Cost Analysis of 15MW Platforms for Horizontal and Vertical Axis Turbines for the West Coast U.S.

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Organized by FWE Quest Offshore

Introduction

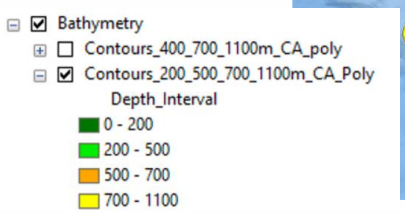
- Infrastructure for constructing and assembling very large floating wind units is limited on the US West Coast.
- Two solutions:
  - 1) Spend a lot of money building out infrastructure, or
  - 2) Implement a modular floating fabrication technology that utilizes existing infrastructure
- We examined a series of modular solutions using VAWTs and HAWTs on floating foundations of Mars-TLP and Mars-SEMI for a small scale, 210 MW wind farm offshore California.
- This solution approach does not require any infrastructure build out on shore and utilizes equipment and technology readily available locally.
- The modular foundation and VAWT technology are derived from an ARPA-E funded program (*ATLANTIS*).

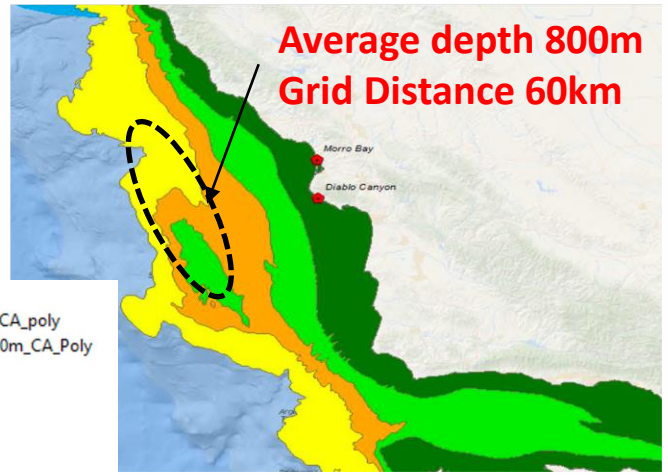
Floating Wind Design Conditions

Metocean Condition for Central California

ABS DLC	Wind	Wave (JONSWAP) *			Current *
	10-min, Hub	Hs	Tp	Gama	Surface
	m/s	m	m/s	-	m/s
DLC 1.6	10.5	4.5	11.3	2.4	0.20
	25.0	8.8	14.0	2.4	0.20
DLC 6.1	26.5	8.8	14.0	2.4	0.8

