OTEC Economics

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Full Disclosure:

I am virtuous and my actions threaten our way of life

Energy conservation is just "a sign of personal virtue" and relying on renewables would threaten "our way of life."

Vice President Cheney, April 2001

Cost of Electricity Production

COE ($/kWh) = CC + OMR&R + Fuel
{+ Profit – Env. Credit}

CC = Capital Cost Amortization

OMR&R = Operations + Maintenance
+ Repair + Replacement

Hawaii Ocean Thermal Resource: Truisms

- OTEC could supply all the electricity and potable water consumed in the State, {but at what cost?};
- Indigenous renewable energy resource that can provide a high degree of energy security and reduce GHG emissions.

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US Federal Government

(*Rephrasing late 70's to early 80's OTEC Mandate*)

By Year 2000 → 10^4 MW Installed

equivalent to 100 x 100 MW Plants

(Capital > $40 B)

Therefore,

<u>Must</u> implement optimized designs and industrial facilities for plantships producing OTEC electricity or other energy carriers to be delivered to shore…

US Federal Government OTEC Program (70's -80's)

Hindsight $\rightarrow$

should have used funds ($0.25 B) to build at least one "large" plant with off-the-shelve hardware...

OTEC in Hawaii 1990's

OTEC Assessment ('90s)

Continuous (24/7) production of electricity and water demonstrated:

- MiniOTEC
- Nauru
- OC-OTEC Experimental Apparatus

210 kW OC-OTEC Experimental Plant

(PICHTR:1993-1998)

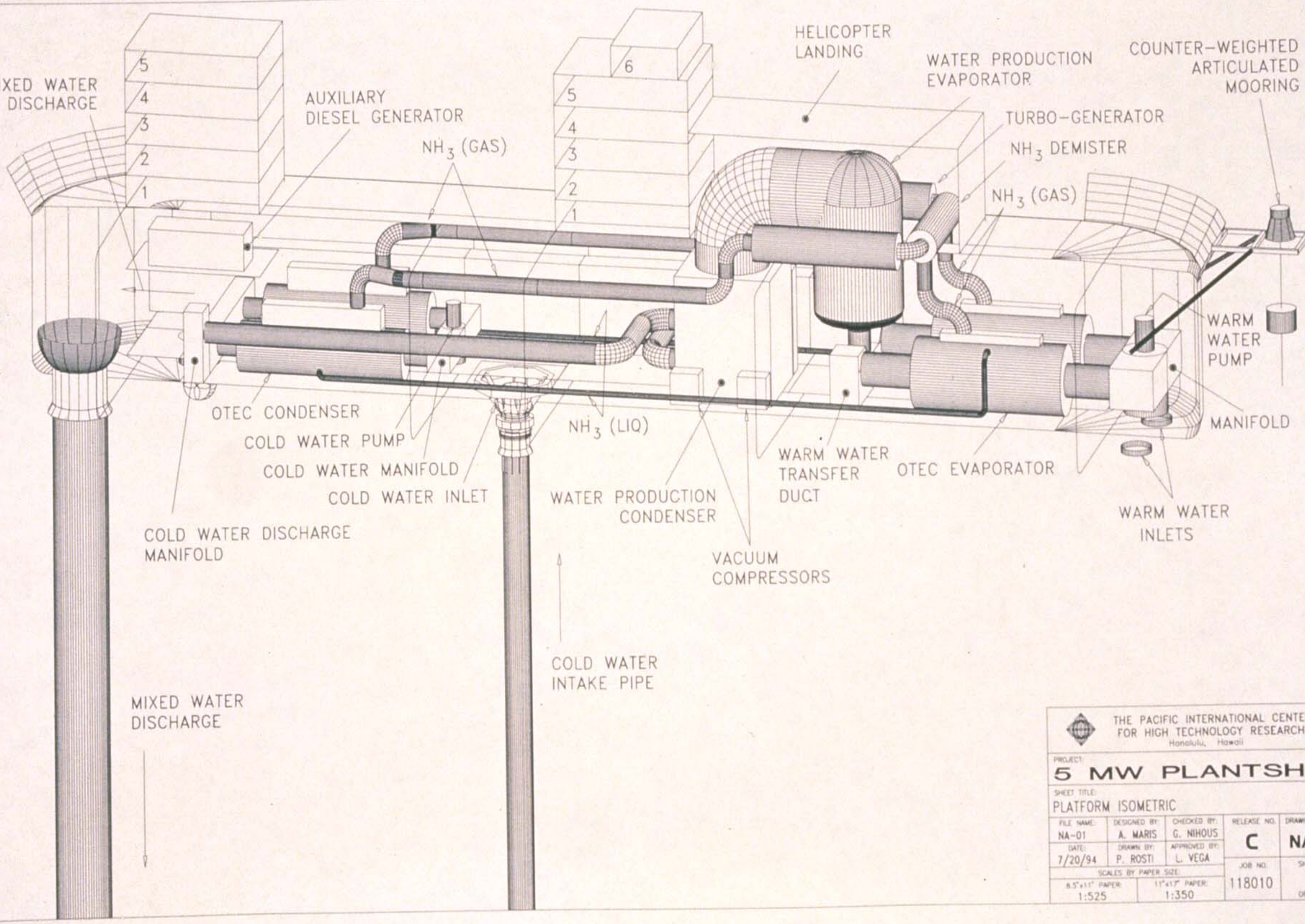
Desalinated Water Production (PICHTR: ‘94-’98)

