MAKAI OCEAN ENGINEERING

CAF Conference in Panama

October 26th, 2015

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President & CEO

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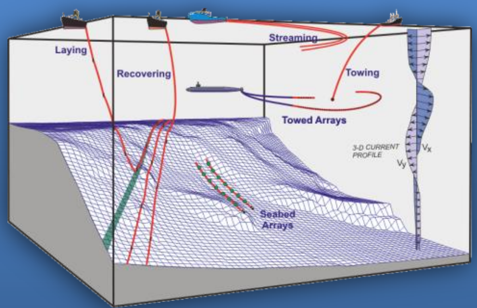
Engineering Manager

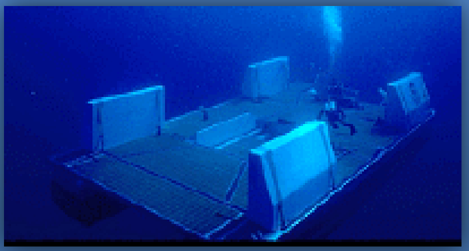
Outline of Talk

1. Makai Ocean Engineering, Inc.
2. OTEC: For the Future
3. District Cooling and SWAC
    - Three types
    - What makes a good site?
    - How to evaluate sites
    - Real-world projects
    - Sites in the Caribbean & Latin America
4. Challenges In Development

Who is Makai?

Ocean Technology Company ● Founded 1973 ● 30 employees ● Ocean Energy since 1978





Submarine Cable Software

- World's #1 cable software
- Installed +250k miles

Ocean Energy

- Pioneers of SWAC/OTEC
- World's largest OTEC plant

Ocean R&D, Engineering

- Navy underwater vehicles
- Subsea sensor networks

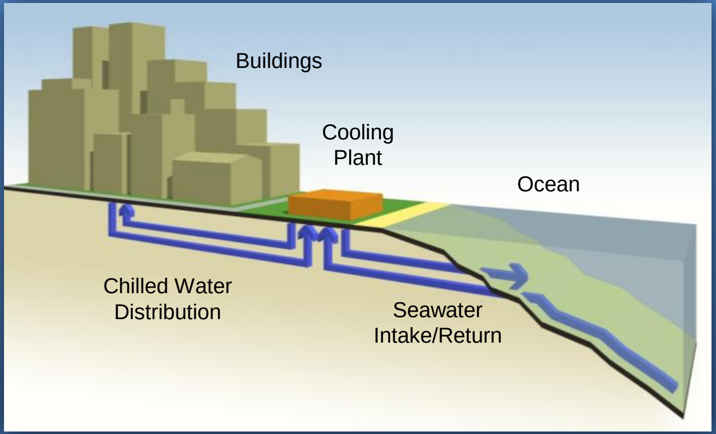
Ocean Renewable Energy

Electricity

OTEC

Ocean Thermal Energy Conversion

District Cooling

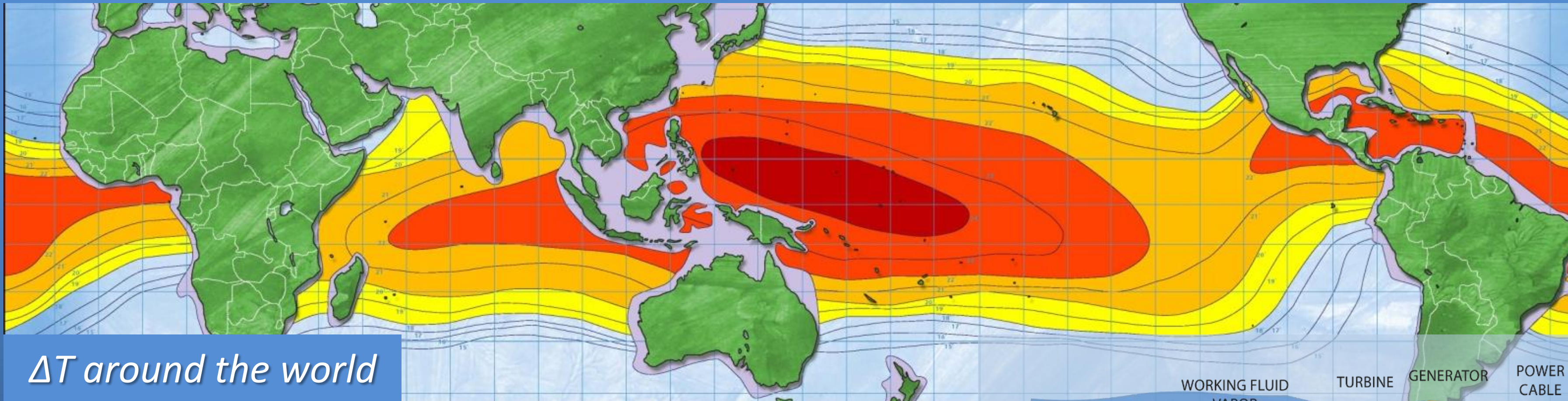


SWAC/DC

Seawater Air Conditioning/District Cooling

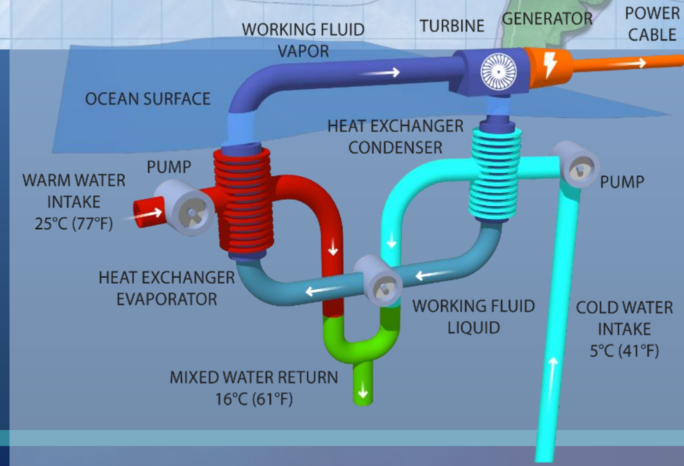
Makai is a leading engineering firm for these technologies

Ocean Thermal Energy Conversion – OTEC



ΔT around the world

- **Stable** *24/7, baseload & dispatchable power*
- **Huge** *~4x global electricity need*
- **Offshore** *Doesn't consume land, water, or food*
- **Clean** *Near zero carbon emissions*



