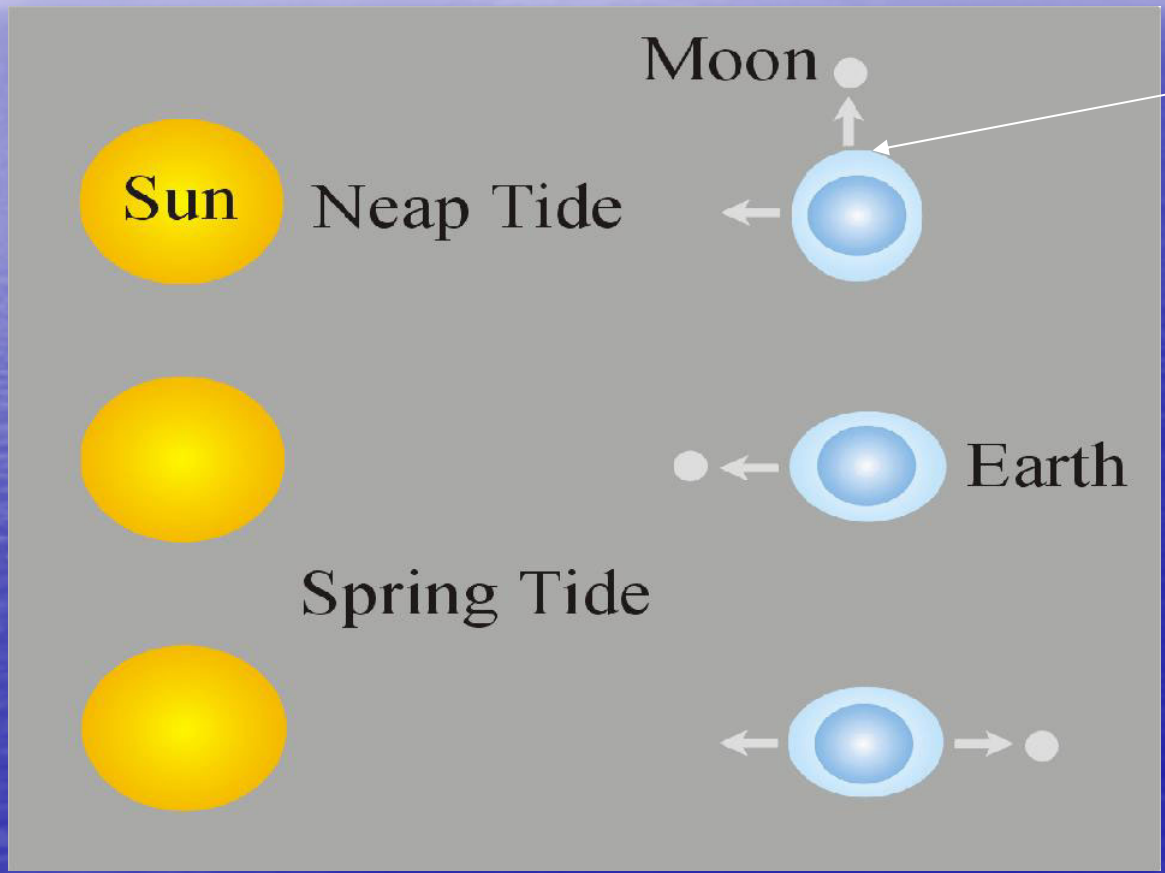
Spring Tides

- Year round
- Occur during full moon and new moon
- Due to the linear pattern of SME
- Causes stronger tides: increased current and tidal ranges

Neap Tides

- Moon and sun are perpendicular to each other
- Weak currents, lower tidal ranges
- Occur during quarter moons