OTEC Assessment ('90s)

- Should build a pre-commercial plant to establish the operational record required to secure financing for commercial size plants;
- Pre-commercial plant would produce relatively high cost products such that government support funding was required.

OTEC Assessment (90's)

- In mid 90s PICHTR designed a 5 MW pre-commercial plant;
- Petroleum fuels price was relatively low and government funding for the pre-commercial plant could not be obtained.



THE PACIFIC INTERNATIONAL CENTE
FOR HIGH TECHNOLOGY RESEARCH
Honolulu, Hawaii

PROJECT:
5 MW PLANTSH

SHEET TITLE:
PLATFORM ISOMETRIC

FILE NAME:	DESIGNED BY:	CHECKED BY:	RELEASE NO.	DRAW
NA-01	A. MARIS	G. NIHOUS	C	NA
DATE: 7/20/94	DRAWN BY: P. ROSTI	APPROVED BY: L. VEGA	JOB NO. 118010	
SCALES BY PAPER SIZE				
8.5"x11" PAPER: 1:525	11"x17" PAPER: 1:350			

Lessons Learned

- Life-Cycle Design
- Constructability
- System Integration
- Capital Cost

Lessons Learned

Life-Cycle Design (cradle to grave)

e.g., locating a component in the water column yields higher efficiencies but result in elaborate maintenance requirements and higher operational costs

Lessons Learned

Constructability

Can equipment be manufactured using commercially available practices and in existing factories?