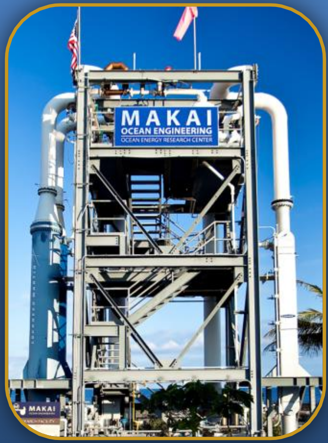
Makai's Ocean Energy Research Center

World's largest operational OTEC plant ● Navy funded ● Kailua-Kona, Hawaii

Gov Ige, Rep Gabbard dedicated OTEC plant Aug 21st

Mission Statement: To reduce the cost of OTEC power

Makai's Ocean Energy Research Center



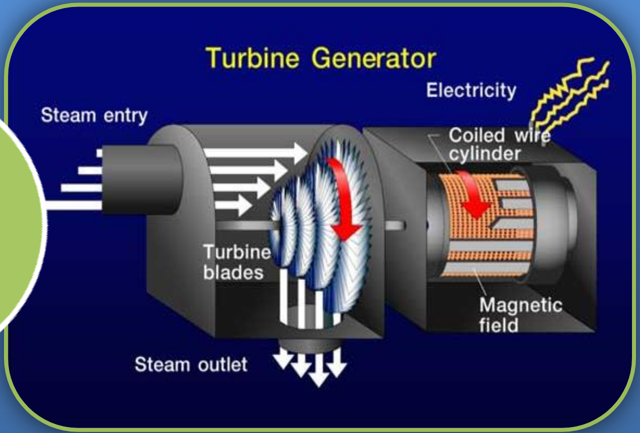
Heat Exchangers

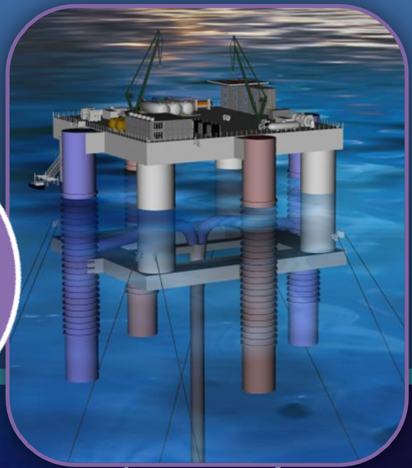
Turbine

Ocean Energy Research Center

Corrosion

OTEC Plant Designs





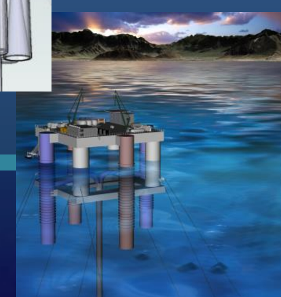
OTEC: Commercialization Strategy

100 kW Demo Plant, Makai
Develop low-cost HXs, controls
2015-2017

1 MW Pilot Plant
Electricity $ covers O&M
2017-2020

10 MW Pilot Plant, Offshore
Semi-commercial Plant
2020 - 2025

50-100 MW Pilot Plant, Offshore
Full Commercial Plant



Development Path:

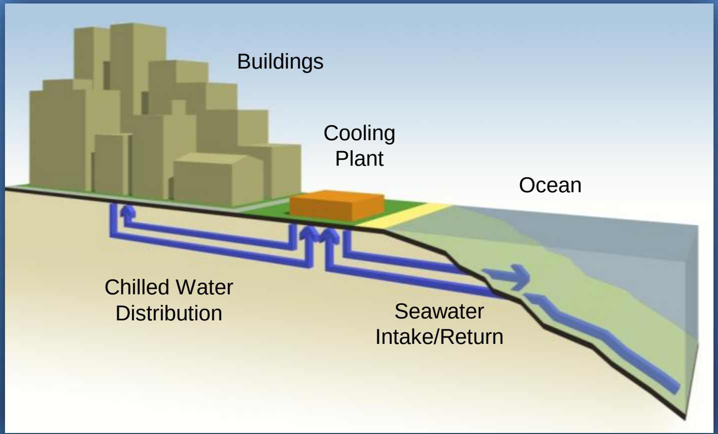
1. 100kW: Reduce cost of HXs, control system
2. 1MW: Demonstrate cost of electricity onshore
3. 10MW: Demonstrate pilot plant offshore, retire risk
4. 100MW: Build full commercial plant

"Baseload & dispatchable power, such as OTEC, is needed to achieve 100% renewable goals in islands like Hawaii."

Ocean Renewable Energy

Electricity

District Cooling



OTEC

Ocean Thermal Energy Conversion

SWAC/DC

Seawater Air Conditioning/District Cooling

Makai is a leading engineering firm for these technologies

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SWAC & District Cooling Systems

Benefits

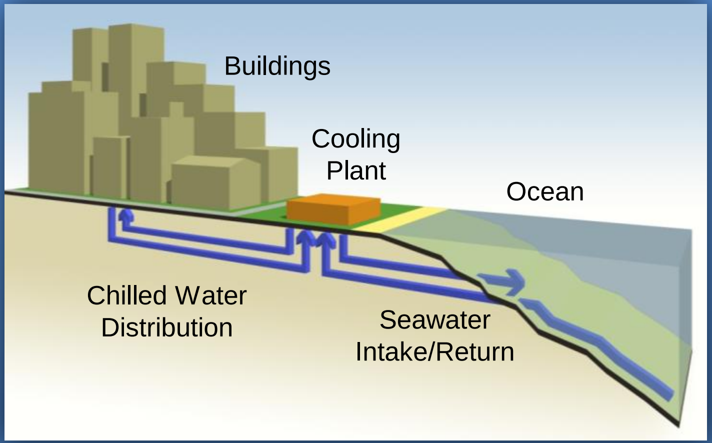
- Lower energy usage & costs
- Lower lifecycle costs
- Reduced emissions
- Centralized equip, easier O&M

Makai experience

- Many district cooling designs
- Currently modeling a district cooling system in Mauritius

Improved w/ natural cooling… lakes, oceans, rivers.

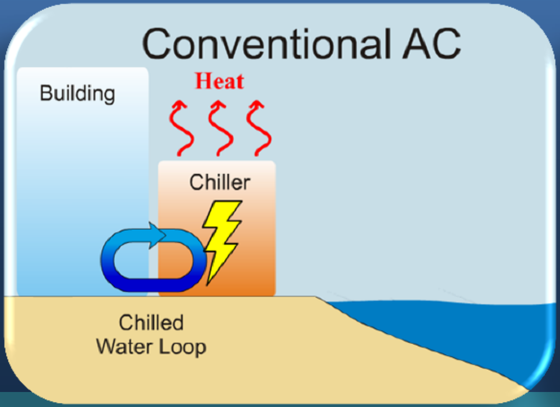
SWAC: Seawater Air Conditioning

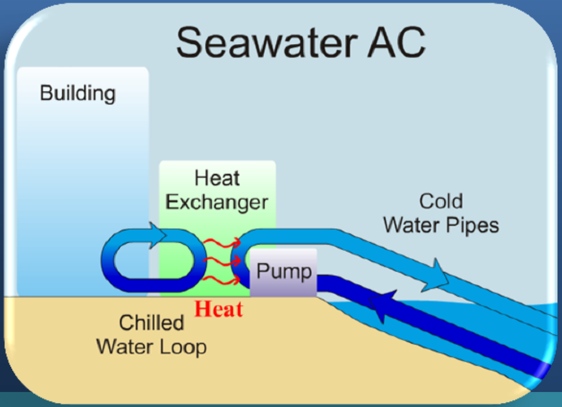


- Large renewable energy projects >$50M
- Payback can be 4-10 years
- Electricity for AC reduced by up to 90%
- Commercial, Cost-Effective Today
- Makai = designer of most operating systems

Main Components:

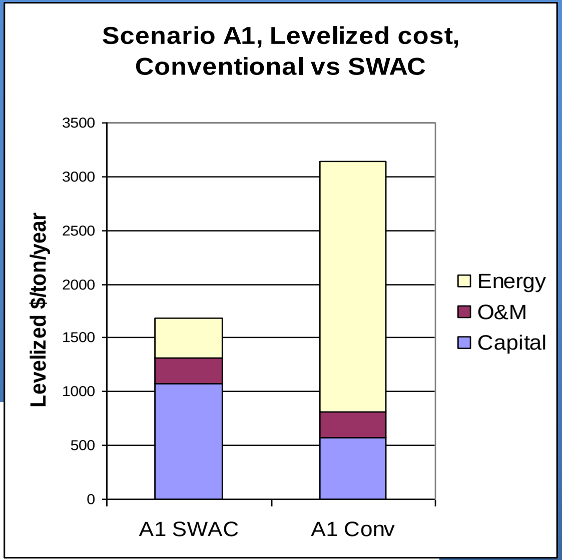
- Offshore pipes
- Pumps
- Heat exchangers
- Chilled water loops

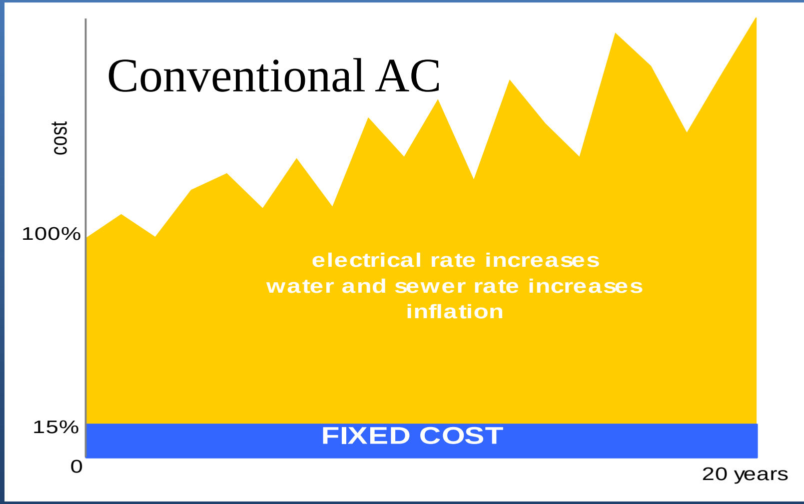


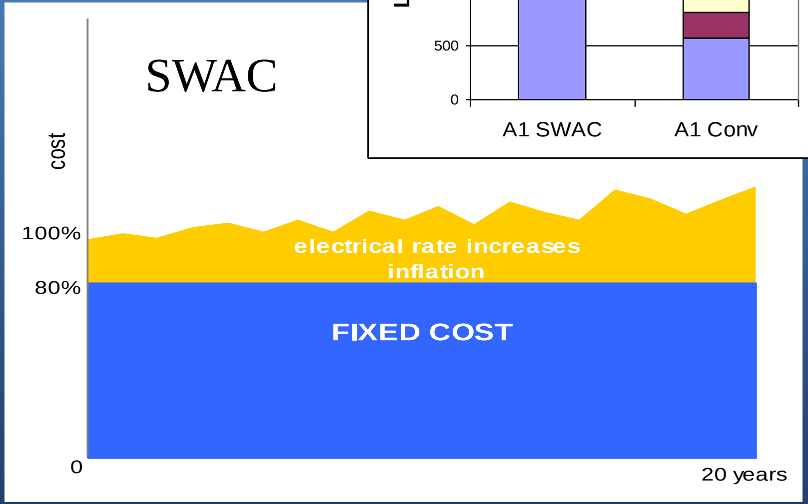


Why SWAC?

- Lucrative: high CAPEX, but lower electrical, O&M costs. Payback can be 4 – 10 years.
- Stable: reliable, low-, stable-cost cooling.
- Green: reduce electricity/water use, gain carbon credits.







Why SWAC?

<u>Secondary uses of water</u>

- Power plants can save up to 20% capacity in summer
- Eco tourism
- Aquaculture, agriculture, etc.

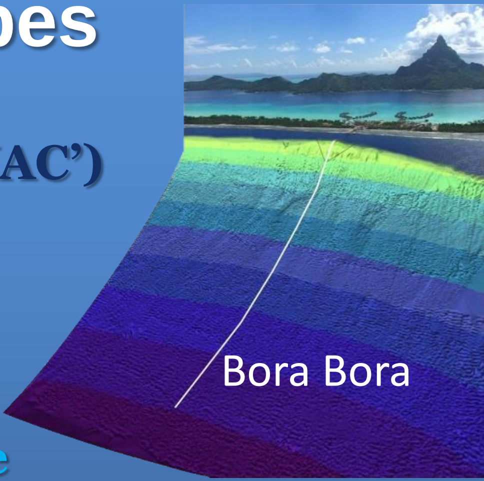
Cooling for Power Plants: Natural Gas, Petrol-fired
(e.g., Montego Bay)

Deep Seawater Spa
(Intercontinental Resort)

Aquaculture
(Big Island Abalone)

Pharmaceuticals, Biofuels
(Cellana, Cyanotech)

Natural Water Cooling: Three Types



1. **DIRECT Cooling:** Deep or cold water (pure 'SWAC')
   ~90% electrical savings
   No chillers

2. **HYBRID Cooling:** Medium depth & temperature
   75% electrical savings

3. **CONDENSER Cooling:** Shallow or warm water
   25% electrical savings

Ideal SWAC/DC Site

- Deep cold water near shore
- Large cooling loads
- High electrical rates
- Proximity to Marine Contractors
- Bldgs close to shore, compact network
- High annual AC utilization
- Secondary uses of water

The more favorable, the better!

Many variables affect profitability of SWAC systems.

How to decide which factors dominate?

Need to quantify benefits to make intelligent decisions…

The METHOD Model

M*akai*
E*conomic*
T*hermal &*
H*ydraulic*
O*ptimization &*
D*esign*

- Optimizes & designs district cooling networks
- Developed over 30 years doing real district cooling designs
- Recently had major upgrade with over $360k investment from U.S. Navy

The METHOD Model

Location Data

Offshore Pipes*

HX & Pumps

Onshore network

Thermal Storage

Chillers?