Neap Tides Versus Spring Tides



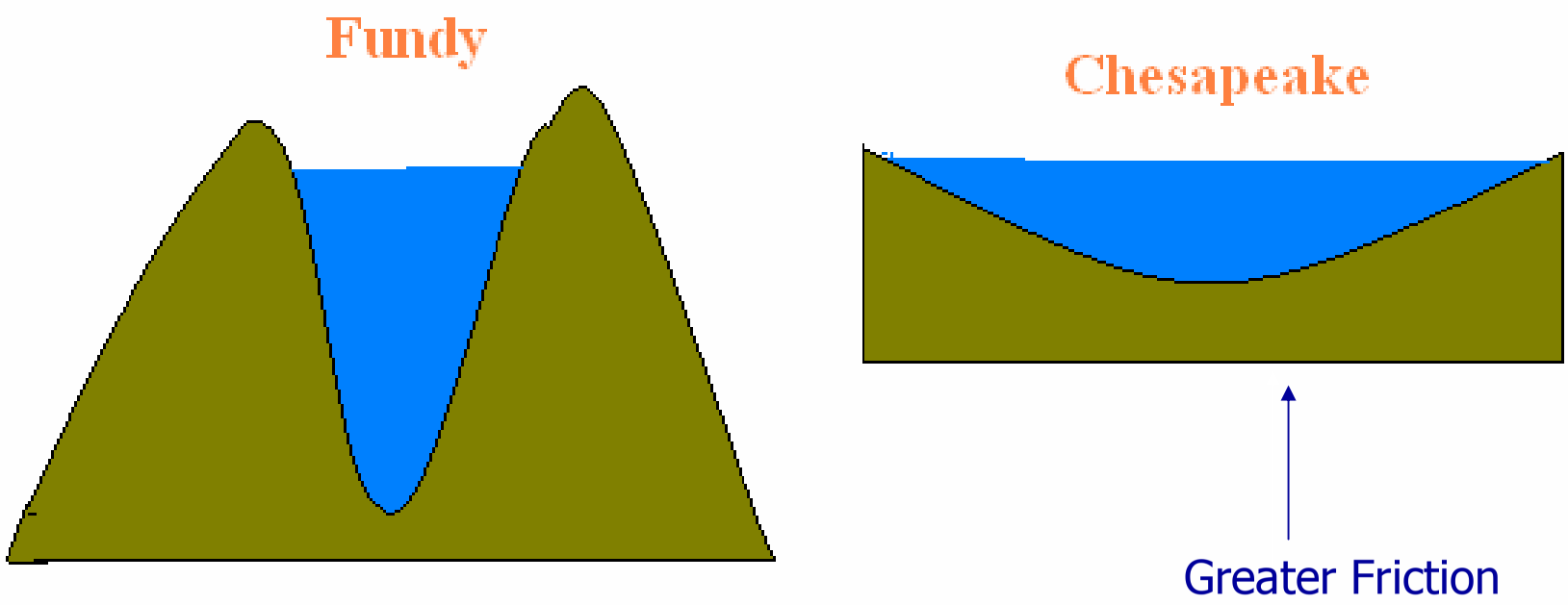
Barrage Logistics

- Largest surface area, greatest tidal range
  - Square Effect
- Effects of ecosystem (fish, sediment, etc.)
- Proximity to population

Waterway Measurement Logistics

	Mean Tidal Amplitude(m)	Basin Area (km^2)
La Rance, France	4	17
Bay of Fundy, Canada	5.5	240
Annapolis, Nova Scotia	3.2	6
Severn Estuary	4	420
Garolim Bay, South Korea	2.5	85

Bay of Fundy VS Chesapeake Bay



Historical Aspects

Ancient Tide Mills

- During the Roman occupation of England, tide mills were built to grind grain and corn
- These tide mills operated by storing water behind a dam during high tide. As the tide receded the water was slowly let out from behind the dam in order to power the mill.

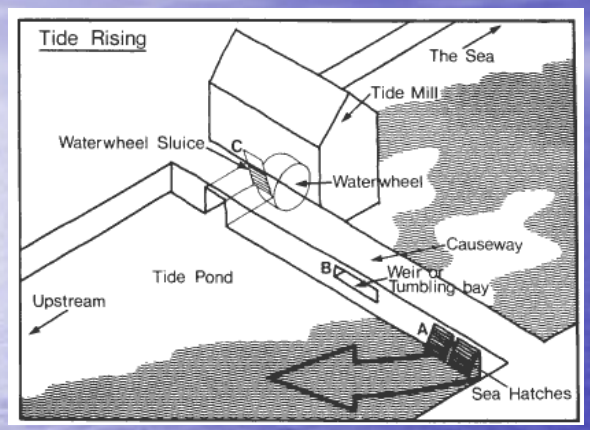
Nendrum Monastic Tidal Site

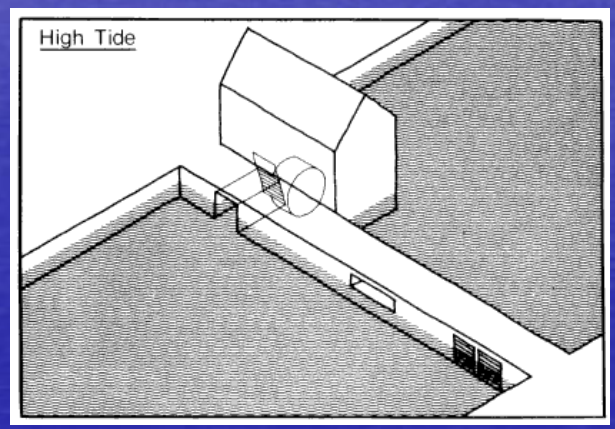
- Discovered in 1999
- Unveiled was a stone built tidal mill and evidence of an ancient tidal mill dating back to 787 A.D.

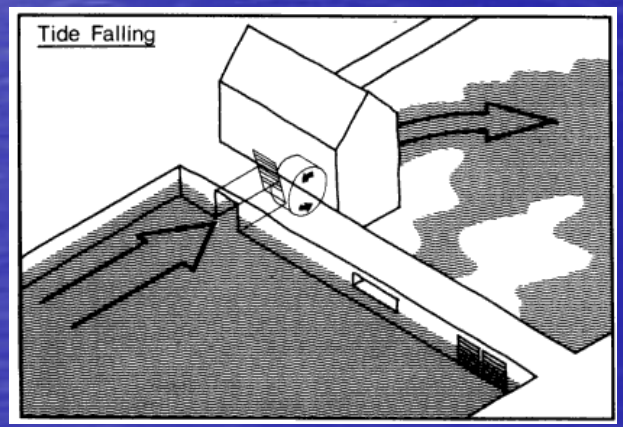
Eling Mill

- The mill was included in the Domesday Survey of 1086
- Originally milled four tons of flour each day at maximum output
- Rebuilt many times, but operates in the same manner