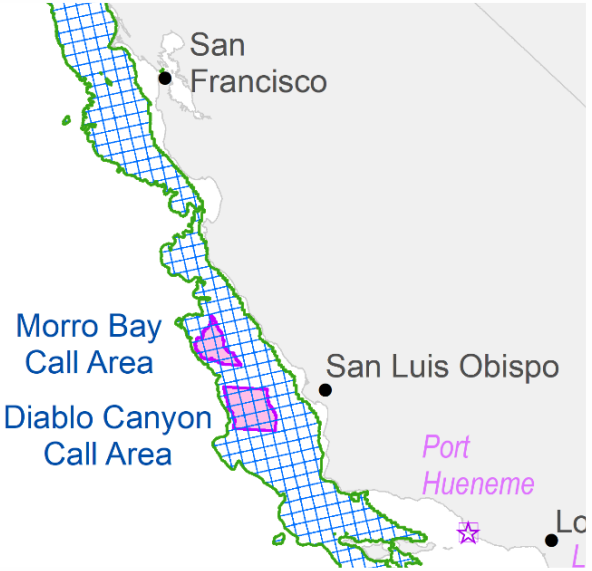
** Source: API 2MET*



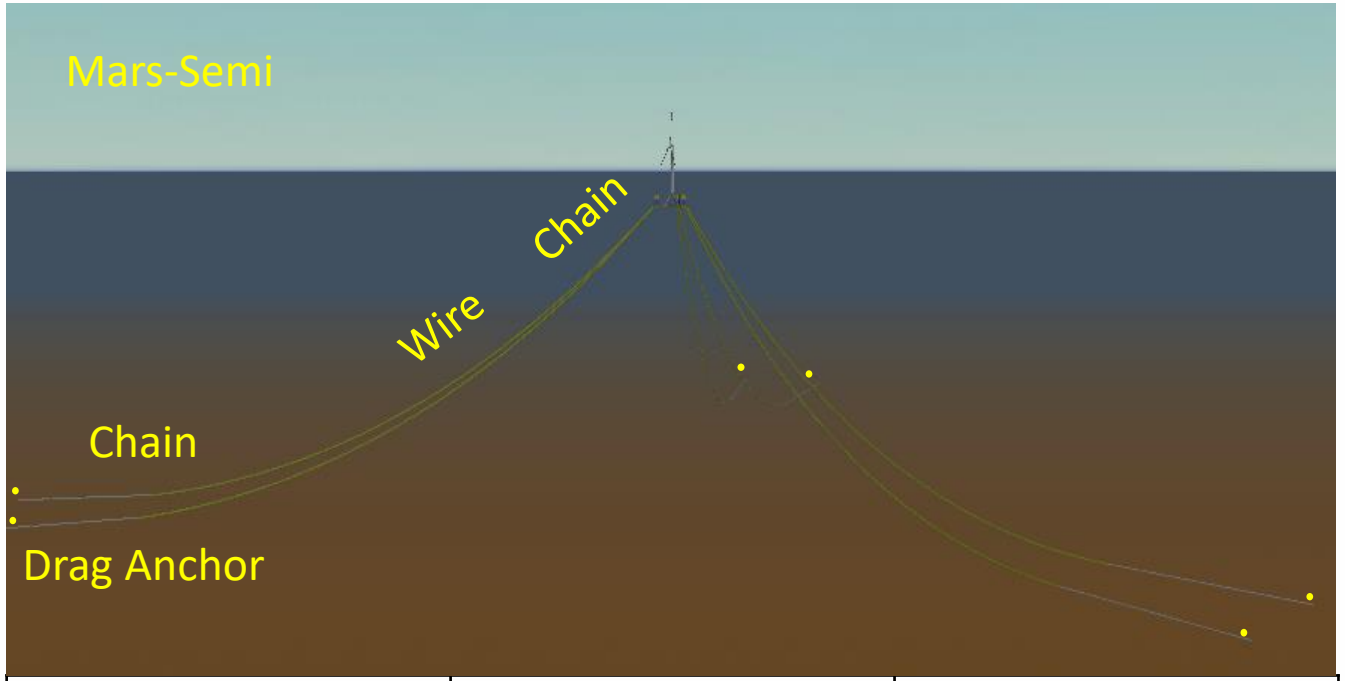


Design Criteria

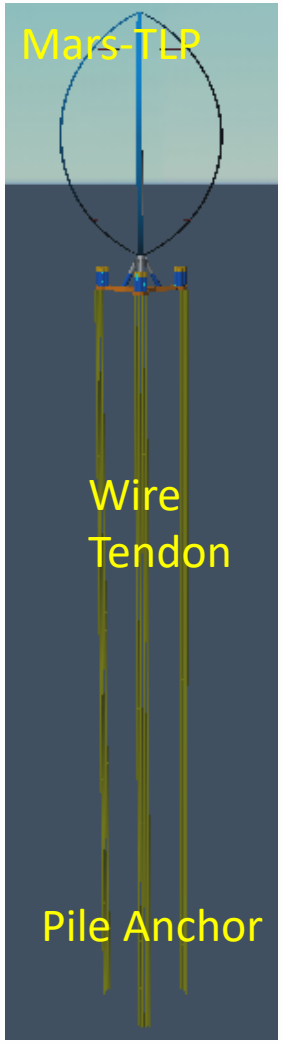
Design Items	MARS-TLP	MARS-Semi
Platform Pitch (Operating)	< 10deg	< 10deg
Platform Offset (Mooring Intact)	< 10% of Water Depth	< 10% of Water Depth
Hull Design	API RP 2T, ABS	ABS
Mooring Design	API RP 2T	ABS, API RP 2SK
Anchor Design	API RP 2T (Driven Anchor)	ABS, API RP 2SK (Drag Anchor)
Wet-Tow (Turbine Integrated)	No Dedicated Vessel Req.	No Dedicated Vessel Req.