Lessons Learned

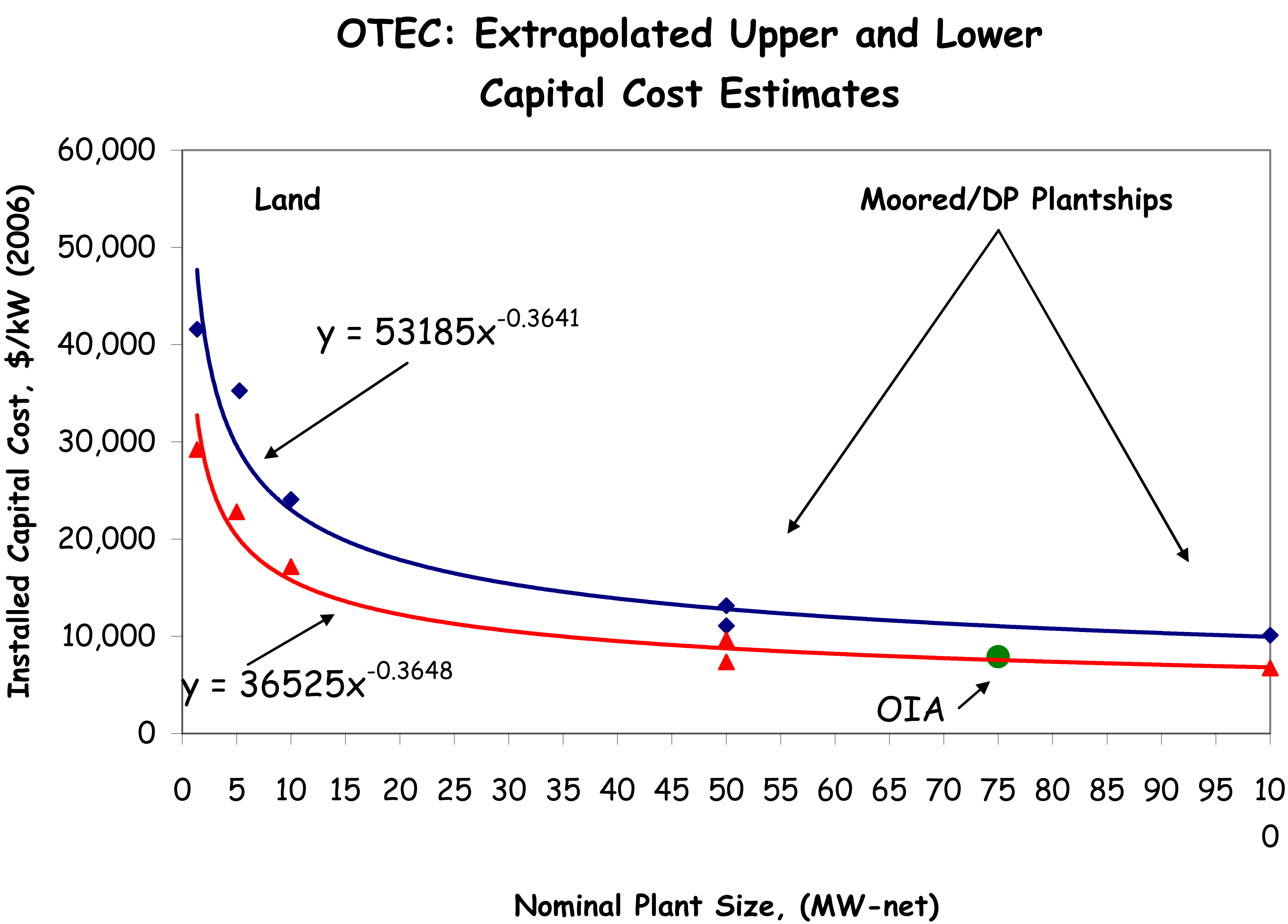
System Integration

In addition to power block (HXs & T-G), OTEC plantship includes seawater subsystems; dynamic positioning subsystems; and, submarine power cable

Capital Cost:
Strong Function of Plant Size

Economic feasibility: under specific (fuel-and-water-costs) scenarios

Present Situation (2007)


OTEC: Extrapolated Upper and Lower
Capital Cost Estimates
Installed Capital Cost, $/kW (2006)
60,000
50,000
40,000
30,000
20,000
10,000
0
Land
Moored/DP Plantships
y = 53185x^-0.3641
y = 36525x^-0.3648
OIA
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Nominal Plant Size, (MW-net)

Please Beware!!