Eling Mill – How it Works







Eling Mill

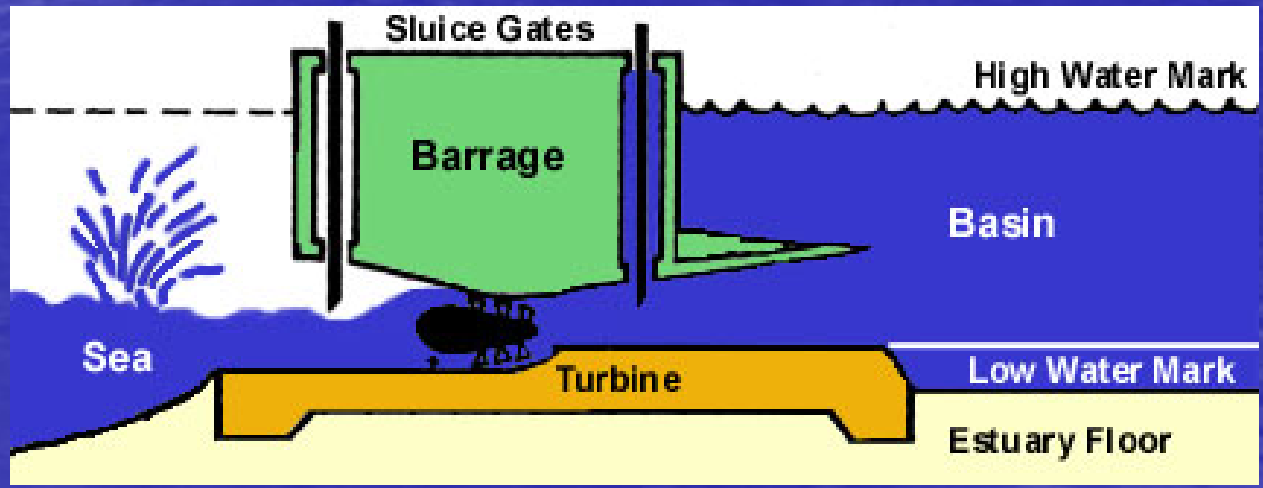
New Technology from an Old Idea

Industrial Revolution

- Brought cheap energy in the form of electricity
- Small tidal mills were replaced with large steam-powered roller mills
- Paleotechnic period means full steam ahead with little though of what was happening to the environment

From Milling to Electricity

- Most common generating system is the ebb generating system
- Double effect turbines are now becoming technologically feasible



Construction

- Caissons are manufactured at shore-based construction yards are delivered to water sites by barges and then positioned by cranes to allow for the structures to correctly settle on the marine floor.
- Another method calls for constructing diaphragm walls of reinforced concrete within a temporary sand island.

Location

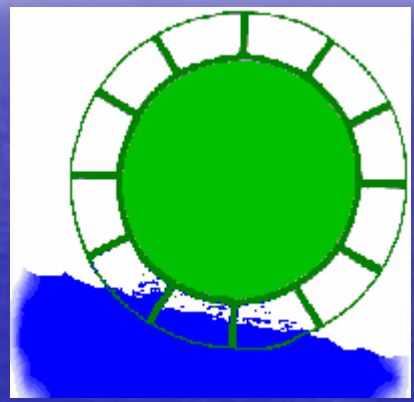
- Tidal mills were usually built on inlets branching off tidal estuaries.
- An estuary is a wide part of a river where it meets the sea.
- Tidal estuaries are characterized by narrow, shallow channels with a relatively constant width and depth.
- Tides are greatly amplified in these areas of smaller volume, which causes the tide to travel up the river.

Tidal Barrage

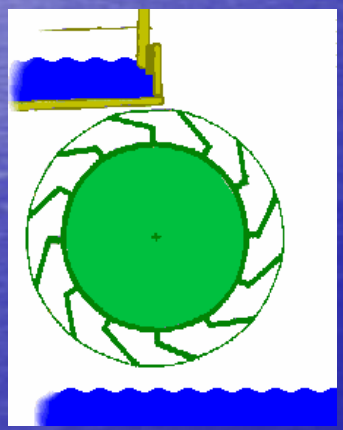
- Similar to a dam
- Structure must span the entire width and height of the estuary

Evolution of Turbine Types

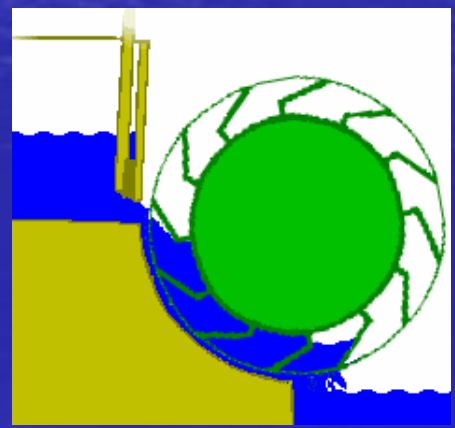
- Waterwheel turbines were used in tidal mills