Semi and TLP Mooring Configuration



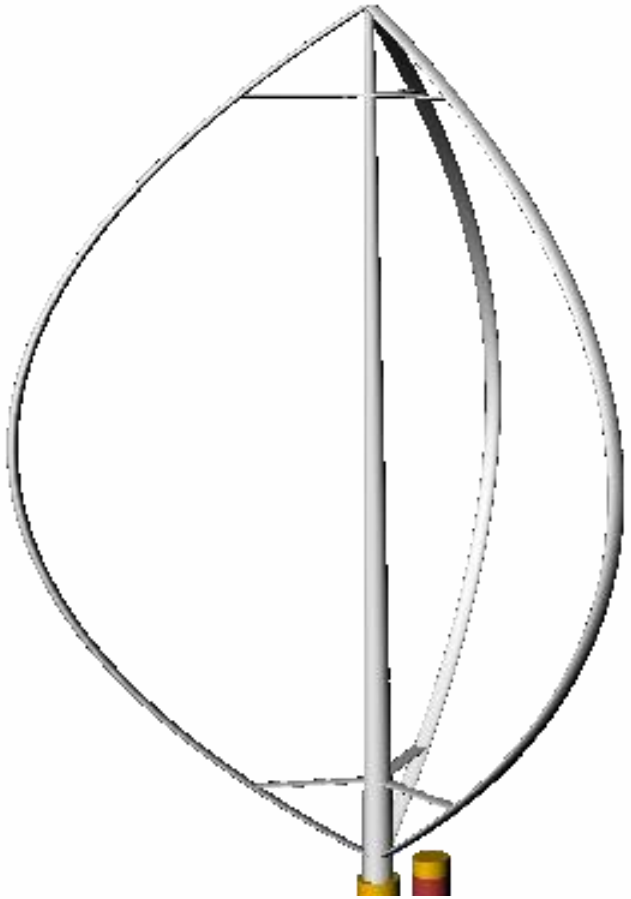
Items	Mars-Semi	Mars-TLP
Water Depth	800 m	800 m
Mooring Type	Catenary	Vertical Tendon
# Lines Total	6	12
Line Material	Chain - Wire - Chain	Wire
Anchor	Drag	Pile Driven

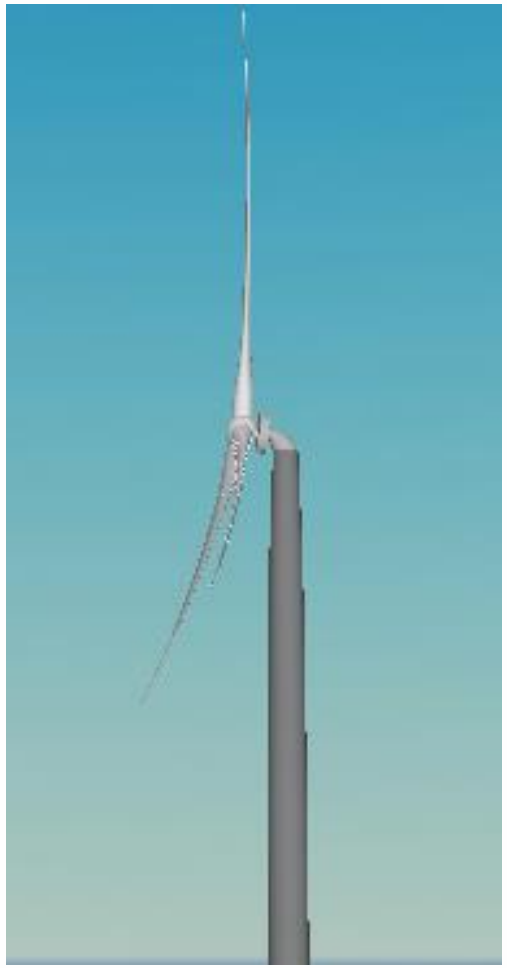


15MW Turbines: UT Dallas vs. IEA/NREL

Item		UT Dallas VAWT, Initial Upscaled	IEA/NREL, U Maine HAWT
Power	MW	15	15
Rotor Dia.	m	191	240
Press. Center	m	120	135 (hub)
Total Weight	tonnes	2,765	2,270
VCG	m	50.0	82.4