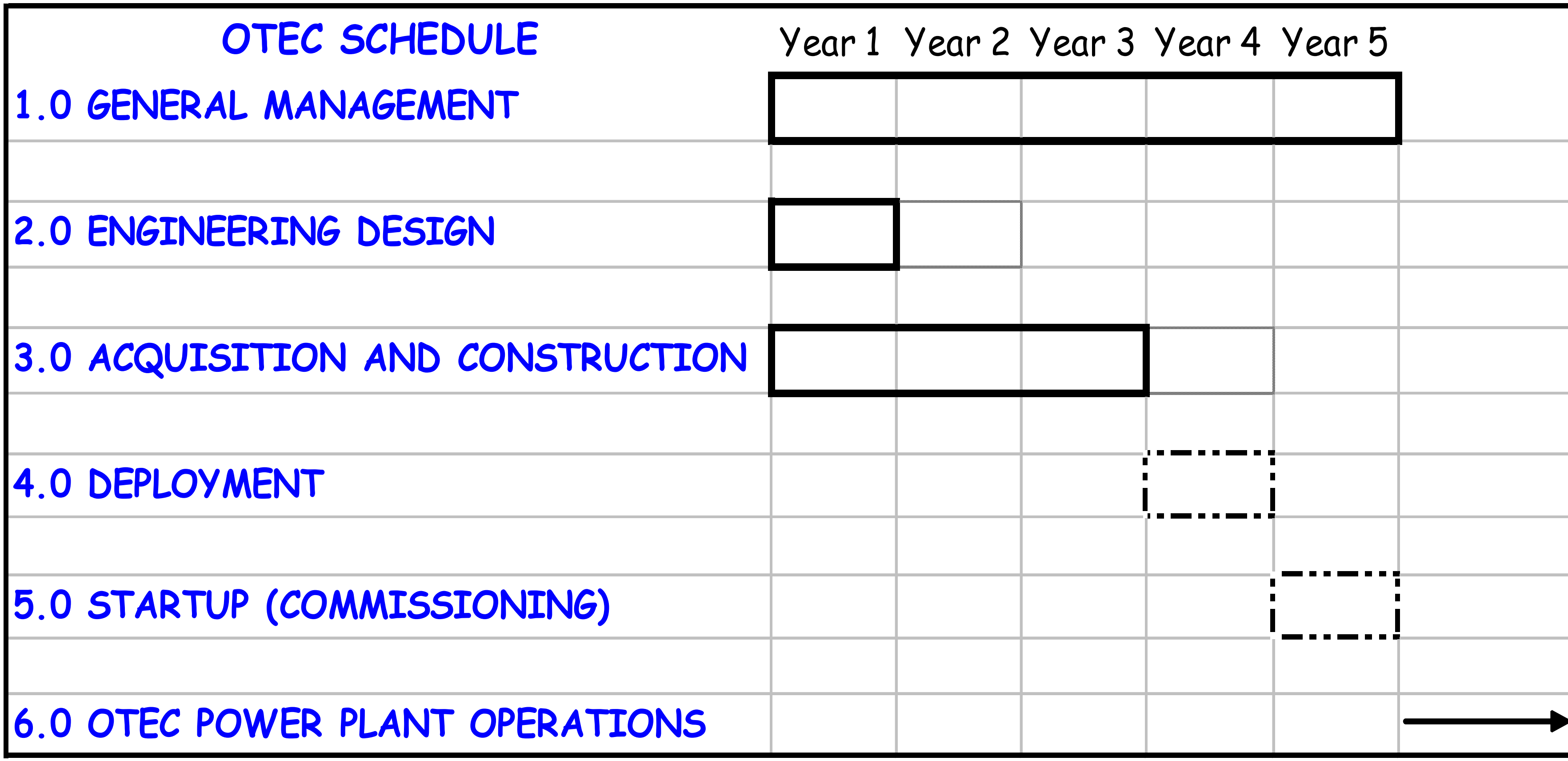
Economy of Scale 10 vs. 100 MW →

- Power Block Cost of 100 MW plant is

  ~ 10 x 10 MW
- Seawater Subsystems & At-Sea Deployment of 100 MW is

  < 10 x 10 MW
- Staffing requirements constant

  100 MW = 10 MW


OTEC SCHEDULE
Year 1 Year 2 Year 3 Year 4 Year 5
1.0 GENERAL MANAGEMENT
2.0 ENGINEERING DESIGN
3.0 ACQUISITION AND CONSTRUCTION
4.0 DEPLOYMENT
5.0 STARTUP (COMMISSIONING)
6.0 OTEC POWER PLANT OPERATIONS

Cost of Electricity Production

COE ($/kWh) = CC + OMR&R

+ Fuel *(for OTEC zero)*

{+ Profit – Env. Credit}

CC = Capital Cost Amortization

(N.B. much higher for OTEC)

