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A refined Wave Resource Assessment for U.S. waters

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U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

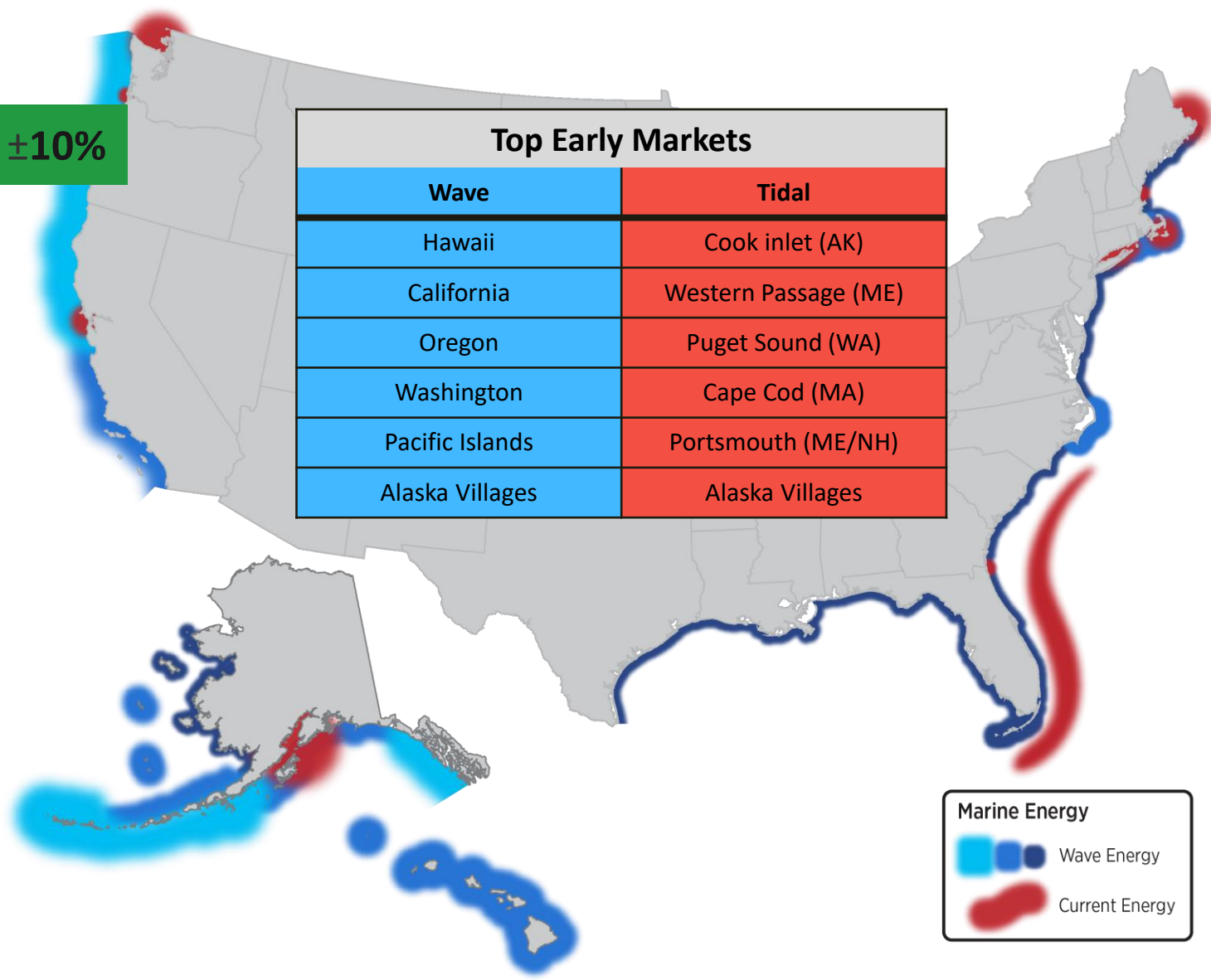
The U.S. Marine Energy Resource

Ocean
Wave
2640 TWh
per year

3500 ±10%

Tidal
Current
445 TWh
per year

Ocean
Current
200 TWh
per year



Marine Energy
Wave Energy
Current Energy

National Academy Review of Version 1 EPRI report (section 3, page 4)