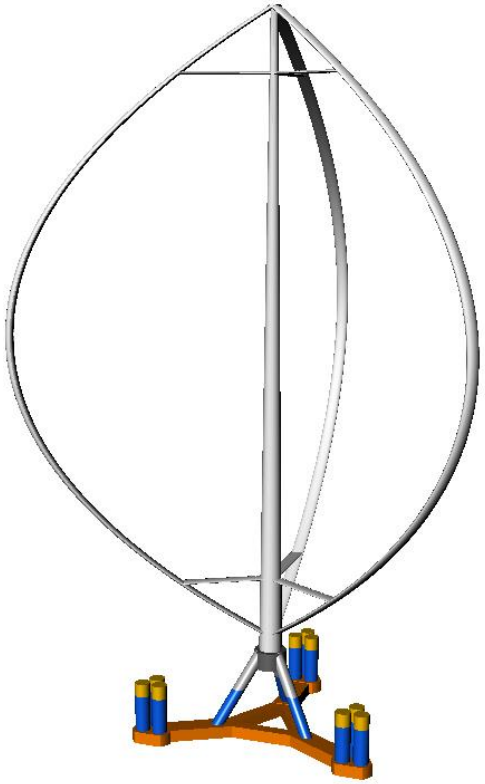
1. *VCG and pressure center are above the tower base.*
2. *VAWT turbine properties will be updated when the optimization is completed through the on-going ARPA-E Atlantis project.*