Technical & Economic Model

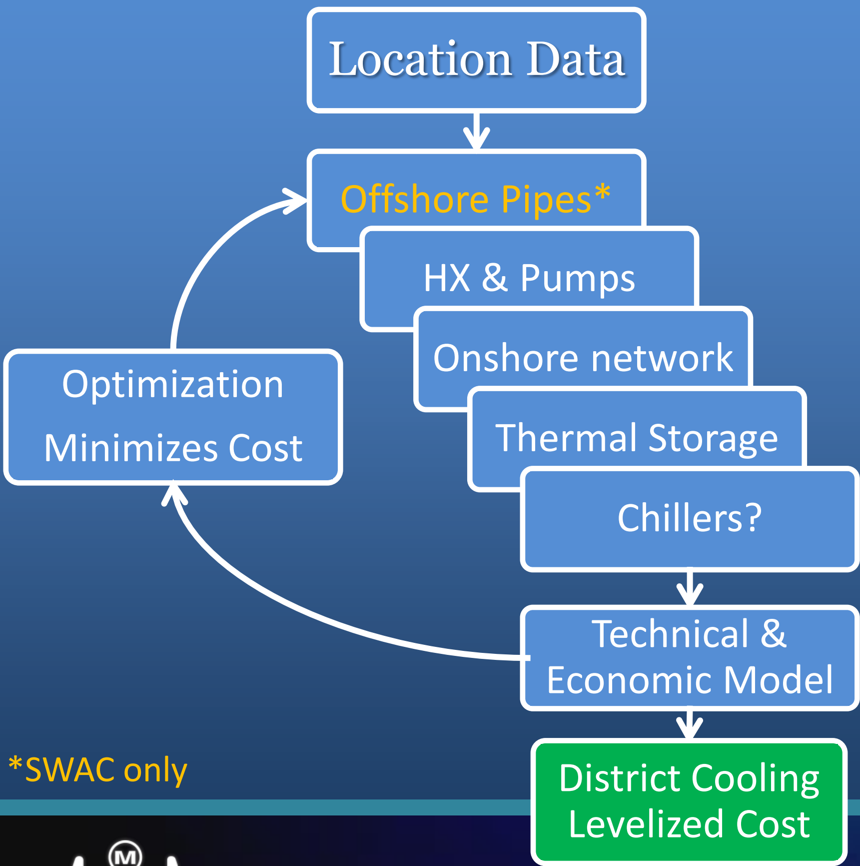
Optimization Minimizes Cost

District Cooling Levelized Cost **vs.** Conventional AC Levelized Cost

*SWAC only

Fairly compares DC cost to conventional AC

The METHOD Model



VS.

Conventional AC Levelized Cost

*SWAC only

Benefits

- Quickly gives engineering layout & costs of entire system
- Enables "what ifs" to make decisions
- Answers questions like:
  - Add more AC load?
  - Start small and expand later?
  - Get colder seawater for direct AC?
  - Use auxiliary chillers?
  - What is the payback at ½ load?
- **Includes real construction costs**

Fairly compares DC cost to conventional AC

METHOD Model

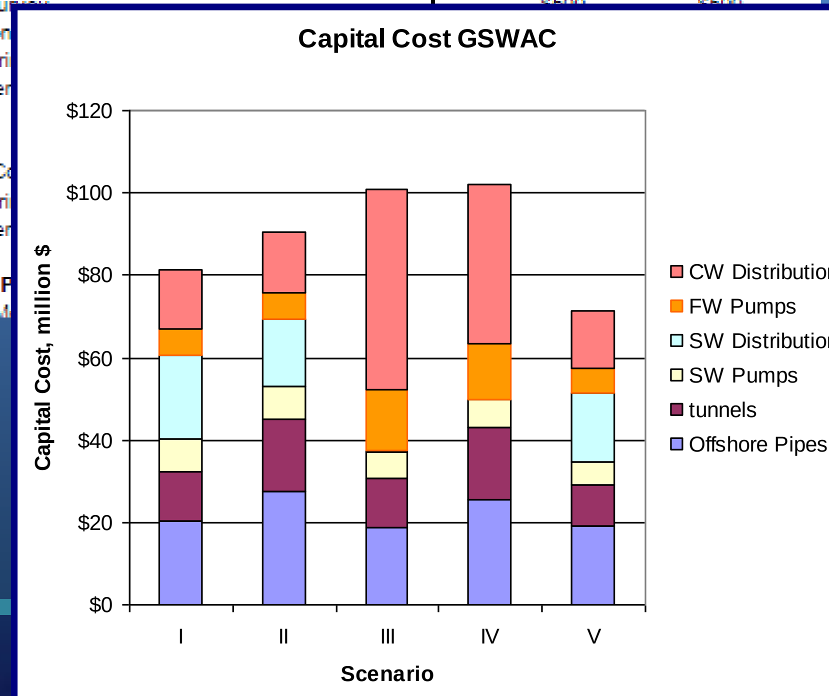
Technical Output

- Solves all flows, pressure, temps
- All pipe/HX/valve sizes optimized
- Accounts for all heat gains

Cost Output

- Gives CAPEX, OPEX, levelized costs
- Optimizes concept design based on lowest cost / shortest payback

Cost Summary			
Scenario	I	II	I
AC Load, tons	16,000	16,000	16,
Deep Water Pipe Landing	SW bay end	mid Bay	SW b
Main Distribution Route	Beach	Beach	San \
Capital Costs			I
Offshore Seawater Pipes			
Pipe and Fittings	$4,440	$5,457	
Anchors and Stiffeners	$1,498	$2,351	
Fabrication	$2,229	$2,919	
Deployment	$3,063	$3,741	
Anchoring	$1,176	$2,206	
Route Su			
Total Con			
Engineeri			
Continger			
Total			
Tunnels			
Tunnel C			
Engineeri			
Continger			
Total			
Seawater P			
Pumps/M			



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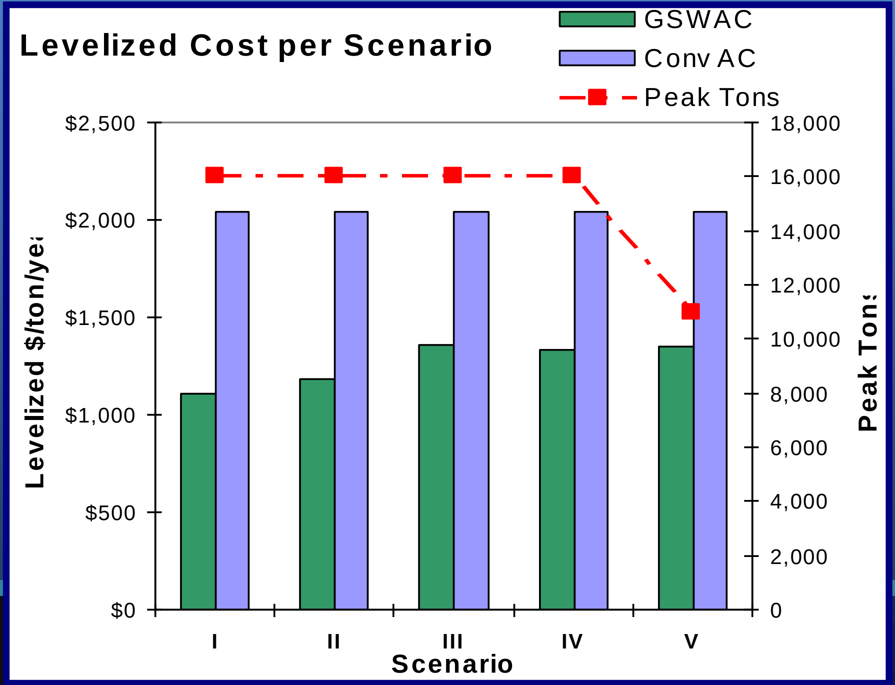
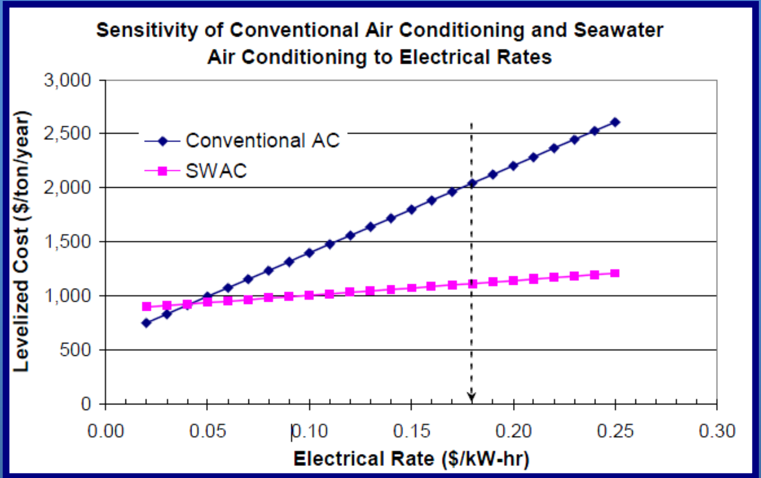
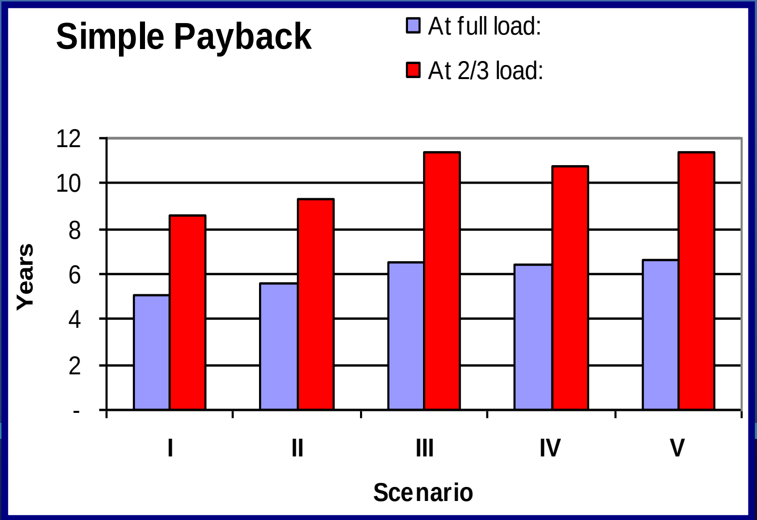
METHOD Cost Analysis