- “[The EPRI 2011] approach **has the potential to double-count a portion of the wave energy** if the direction of the wave energy flux is not perpendicular to the line of interest or if there is significant wave reflection from the shore.”
- “Despite acknowledging the bias of [the EPRI 2011] approach..., the assessment group continued to use [it] rather than the perpendicular component of power density. Although this is consistent with various European wave resource assessments, **it clearly overestimates the total theoretical resource.**”

Literature Review

- Several international authors use directional method:
 - [Hemer and Griffin, 2017](#) (Australia)**
 - [Reguero, Losada and Mendez, 2015](#) (GLOBAL)**
 - [Garcia-Medina, Ozkan-Haller and Ruggiero, 2014](#) (Pacific NW)**
 - [Mota and Pinto, 2014](#) (Portugal)
 - [Gunn and Stock-Williams, 2012](#) (GLOBAL)**
- There are still a few modern uses of the non-directional method
- Most other resource assessments do not calculate coastline totals. Rather, they estimate production potential at sites.

** : These authors strongly advocate for the importance of directionality.

New Approach

National Academy Review:
“double counting”?

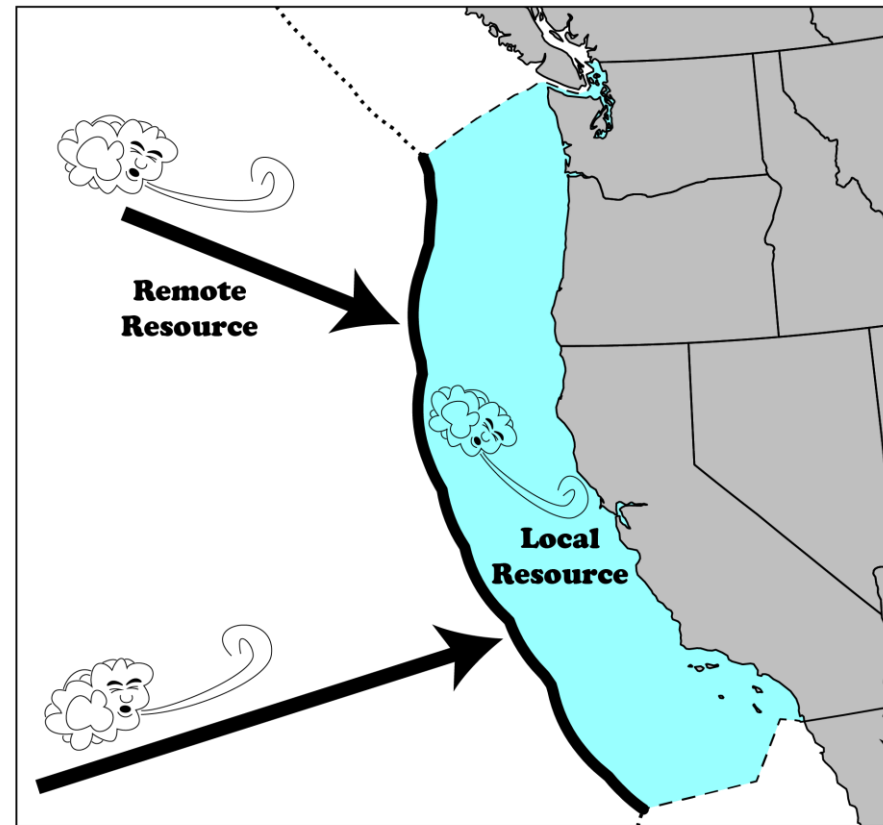
One-way dot-product to
calculate **‘remote resource’**

“What about winds inshore of
WEC array?”

Area integral of source terms
gives **‘local/potential
resource’**

Arbitrary resource area?