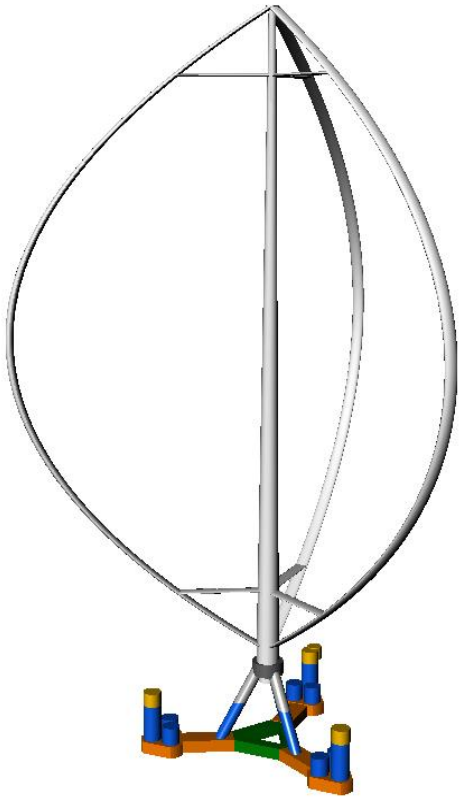


VLO's Floating Wind and Substation Platform Designs

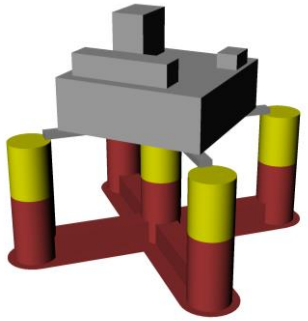
Mars-Wind HAWT Semi



Mars-Wind VAWT TLP



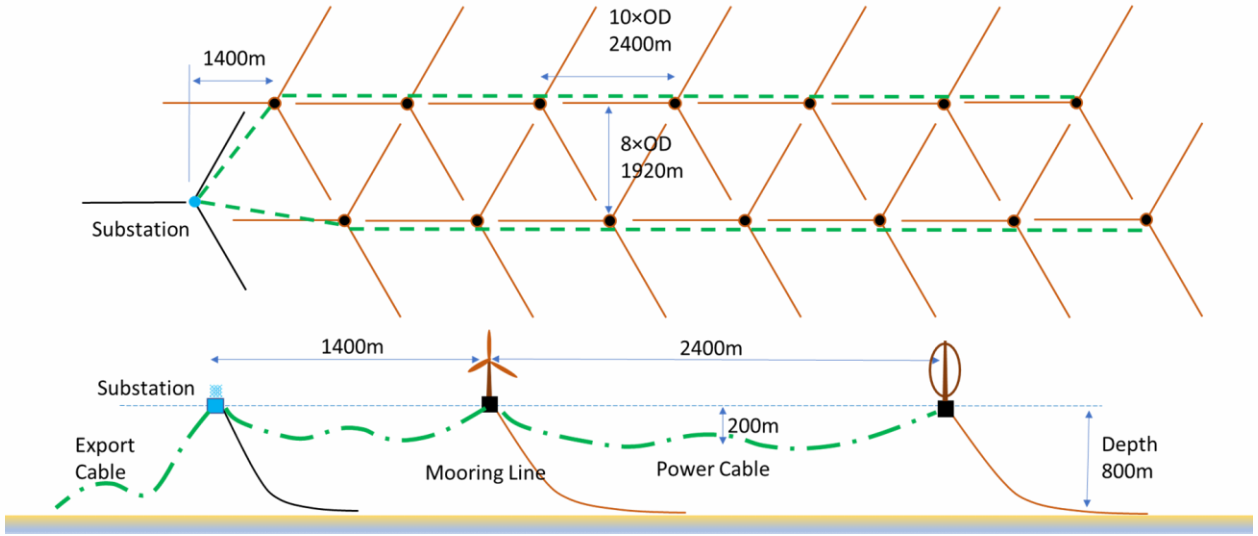
Mars-Wind VAWT TLP with Short Column



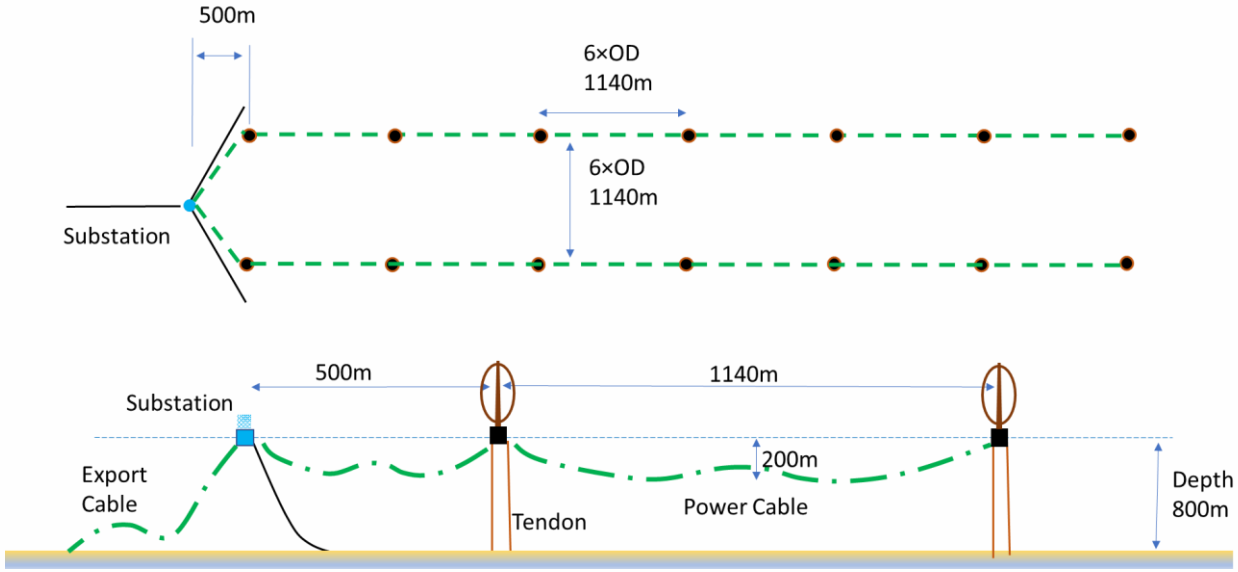
Floating Substation Semi

Wind Farm Layout: 14 SEMIs and TLPs (HAWT, VAWT)