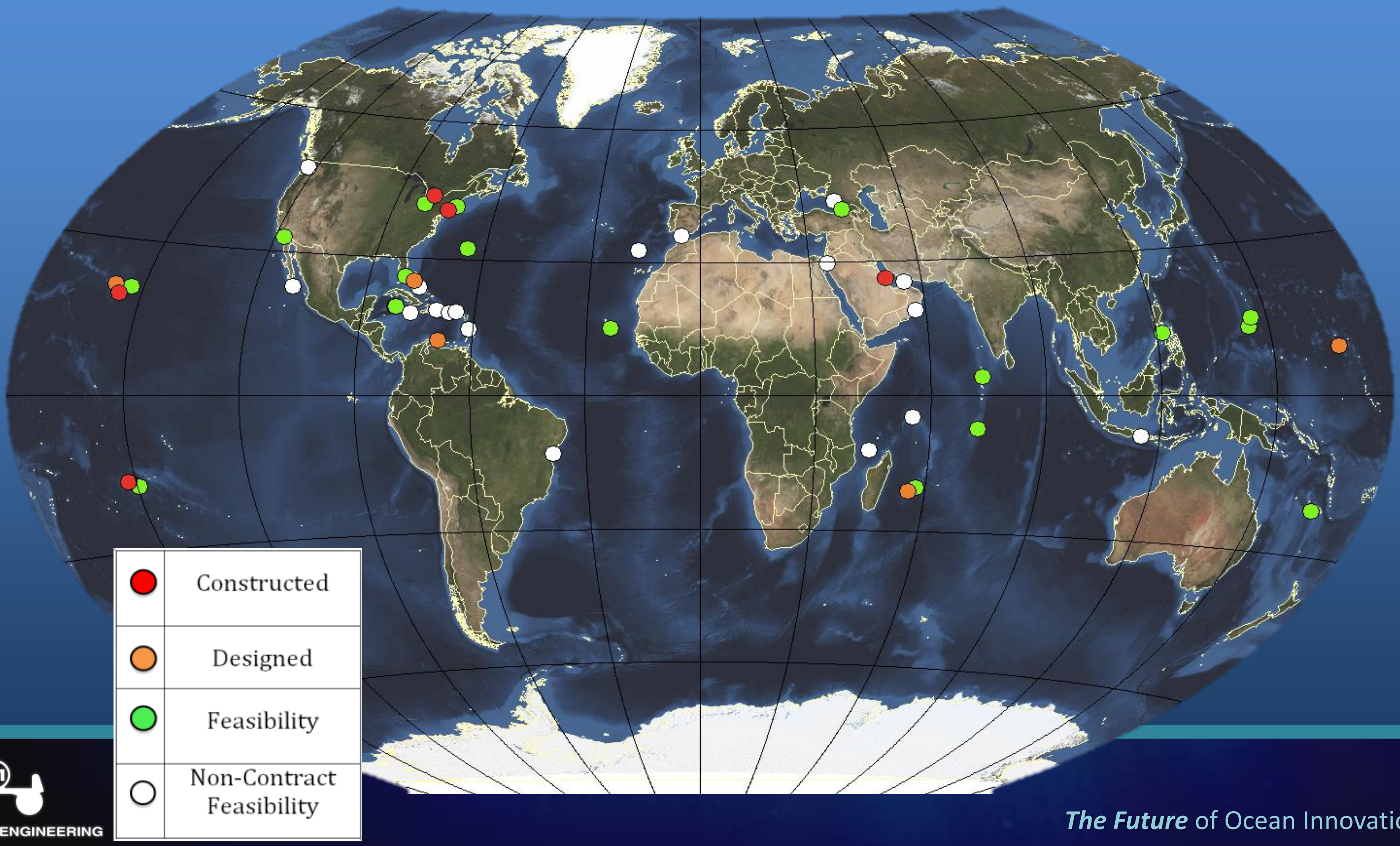
- Rapid "what-if" analysis of various scenarios
- Sensitivity studies (e.g. electricity rates)
- Compares to Conv AC, gives payback periods