Extend to **full EEZ**, don’t count
fluxes across **‘borders’**



$$\text{Total} = \text{Remote} + \text{Local}$$

Results

Region	EPRI 2011 <i>Remote Only</i> TWh/yr	New <i>Total</i> TWh/yr	% Change
West Coast	590	510 – 610	-5 ±10
Hawaii	130	300 – 380	+160 ±30
East Coast	240	280 – 320	+25 ±8
Gulf of Mexico	80	63 – 73	-15 ±7
Alaska (Pacific)	1570	2000 – 2430	+40 ±15
Puerto Rico	30	17 – 32	-20 ±25
TOTAL	2640	3170 – 3845	+33 ±13

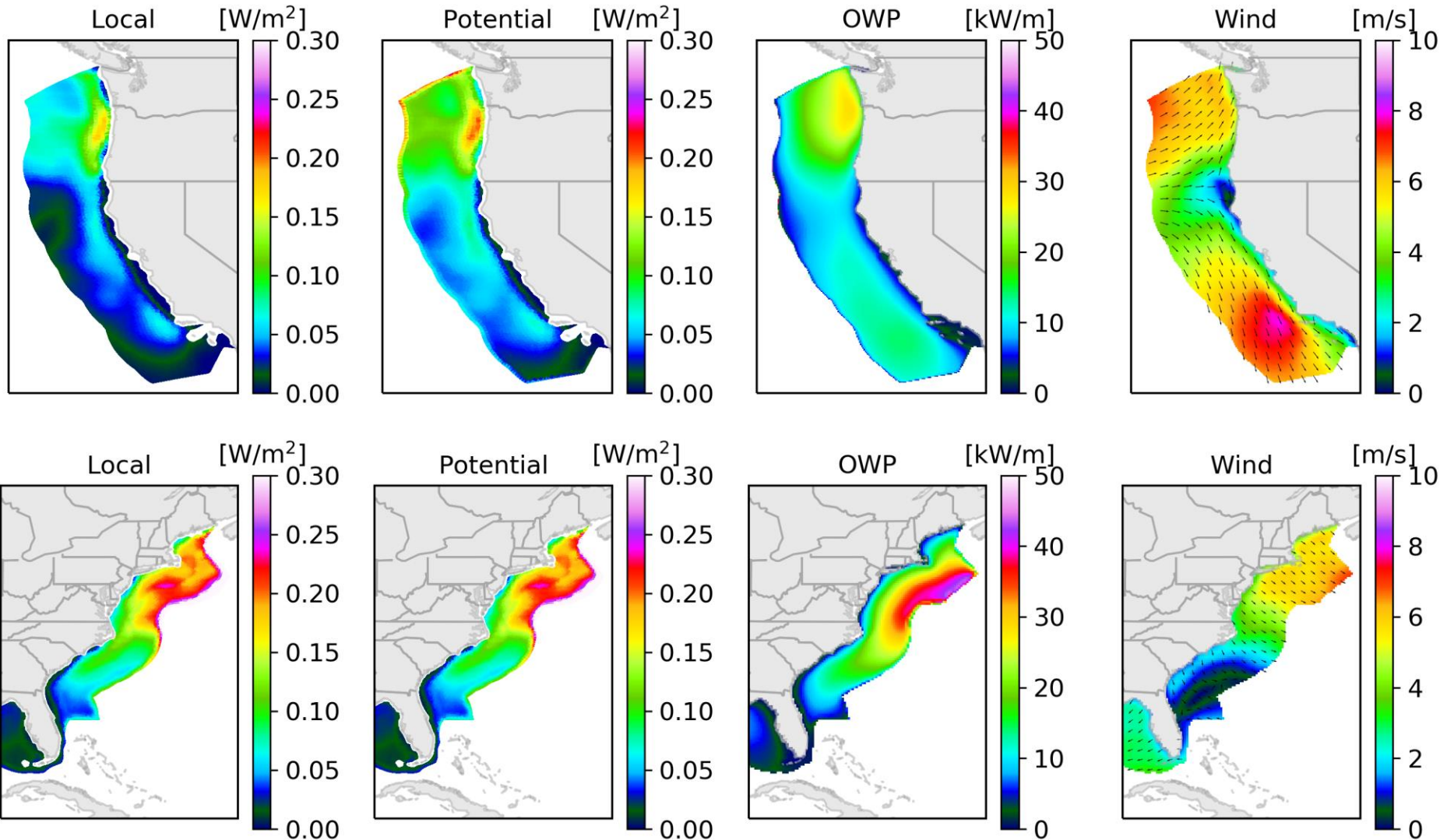
New Resource Assessment Results

- "Local resource" is area-integral of source terms with no extraction
- "Potential resource" is area-integral of source terms with 100% extraction at EEZ boundary