Undershot



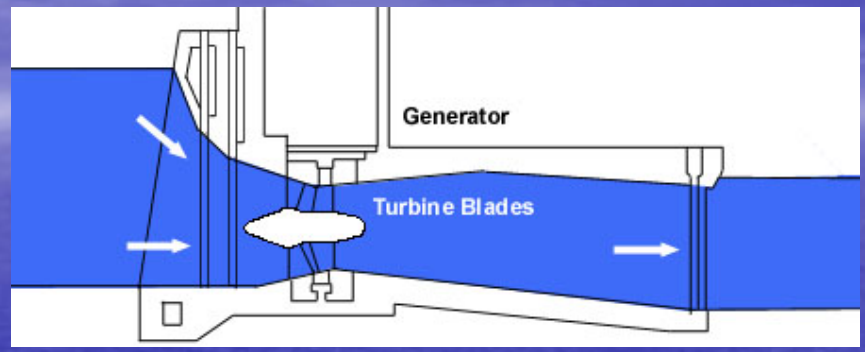
Overshot



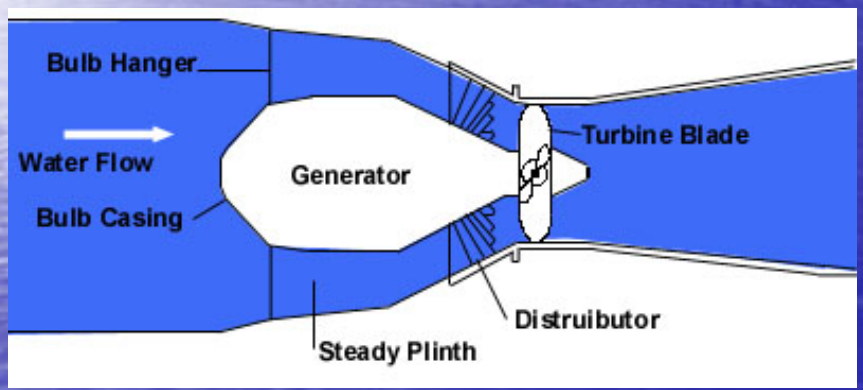
Breast-shot

Recent Turbines

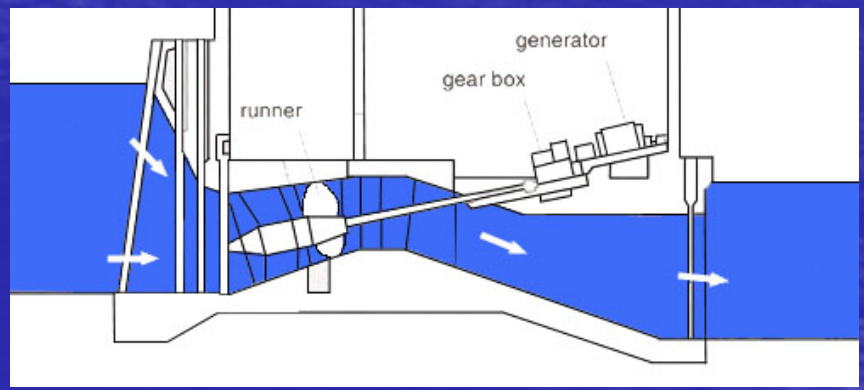
- Bulb, Rim, and Tubular



Rim Turbine (Copyright Boyle, 1996)



Bulb Turbine (Copyright Boyle, 1996)



Tubular Turbine (Copyright Boyle, 1996)

La Rance Case Study

La Rance Tidal Power Plant

- Only full scale power station of its type in the world
- Located in northern France on the La Rance River

La Rance

- Completed in 1967 after 25 years of studies and six years of construction
- 24 bulb turbines, each capable of producing ten megawatts of power
- The dam is 2460 feet (750 meters) long, and 43 feet (13 meters) high
- One of the greatest tidal ranges in the world, at 13.5m.

La Rance Turbines

- Bulb turbines
- The blades of the turbine can change directions depending on the current flow.
- The turbines weigh 470 tons and have a blade diameter of over seventeen feet.
- The plant is also equipped with pumps that allow water to be pumped into the basin when the sea is close to basin level at high tide. This allows for more electricity to be generated if there is an anticipated increase in demand.

No Drawbacks?

- No adverse impact on species native to the water
- No flooding has occurred
- Road was created
- Tourist site
- Generates electricity for over 300,000 homes
- Not all tidal barrages will have such negligible affects

Severn Project

Severn Barrage History

- Second largest tidal ranges in the world
- Proposals to dam the Severn have existed for over one hundred years
- When the Severn Barrage concept was originally proposed in the 1840s, it was to improve shipping and prevent flooding. In addition, the barrage would create a roadway and railway across the river.

Power Plant Proposals

- Proposal in 1918, but the low cost of coal used to generate electricity did not make the project economically feasible.
- In 1943 the formation Brabazon Commission to reinvestigate the barrage.
  - The proposal called for a single basin operating on discharge only that would produce 800,000 kilowatts of output (UN, 1957).
  - Again, the plan was abandoned, because of poor economic feasibility.
- The Severn Barrage Committee was organized in 1978
  - The committee spent two and a half years deciding that a barrage across the Severn would be technologically feasible, but not economically feasible

The Proposed Scheme

- 10 mile long barrage between Brean Down in Somerset and Lavernock Point in Glamorgan.
- The tidal basin would be over 190 square miles (500 square kilometers).
- The proposed barrage would be comprised of caissons to house the turbines and sluices.
- The 216 tubular turbines would be located in the central portion of the barrage, and each would drive a 40 megawatt generator
- Estimated 17TWh each year
- The proposed scheme has a lifetime of at least 120 years
- Ship locks were also included in the scheme
- Ebb generating scheme with pumps

Will It Be Feasible?

- What has changed?
  - Kyoto
  - Government Policy – Renewables Obligation
  - Global Warming and possible flooding?

The Renewables Obligation

- 10% of electricity from renewables by 2010, 20% by 2020
- This scheme could provide 6% of the UK's total electricity
- Not online until at least 2014

Kyoto Protocol

- The Protocol calls for developed nations to reduce their greenhouse gas emissions.
- A market based permit system was used to create incentive for greenhouse gas emission reductions.
- The electricity from the barrage would avoid the emission of eighteen million tons of carbon dioxide every year.

Flooding

- Global Warming may cause flooding and coastal erosion in the Severn Estuary Region
- The annual average flooding damage cost risk currently totals £40-200 million, and this is expected to rise.
- These costs and costs of potentially installing flood mitigation could be avoided if the Severn Barrage was constructed.

New Definition Study – New Hope?

- Costs are still very high (£10.3 – 14 billion) and the project could take up to nine years to construct.
- Difficult to find investors because of long payback period.
- If positive externalities are included in the market, then the electricity from tidal can be competitive with that of other resources