Makai's Natural Water Cooling Systems



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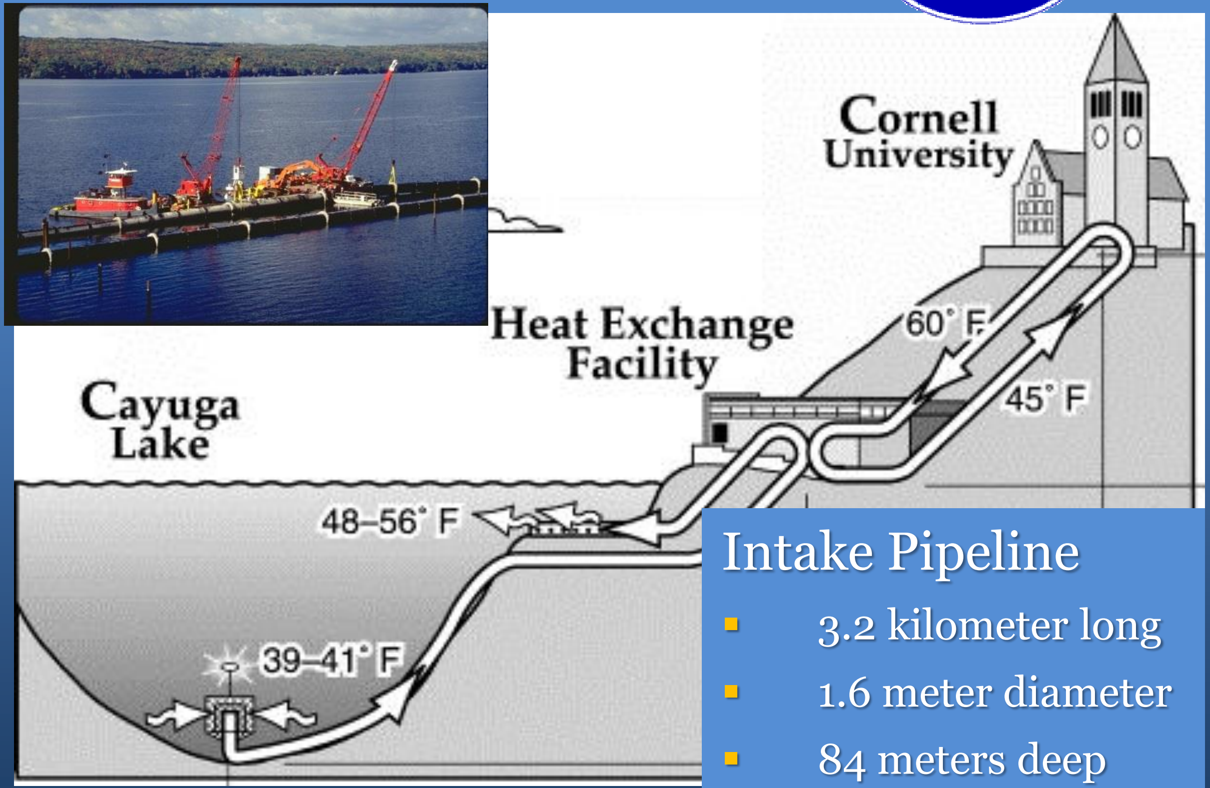
Cornell University – 1999

$60M project

- **SAVES ~25 MW of peak electricity**
- 86% savings on cooling electricity
- Trophy case full of awards

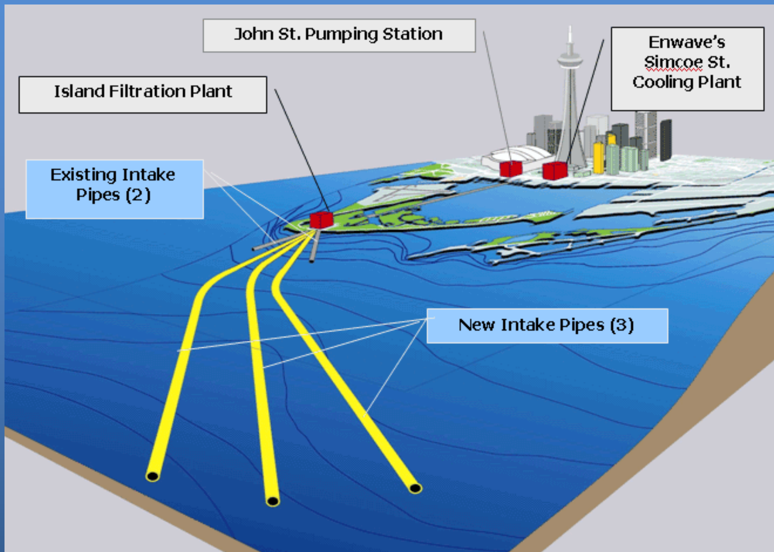


Intake Pipeline

- 3.2 kilometer long
- 1.6 meter diameter
- 84 meters deep

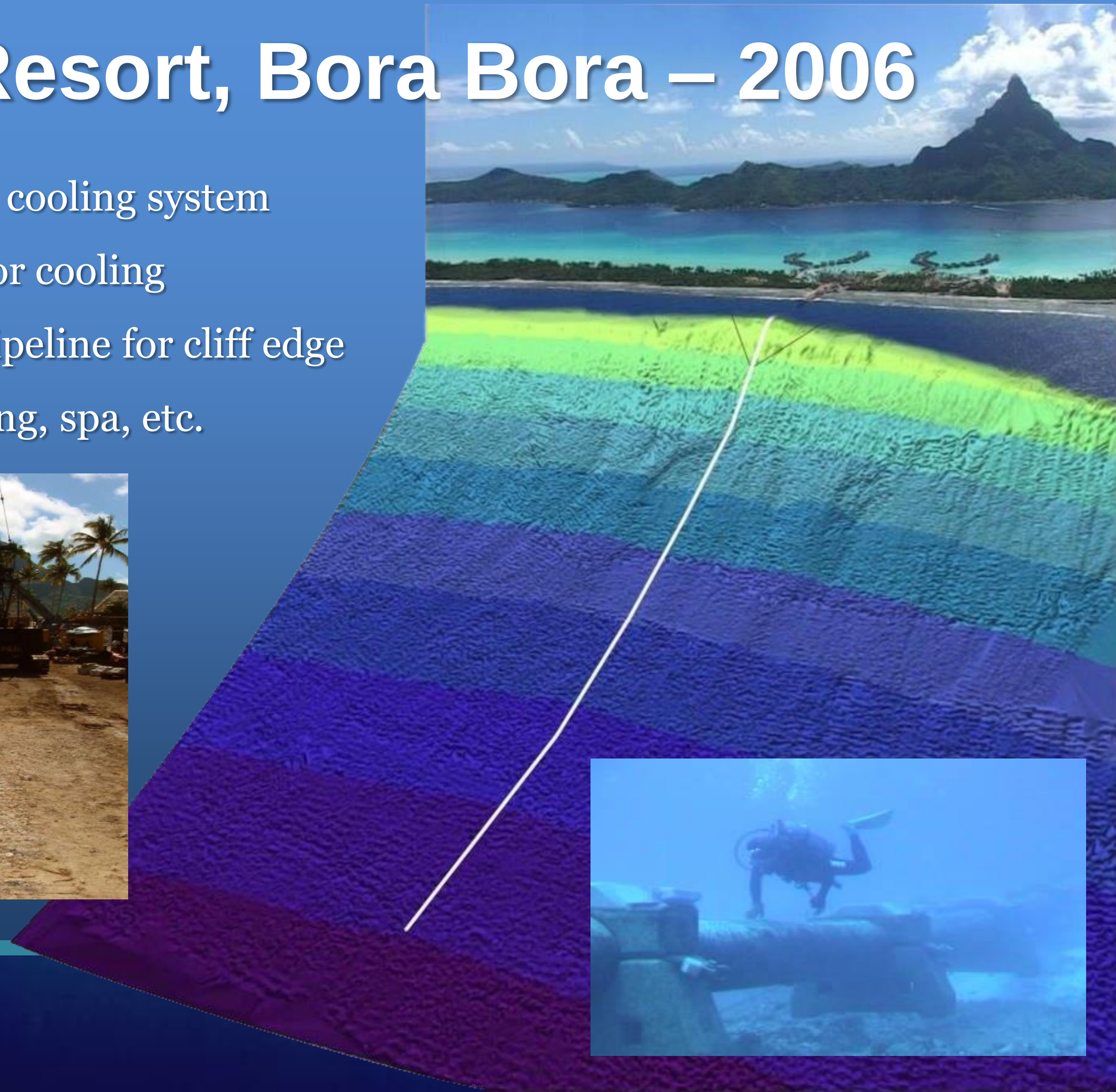
Toronto - 2001

- SAVES 61 MW of peak electricity
- 90% energy reduction over chillers
- Three pipes: 1.6m dia, 5 km, 84m deep
- ~12 km of underground distr. pipe
- Reduce 79,000 tonnes CO_2, + NOx, SOx
- 58,000 tons cooling, expand to 95,000
- Filtered and used for drinking water!