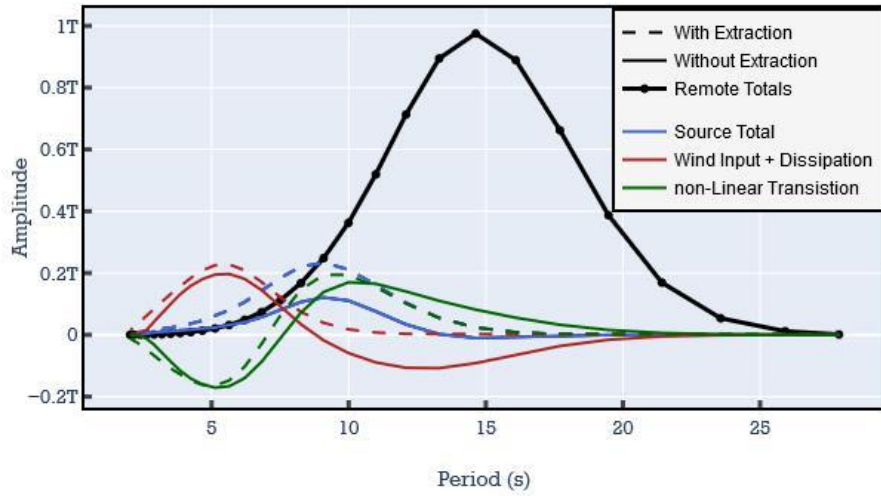
Region	<i>Remote</i> TWh/yr	<i>Local</i> TWh/yr	<i>Potential</i> TWh/yr	<i>TOTAL</i> TWh/yr
West Coast	420	90	190	510 – 610
Hawaii	290	10	90	300 – 380
East Coast	110	170	210	280 – 320
Gulf of Mexico	13	50	60	63 – 73
Alaska	1040	960	1390	2000 – 2430
Puerto Rico	6	11	26	17 – 32
TOTAL	1879	1291	1966	3170 – 3845

Distribution of local resource

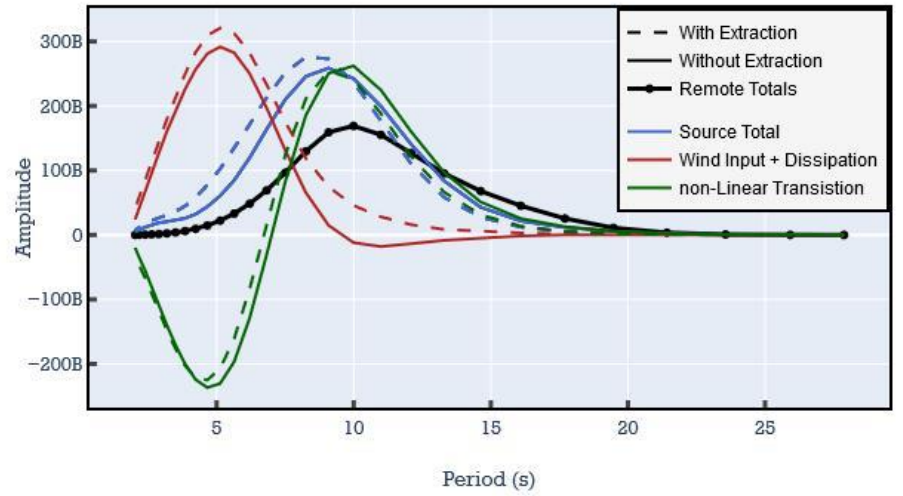
- OWP is the wave power with 100% extraction