OMR&R = Operations + Maintenance + Repair + Replacement

OTEC IPP Company: OMR&R

Operations & Maintenance

- Land Based: 10 employees
- Plantship: 17 employees

12 operators (for 24/365) plus 5 Eng/Admin/Management

Repair and Replacement

- Equivalent to 30-year Replacement

OMR&R Budget ($M, 1st Year)

Size	Labor	R&R=f(CC_{upper})	R&R= f(CC_{lower})
1.3	2.0	1.0	0.7
5	2.0	3.5	2.3
10	2.0	4.8	3.4
50	3.4	8.0	5.4
100	3.4	16.9	11.3

Levelized COE ($/kWh)

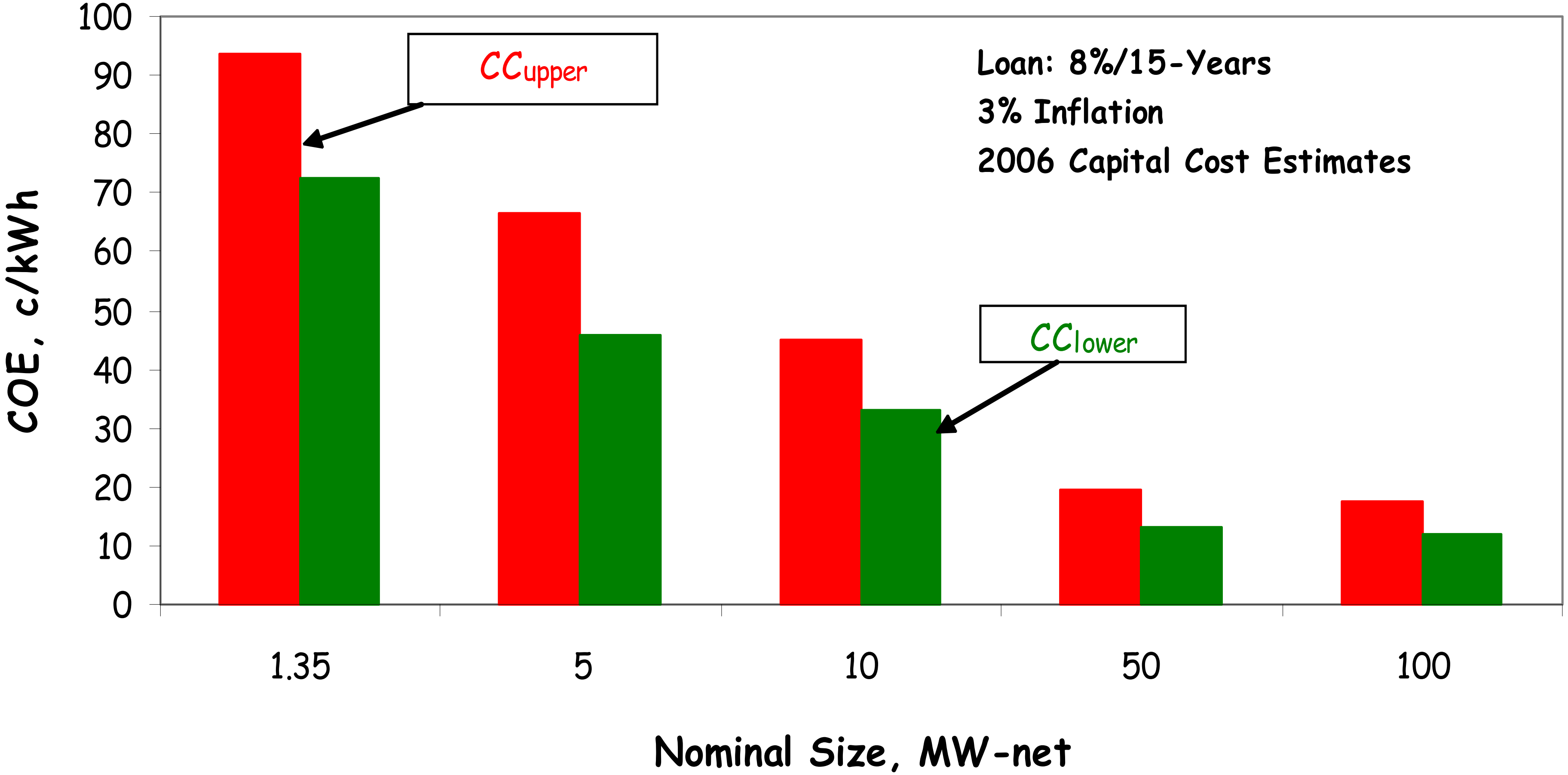
Cost of Electricity Production *(no profit)* is levelized over the life of the specific loan with Inflation constant at 3%