Long Island Sound Barrage Case Study for the Future

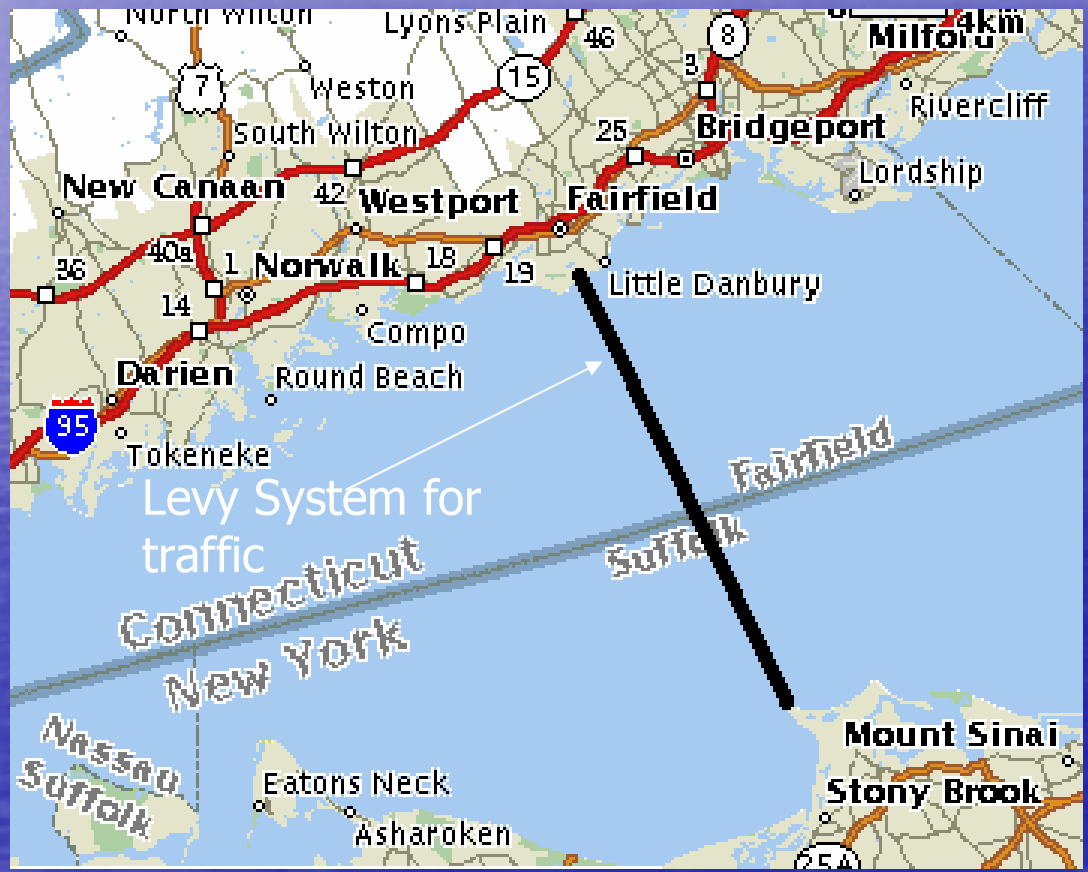
Where on the East Coast do we have a large population near a waterway with a large tidal range?

Long Island Sound

Long Island Sound Barrage

- Tidal range increases heading west
- Max tidal range = 10 meters
- Build barrage halfway into sound→ greater range, less surface area
- Surface Area = 2,092 km^2
- Tidal Amplitude = 3.5 meters at Mt. Sinai