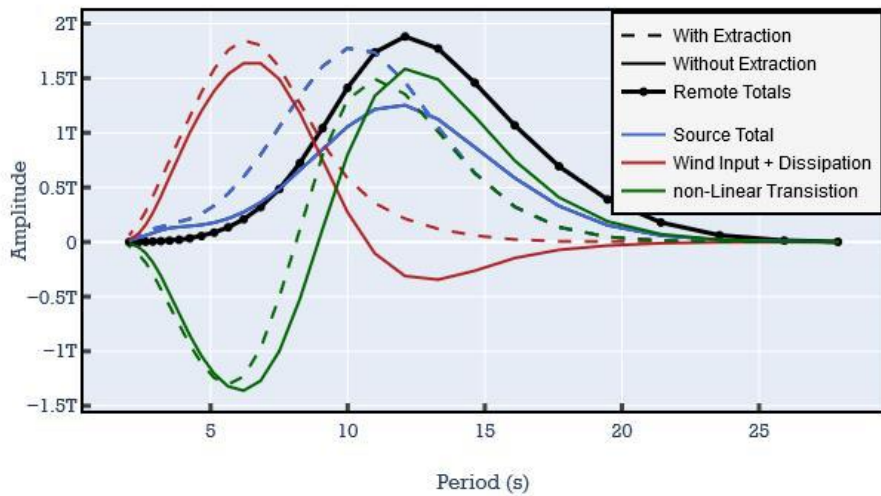
West Coast Resource



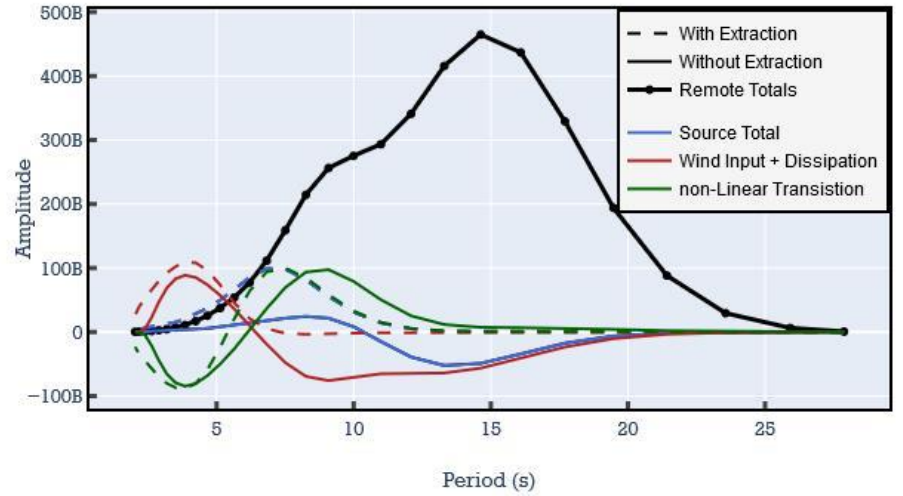
Atlantic Resource



Alaskan Resource



Hawaiian Resource



Summary

- Total resource increase by 30%
- Regional differences for the increase:
 - longer integration contour (HI)
 - Large area of source terms (AK, HI, East Coast)

Next Steps

- Publish
 - Energy, Applied Energy, PNAS, Nature Energy
- Build international consensus

Thank You!

Questions?