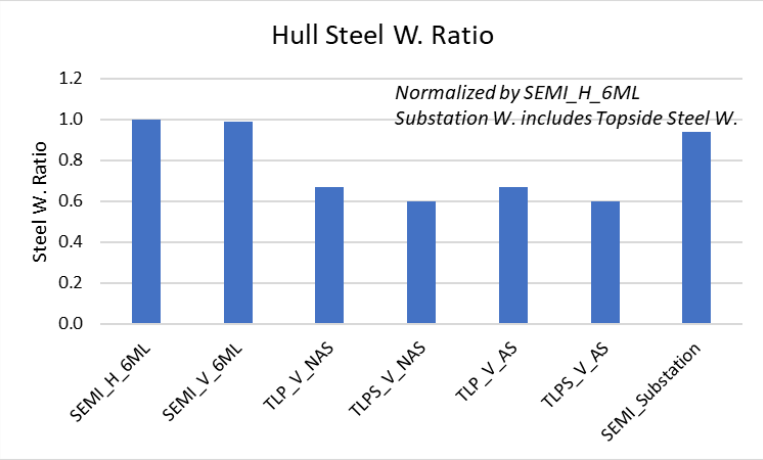
SEMI with HAWT or VAWT

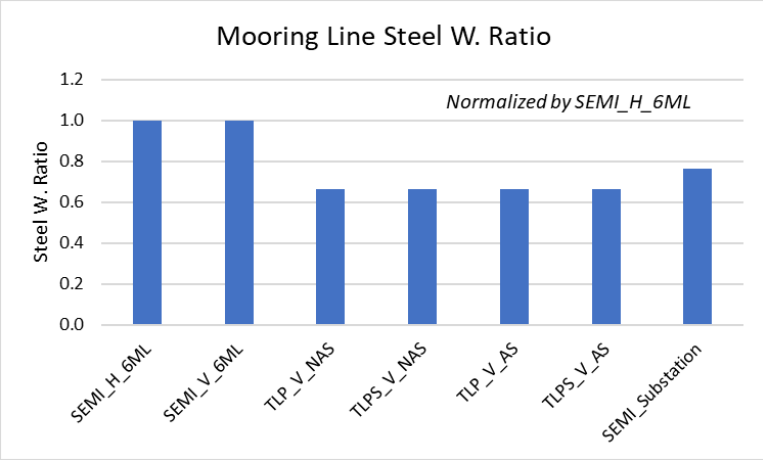


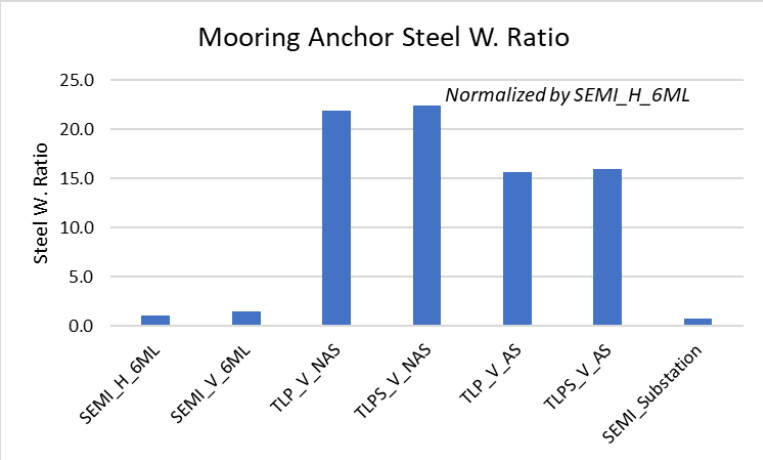
TLP with VAWT

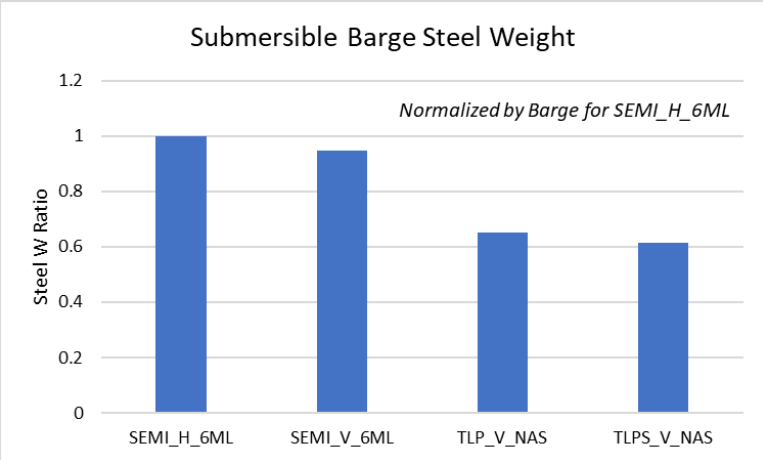


Platform Design Results: Steel Weight









Platform	Hull Type	Turbine	# Lines	Anchor Sharing
SEMI_H_6ML	Semi	HAWT	6	N
SEMI_V_6ML	Semi	VAWT	6	N
TLP_V_NAS	TLP	VAWT	12	N
TLPS_V_NAS	TLP Short Column	VAWT	12	N
TLP_V_AS	TLP	VAWT	12	Y
TLPS_V_AS	TLP Short Column	VAWT	12	Y
Substation	Semi	-	8	N

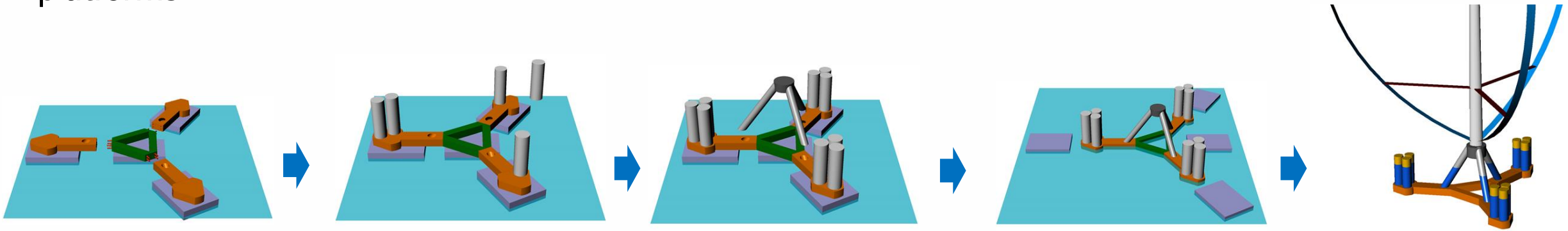
- Conducted numerical simulations for DLCs.
- Confirmed the designs per the criteria.

Cost Components

- From FID to first platform in field is 3 years, followed by 25 years of operations
- All costs required to get the wind farm on site and operating are included
  - Project Management and Engineering
  - Procurement and Fabrication
  - Mating and Integration
  - Offshore Tow, Installation and Commissioning
  - Substation, in-field power cables and export cable to beach connection to grid
  - Some decommissioning costs are included
- Costs not included are:
  - Site permitting, site surveys and environmental reviews
  - Owner's costs and insurance
  - On-shore grid costs (such as any additional transmission lines to the beach connection)