Placement of Barrage Structure



South half of Sound is shallow =less freighter traffic

Theoretical Mean Power Output

$$S \int \rho g dz$$

Surface Area

Density

Gravitational Acceleration

Change in Water Height Column

$$2S\rho g H^2$$

Surface Area

Gravitational Acceleration

Mean Amplitude of Tide

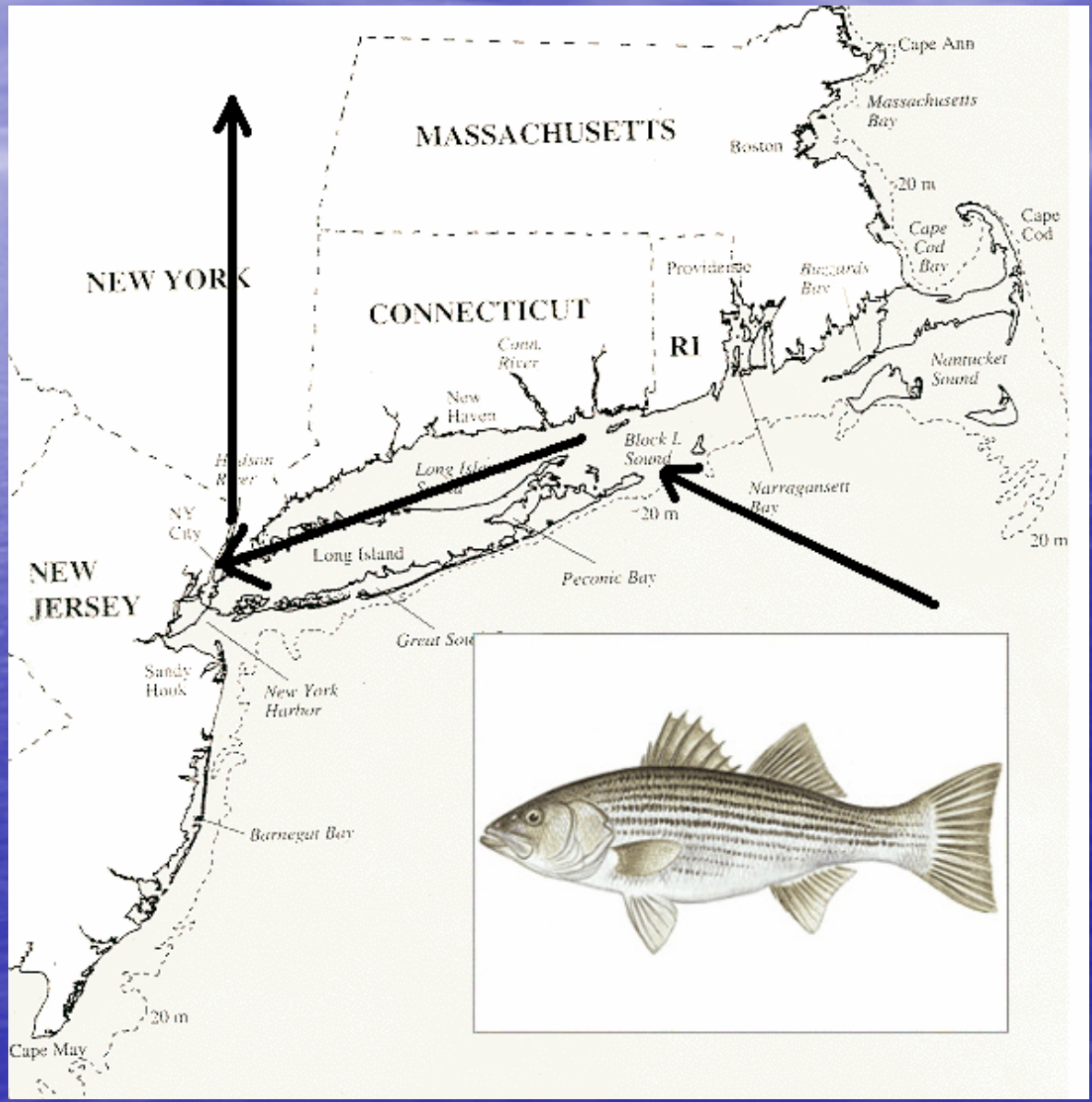
LI Sound Barrage—Energy Output

2,135 Mw

-About 1/3 of what is expected from Severn Barrage

-If calculations were 85% inaccurate, LISB would still produce more power than La Rance

Major Setback—Fishery Migration



Would Barrage help clean up sediment problem?

Fundy Bay - Case Study

Environmental Impacts of Tidal Energy
Economics of Tidal Energy
Policy Concerns
Other Tidal Schemes