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www.nrel.gov

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Extra Slides

The importance of wave directionality

Incoming Wave



$$J = 1 \text{ kW/m}$$

Contour



$$d = 1 \text{ km}$$

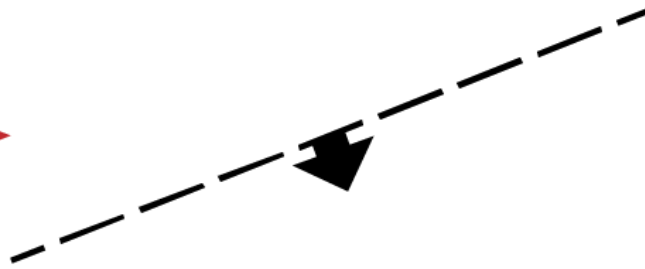
Directionality coefficient



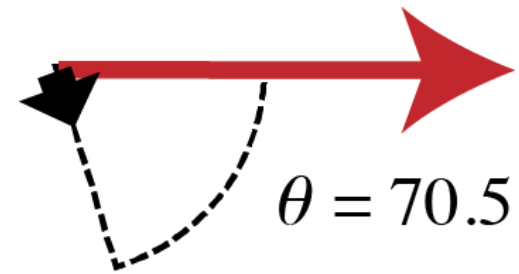
$$\alpha = \cos \theta = 1$$



$$J = 1 \text{ kW/m}$$



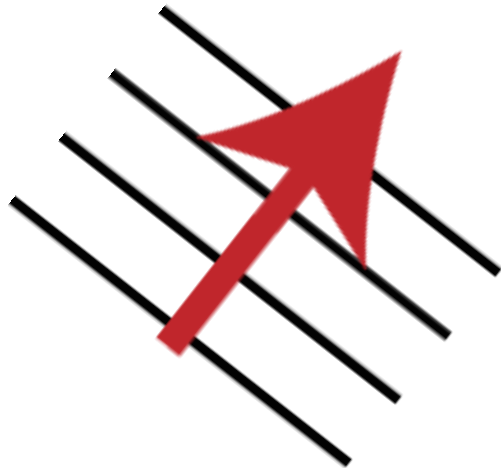
$$d = 3 \text{ km}$$



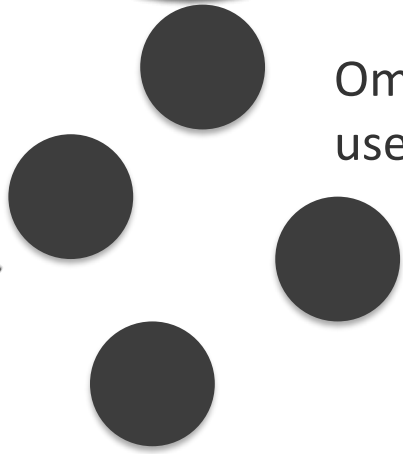
$$\alpha = \cos \theta = 1/3$$

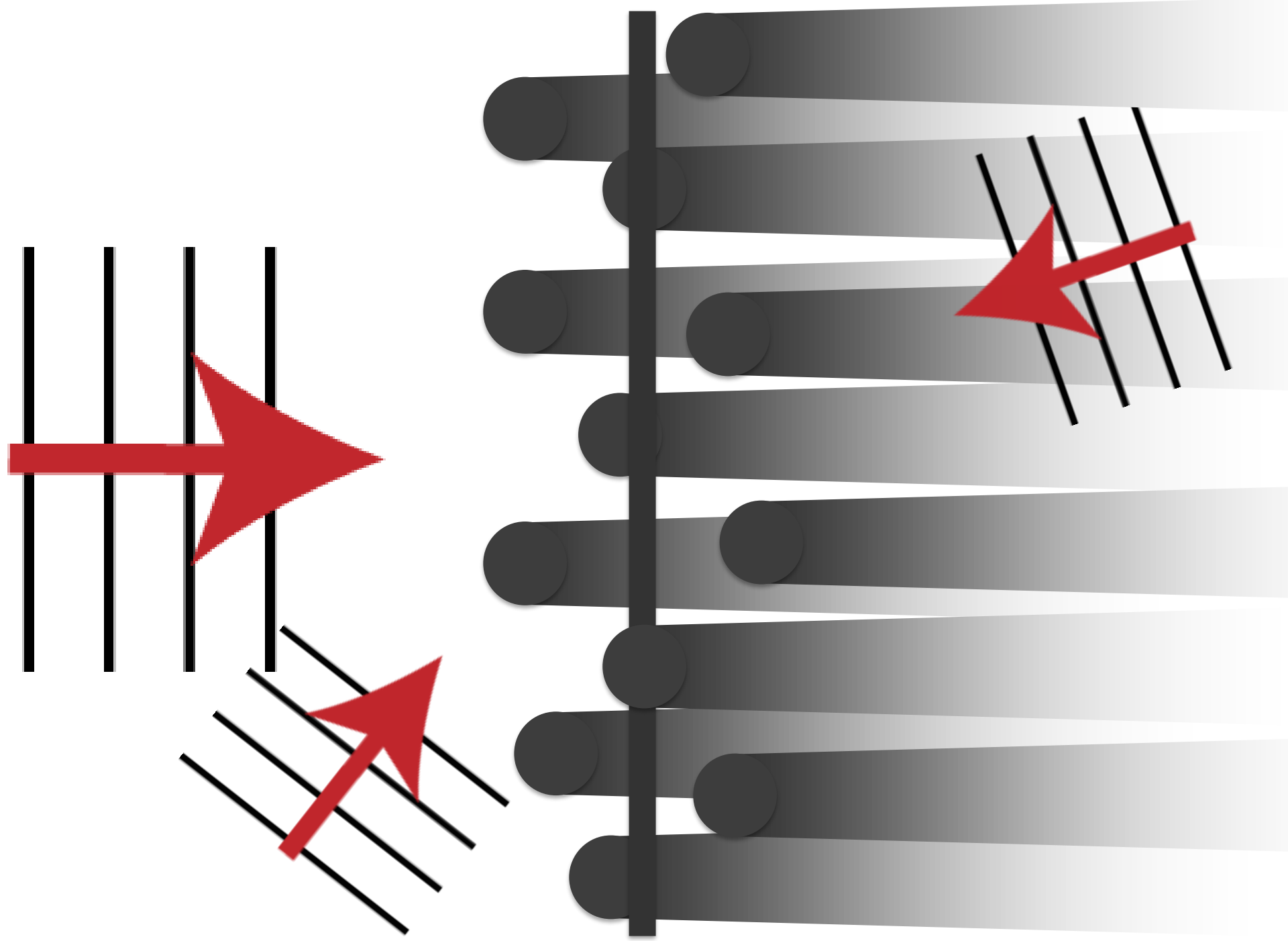
$$P = J \cdot d \cdot \alpha = 1 \text{ MW}$$