- Commercial Loan: 8%/15-years

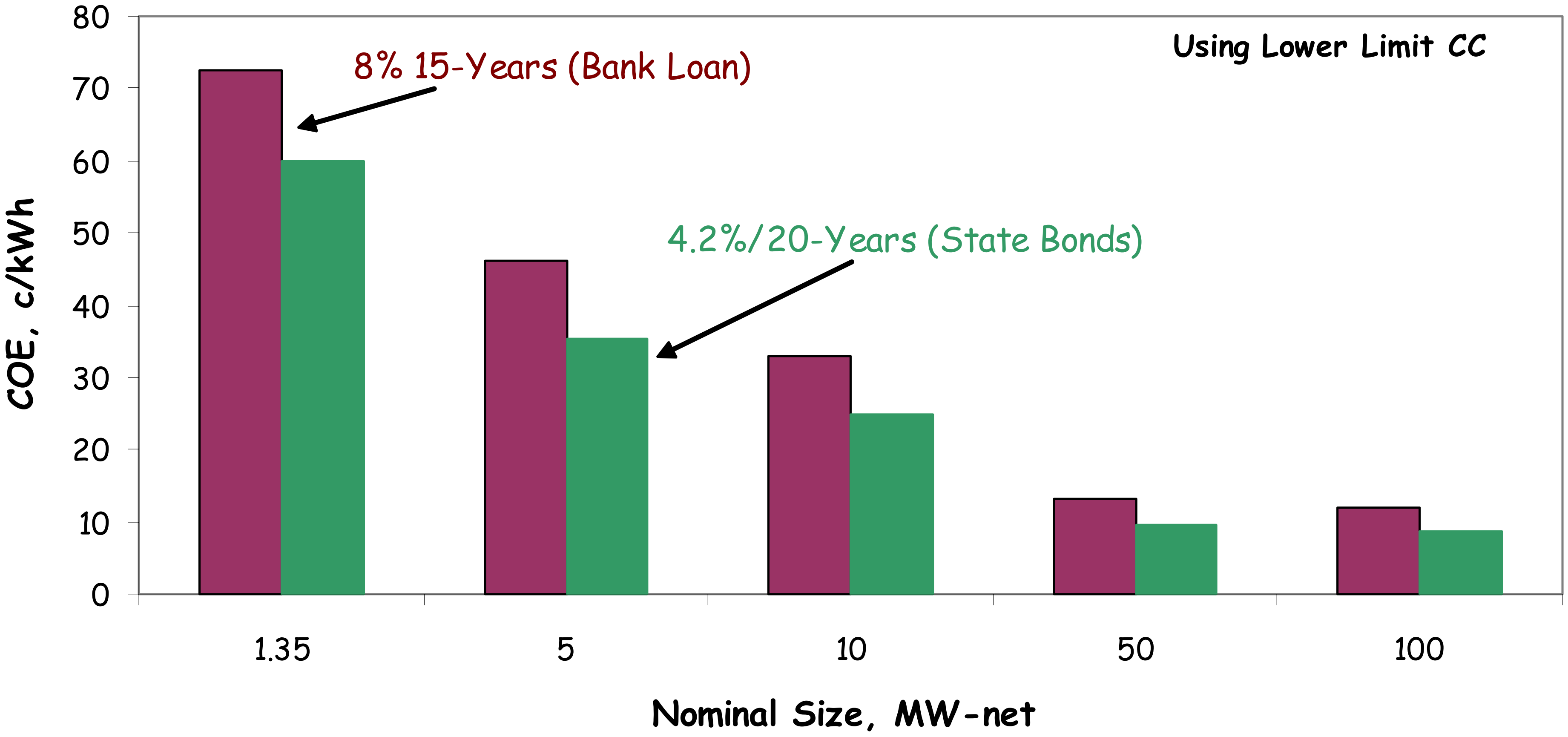
- State Bonds: 4.2%/20-years