InterContinental Resort, Bora Bora – 2006

- First commercial deep seawater cooling system
- 450 tons - Saves >95% energy for cooling
- 900m deep, steep, innovative pipeline for cliff edge
- Deep seawater used for marketing, spa, etc.



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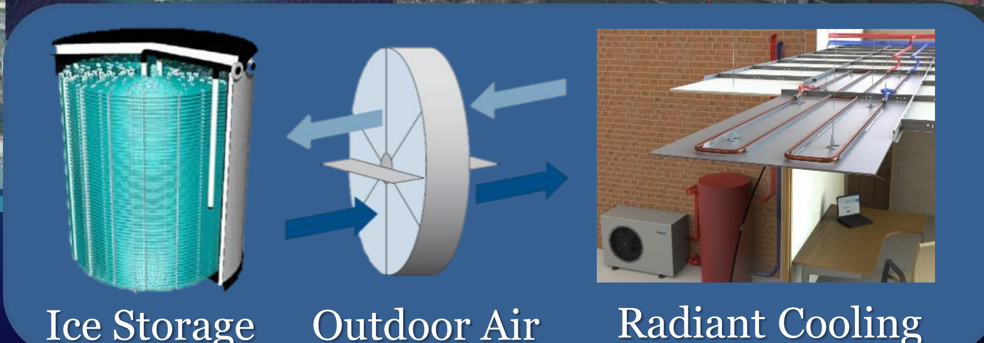
Studies and Designs Since 2010

Navy upgrades to model:

- New AC technologies



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METHOD Analysis of Caribbean SWAC sites

- CAF funded competitively bid study
- Makai performed work from 2013-2014

- Kingston
- Ocho Rios
- Montego Bay

- Santa Domingo
- Las Américas Int'l Airport
- Puerto Plata

Basse-Terre

Fort de France

METHOD Analysis of Caribbean SWAC sites

- Down-selected to 6 sites:

	System Parameters		SWAC Costs			Conventional Cooling		Results	
	Peak Load [tons]	Electrical Rate [$/kW-hr]	Capital Cost [k$]	Operating Cost [k$]	Levelized Cost [$/ton/year]	Operating Cost [k$]	Levelized Cost [$/ton/year]	**Levelized Savings**	**Simple Payback** [years]
Fort-de-France	3,042	$0.28	$57,080	$2,319	$5,266	$5,926	$4,251	**-24%**	**15.8**
Basse-Terre	2,335	$0.28	$32,380	$1,065	$4,385	$4,084	$4,314	**-2%**	**10.7**
Puerto Plata	6,835	$0.32	$70,150	$2,068	$2,254	$18,145	$4,691	**52%**	**4.4**
Kingston	23,340	$0.45	$307,190	$10,153	$3,906	$65,034	$6,567	**41%**	**5.6**
Montego Bay	7,877	$0.45	$108,550	$4,789	$3,386	$28,593	$6,428	**47%**	**4.6**
Ocho Rios	3,305	$0.45	$47,700	$1,703	$3,393	$12,082	$6,425	**47%**	**4.6**

- French Islands: Small loads, large distribution system, low elec. rates hurt
- Kingston & Santo Domingo: Complex distribution system, long offshore pipes
- Montego Bay & Puerto Plata: studied further