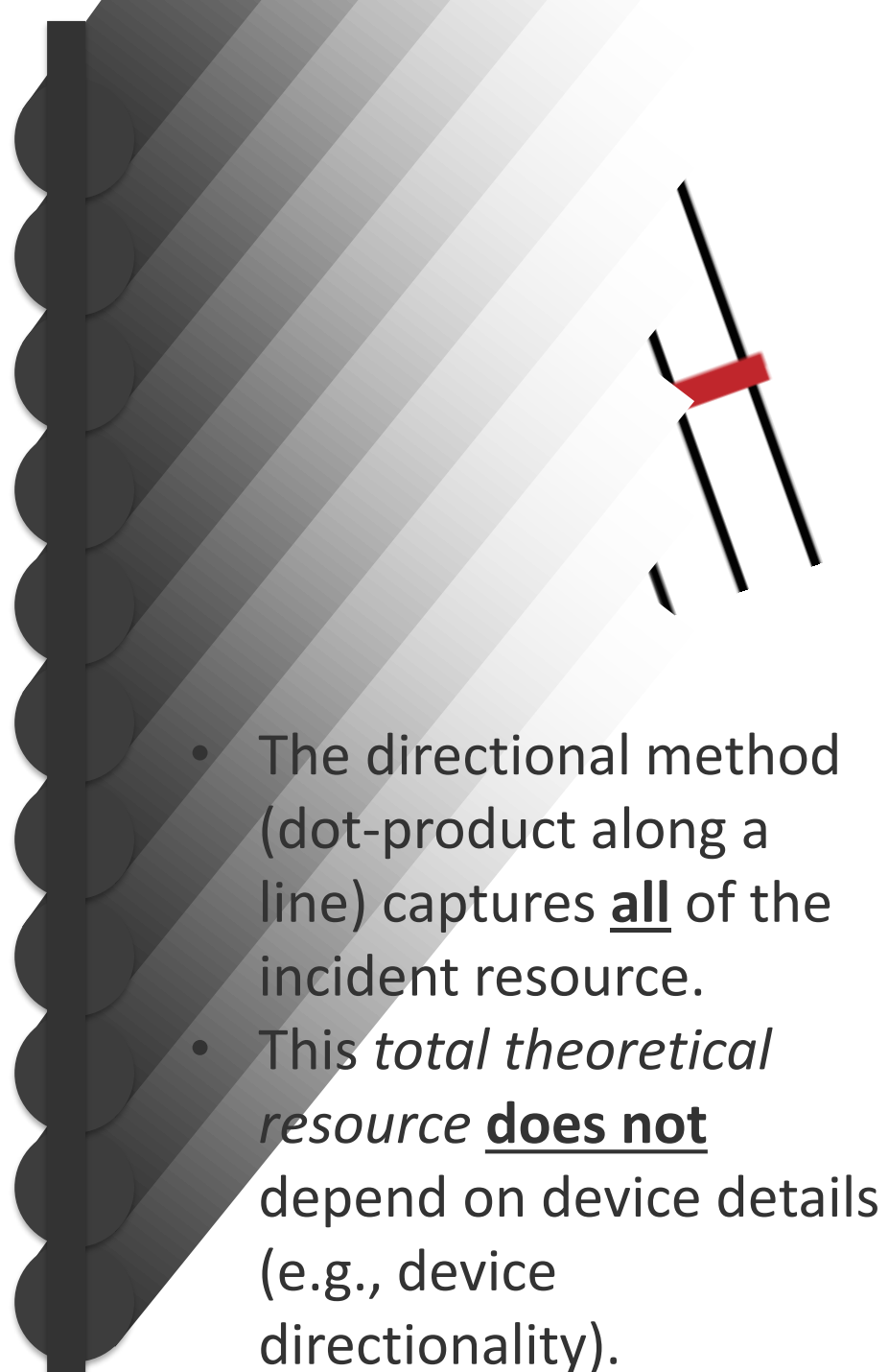
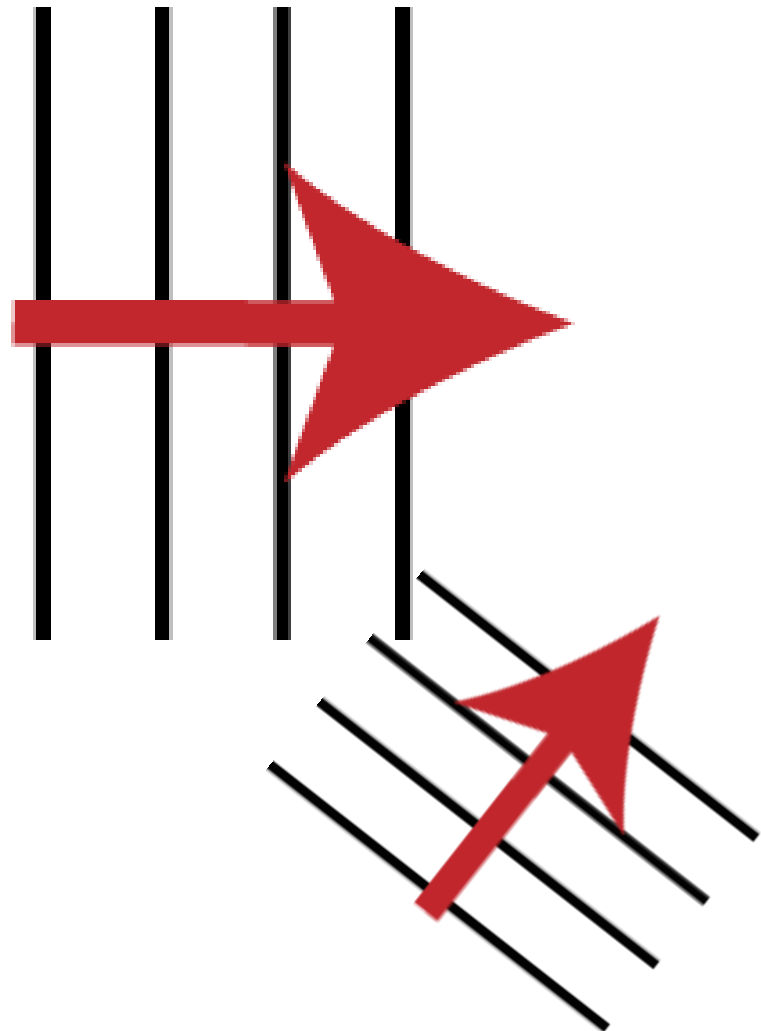
Point absorbers generate equally for waves in all directions.



Omni-directional wave power *is* useful for *one* point absorber







- The directional method (dot-product along a line) captures all of the incident resource.
- This *total theoretical resource* does not depend on device details (e.g., device directionality).

Results: A look back

- EPRI 2004 uses EEZ and directionality, but only a few regions and old models
- "NREL 2018" uses same contour as "EPRI 2011", with directionality

Region	EPRI 2004 TWh/yr	EPRI 2011 TWh/yr	NREL 2018 TWh/yr	EEZ: Remote TWh/yr	EEZ: TOTAL TWh/yr
West Coast	440	590	360	420	510 – 610
Hawaii	300	130	80	290	300 – 380
East Coast	110	240	120	110	280 – 320
Gulf of Mexico		80	30	13	63 – 73
Alaska	1250	1570	1070	1040	2000 – 2430
Puerto Rico		30	20	6	17 – 32
TOTAL	2100	2640	1680	1879	3170 – 3845