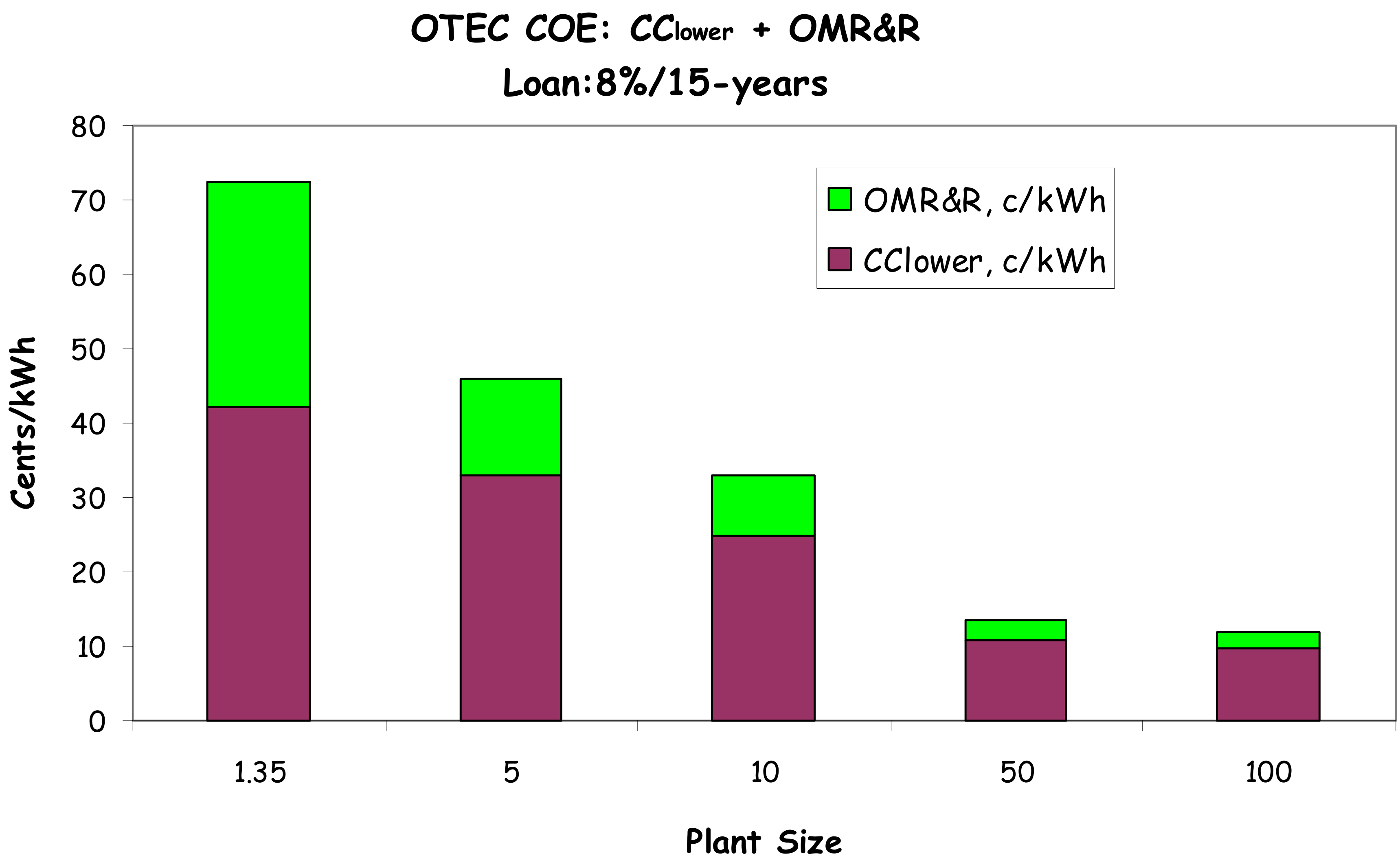
Cost of Electricity Production for CCupper and CClower