METHOD Analysis of Montego Bay

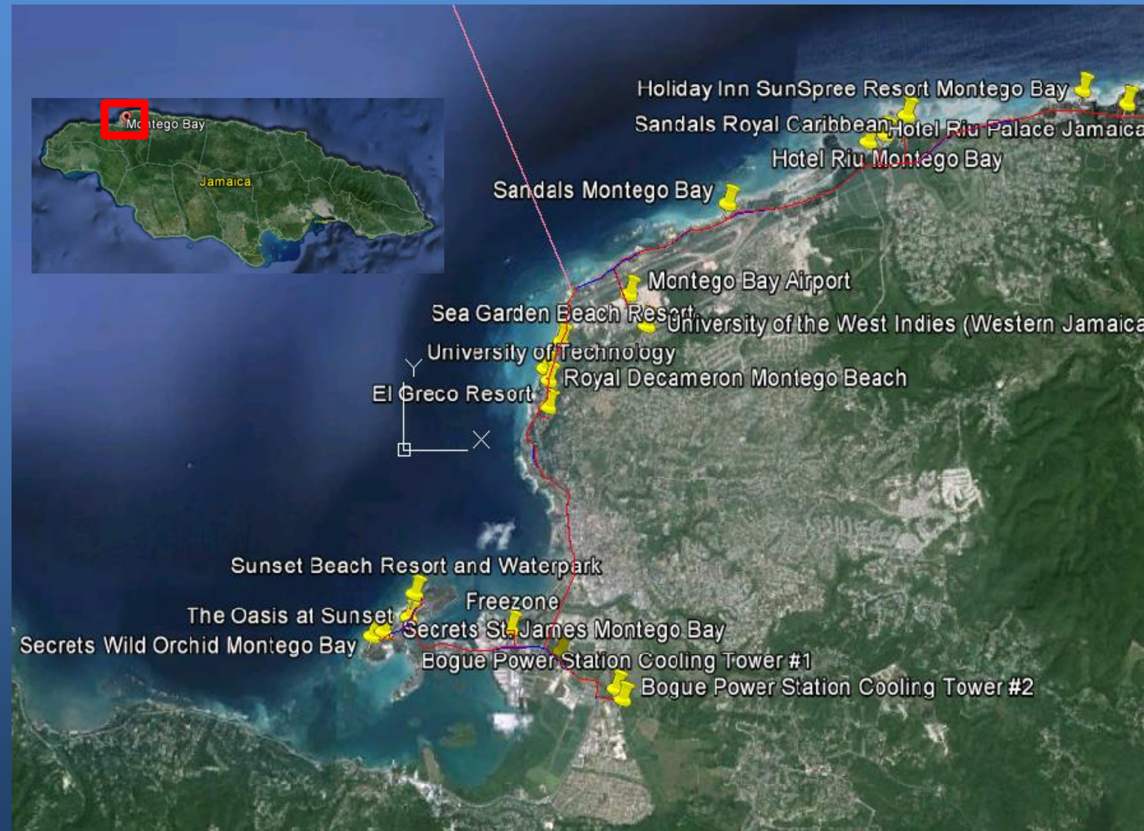
Levelized cost

- SWAC: $3,500/ton/yr
- Conv AC: $5,300/ton/yr

CAPEX: $100.3 million

Peak load: 7,700 tons

SIMPLE PAYBACK: 6yrs



METHOD Analysis of Puerto Plata

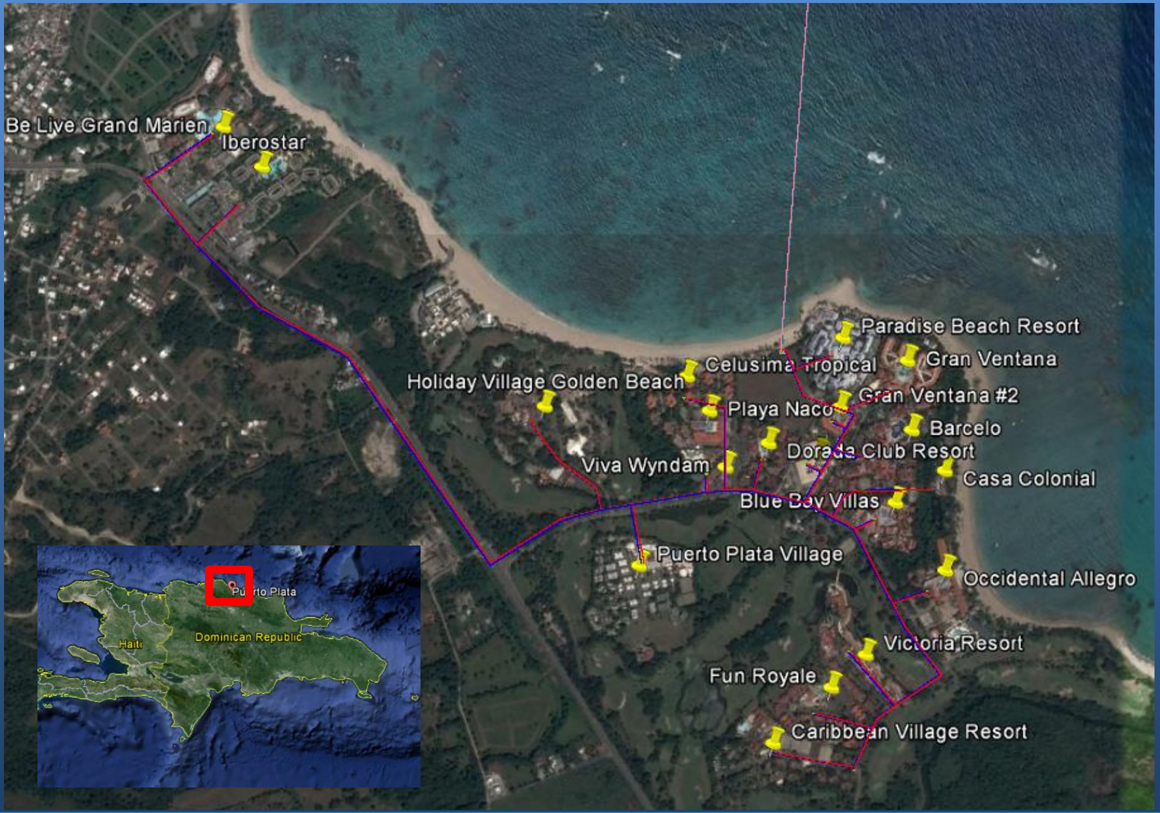
Levelized cost

- SWAC: $2,400/ton/yr
- Conv AC: $4,700/ton/yr

CAPEX: $68.4 million

Peak load: 6,835 tons

SIMPLE PAYBACK: 4.5yrs



District Cooling & SWAC in the Caribbean

KINGSTON - JAM	MEDIUM
SANTO DOMINGO - D.R.	LOW
SAN JUAN - P.R.	HIGH
MAYAGUEZ - P.R.	VERY LOW
PUERTO PLATA - D.R	**VERY HIGH**
MONTEGO BAY - JAM	**VERY HIGH**
SAN ANDRÉS - COL	MEDIUM
PUNTA CANA - D.R.	LOW/MEDIUM
OCHO RÍOS - JAM	HIGH
PONCE - P.R.	LOW

District Cooling & SWAC in Latin America

CIUDAD DE PANAMÁ - PAN	HIGH
CANCÚN - MEX	MEDIUM/HIGH
RECIFE - BRA	LOW/MEDIUM
SALVADOR - BRA	HIGH
BARRA DE TIJUCA - BRA	MEDIUM/HIGH
VIÑA DEL MAR - CHI	LOW
RÍO DE JANEIRO - BRA	HIGH
BRASILIA - BRA	LOW/MEDIUM
ACAPULCO - MEX	MEDIUM/HIGH
MONTEVIDEO - URU	LOW
CARTAGENA - COL	HIGH
SANTA MARTA - COL	LOW/MEDIUM
CABO SAN LUCAS, MEX	HIGH

Panama City, Panama *Overall Rank: HIGH*

- Centrally located DC system (red dot) would be 1.5km from all loads
- Very large cooling load – Some of the largest buildings in L. Amer.
- Multiple DC systems could be built to serve this central area
- Ocean water in Bahia de Panama is warm and shallow

Challenges to District Cooling / SWAC

- Requires large project development experience
- Need of long-term financing for 'new' technology
- Many stakeholders – regulations and customers
- NEED LOCAL CHAMPION
  - Knows local political / regulatory / business ecosystem
  - Committed to project realization
  - Persuade 'status quo' (HVAC & utilities) to be involved

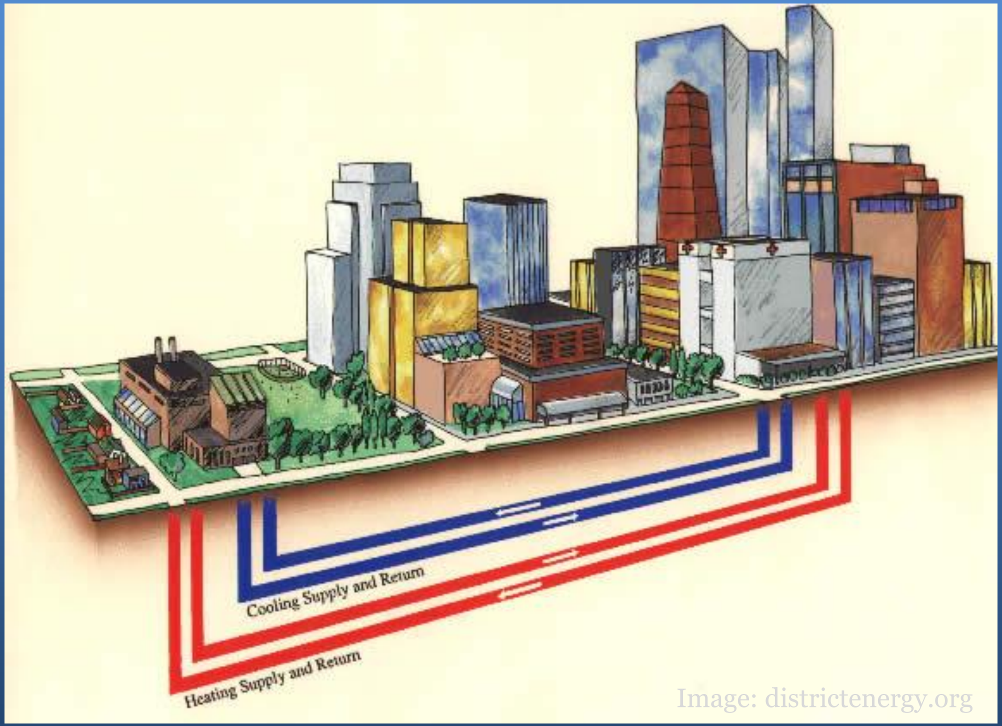


Image: districtenergy.org

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Thank you