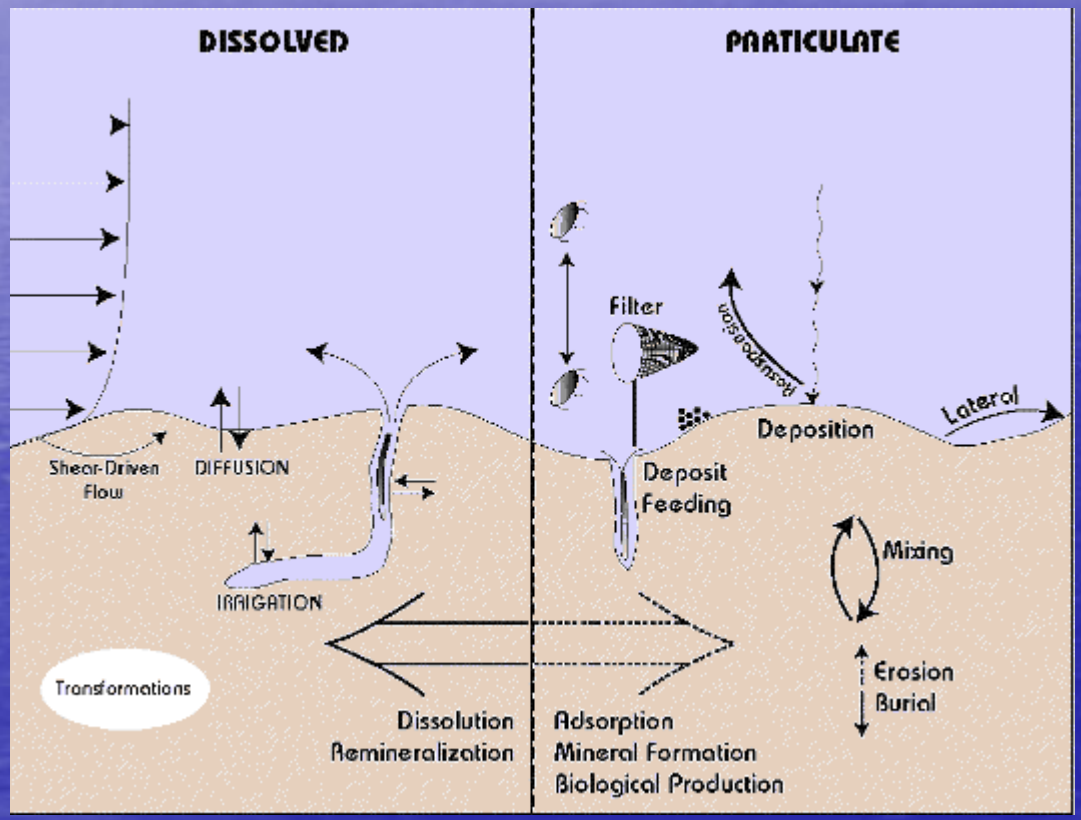
Romancing the Tide

Creating a new paradigm for renewable energy choices

Impacts

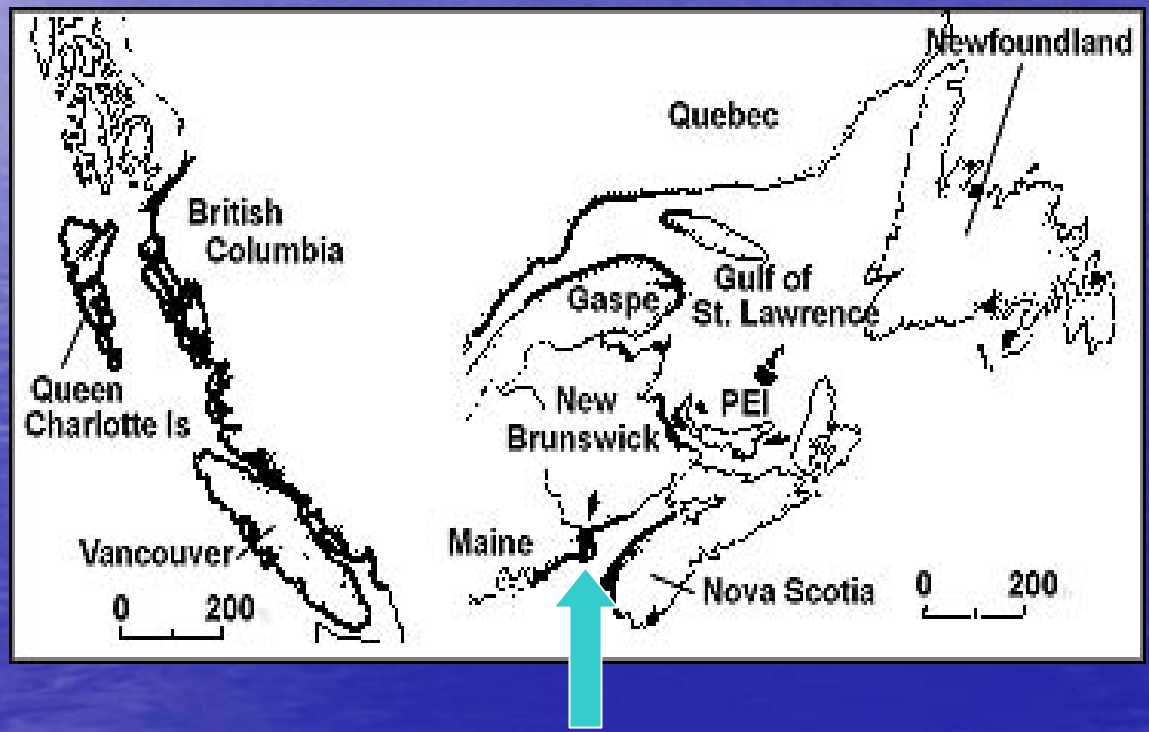
- Environmental
- Economic
- Social

Boundary Layer Effects



http://129.173.3.163/BBLCh1.html

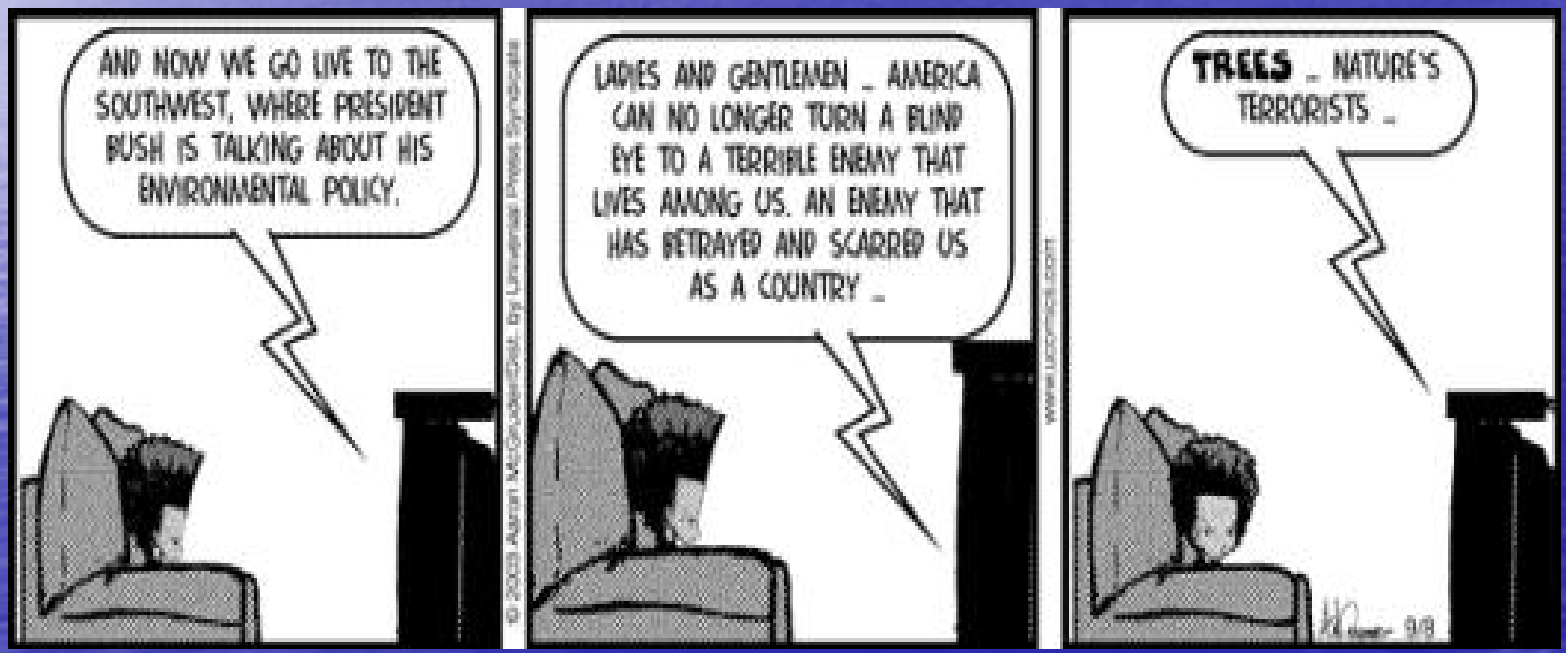
Red Tide Incidence



Bunnies aren’t ferocious enough

But Squirrels Are

Politics and Policy: Spin makes the earth go 'round



City by the bay

San Francisco's Tidal Power Potential

The Loyal Subjects of King Canute

It's the end of the world as we know it …

- Yesterday is past, the future will come without warning, but today is a *present*
- We cannot go back to the historical context of a sparsely populated world ~ our energy choices today reflect a different starting point