[COE = CC + OMR&R]



OTEC Cost of Electricity Production as a Function of Loan Term





OTEC COE: CClower + OMR&R
Loan:8%/15-years
80
70
60
50
40
30
20
10
0
Cents/kWh
OMR&R, c/kWh
CClower, c/kWh
1.35
5
10
50
100
Plant Size

Case Studies:
Hawai'i
Kwajalein (RMI)

Updated Assessment ('07)

Presently, Avoided Energy Cost in SOH ~ 0.20 $/kWh [was < 0.06 $/kWh in 90's]

Therefore,

→ OTEC > 50 MW is cost competitive in Hawaii

Hawai'i: 100 MW OTEC Plant

- Floating platform stationed ~ 10 km offshore, delivering:

  800 million kWh/year to the electrical grid

  32 million-gallons-per-day (MGD) of water

- Up-to-date cost estimates yield electricity produced at a levelized cost below current avoided cost in Hawaii

Hawai'i: 100 MW OTEC Plant ('07)

- A PPA from the utility at ~ 17 c/kWh includes ample return-on-investment
- In addition, at $2 per-thousand-gallons sale price to the Board of Water Supply, revenue is equivalent to a reduction of 3 c/kWh in the cost of electricity production.

Kwajalein Atoll (Marshall Islands)

According to USN:

Current COE (May'05-June'06)

~ 10 MW Capacity (diesel gensets)

COE ($/kWh) : [0.16 + 0.05] = 0.21

[fuel + OMR&R]

Kwajalein Atoll (Marshall Islands)

- USN willing to issue Power-Purchase-Agreement if COE reduced by at least 10% ($\sim 0.9 \times 0.21 = 0.19$ \$/kWh)

$\rightarrow$ Not feasible with ~ 10 MW OTEC

Updated Assessment ('07)

- Update is encouraging but securing financing for a 100 MW plant, without operational records, remains a daunting challenge;
- Should reactivate the OTEC program at the US DOE with the specific goal of designing and operating a scaled version of one of the modules from a commercial size plant (~ 5 MW over a 5 year period with annual budgets of $25M)
- Federal Program would show equipment suppliers potential market for the technology, and should lead to design refinement.

Futuristic View

Petroleum resources (IEA, API, USGS) available to meet world demand for the next 30-50 years;

diminishing resources → price increases

Energy Carriers

OTEC energy could be transported via electrical, chemical, thermal and electrochemical carriers:

Presently, *all yield costs higher than those estimated for the submarine power cable (< 400 km offshore).*

Energy Carriers

Two to three decades from now, would it make sense to produce H_2 or NH_3 in floating OTEC plantships deployed along Equator?

→ Presently, would need barrel of petroleum fuel at least 7x higher ($400) to be "cost effective"

Therefore, Revive OTEC?

President Sarkosy, April 2007

- "La mer tropicale est une source majeure d'énergies renouvelables", rappelle le nouveau chef de l'Etat, qui cite notamment l'énergie thermique des mers comme piste pertinente de recherche"
- "La mer tropicale est également une source majeure d'énergies renouvelables, malheureusement inexploitée aujourd'hui. Leur développement passe par une recherche appliquée pertinente sur l'éolien offshore, sur l'hydrolien et surtout sur l'énergie thermique des mers, actuellement ignorée.

President Sarkosy, April 2007

" The Tropical Sea is also a major source for Renewable Energies, unfortunately not exploited today. Their development needs relevant applied research on offshore wind , sea current and more especially on OTEC which is presently ignored".