Choose your own future

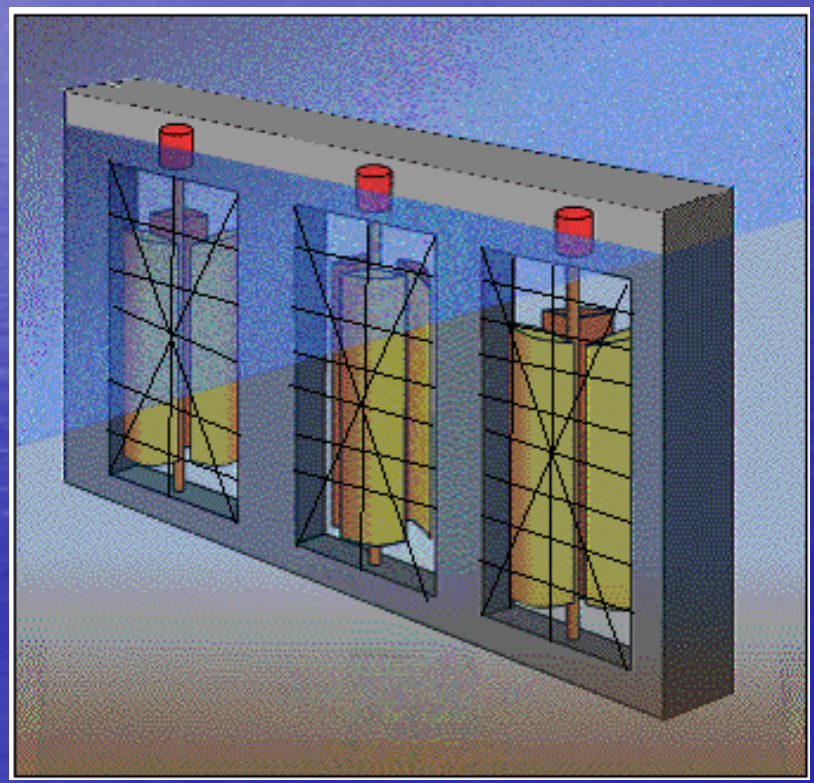
http://www.open.ac.uk/T206/4longtour.htm

http://www.infinitytrading.com/crude_oil_futures_options.html

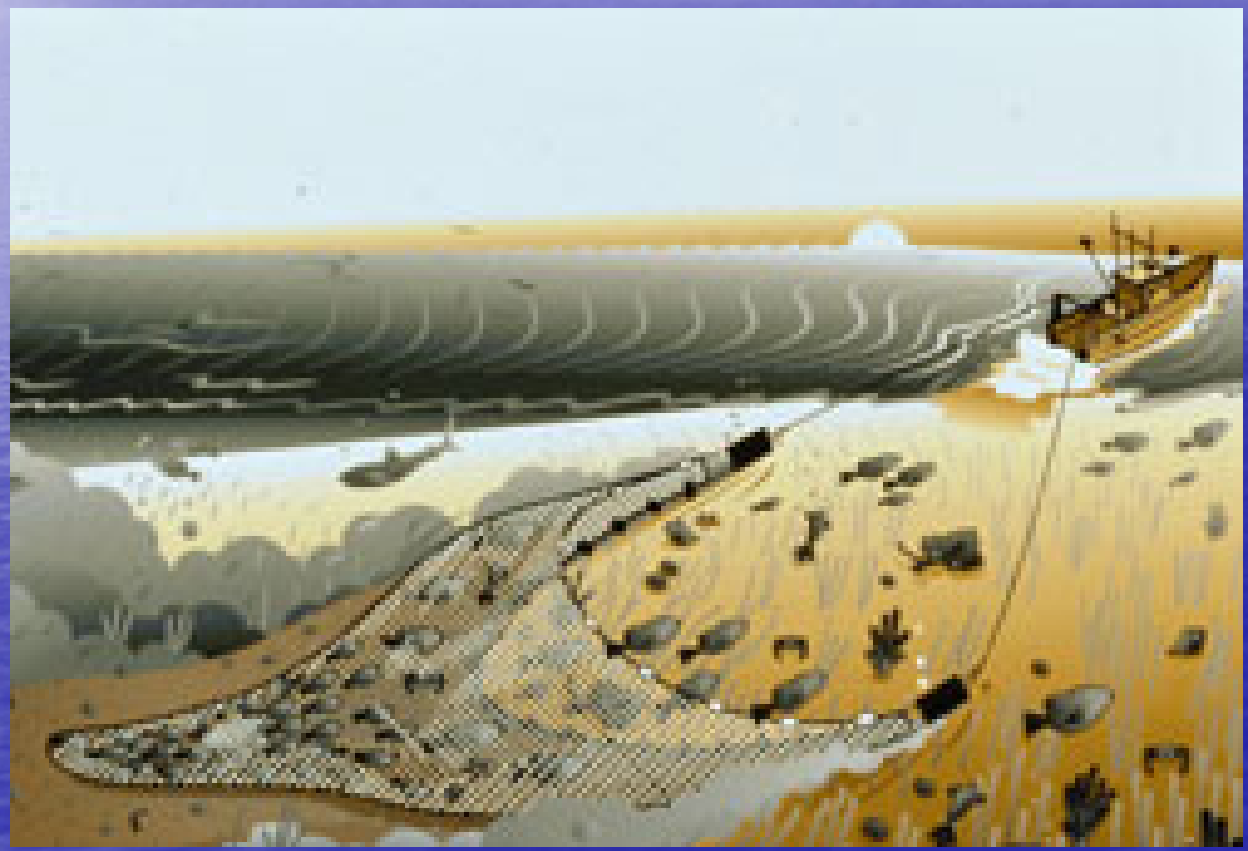
A More Futuristic Approach –Artificial Reef Program: Offshore Rigs

NJ Artificial Reef Program

Marine Conservation Structure



Maximized Conservation



Conclusions

- Tidal Energy is interesting!
- Economics are difficult to get around
- These projects are expensive
- Are people really willing to pay?