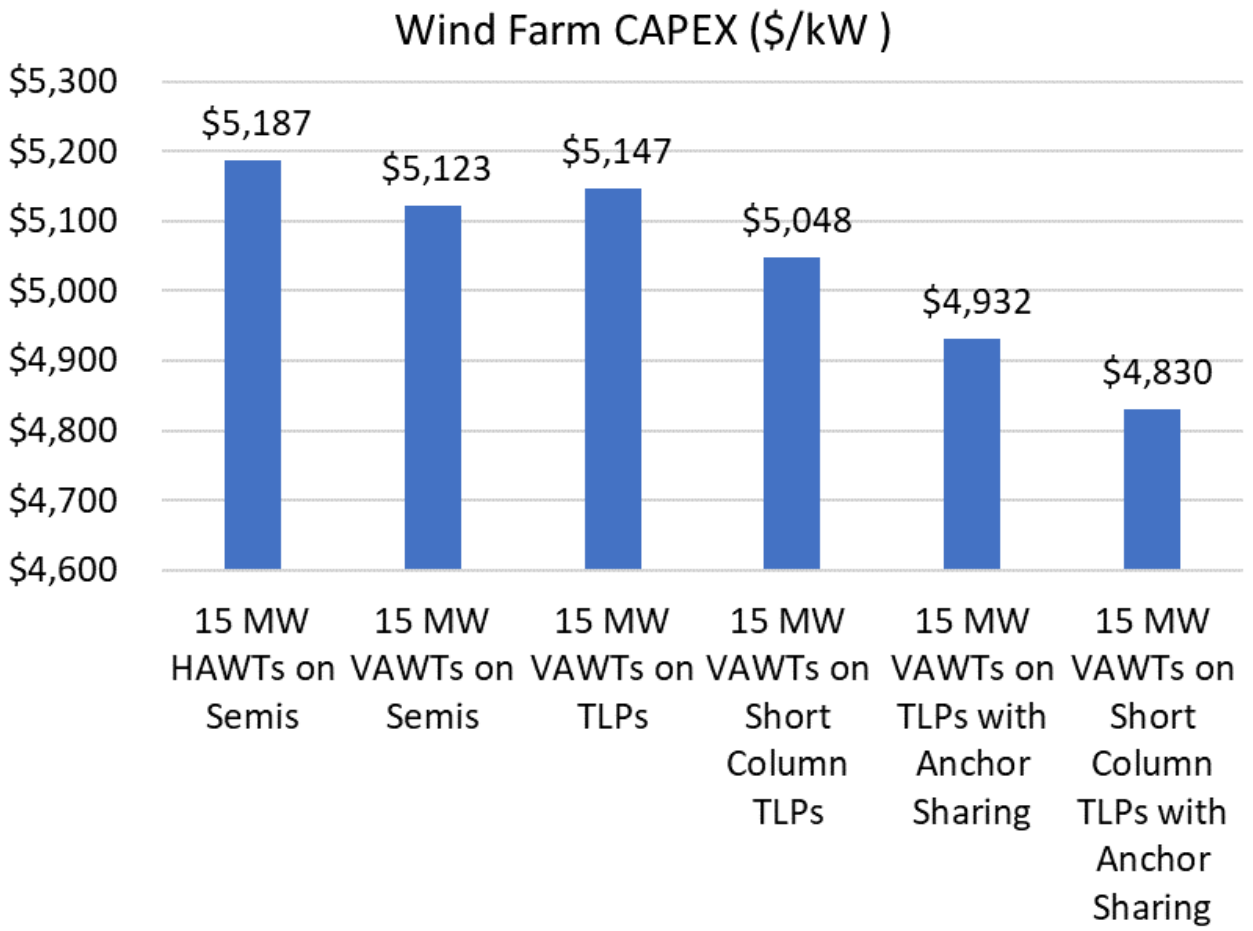
Execution Assumptions

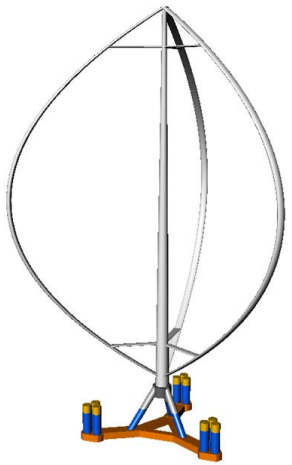
- All modules of Mars-Wind platforms are fabricated at a West Coast facility and then transported to an assembly area
- The hull modules are assembled quayside on water; Turbine lift and set (integration) occurs quayside
- The completed platform (foundation and turbine) is then towed to site by vessels of opportunity
- Anchors and mooring lines are pre-installed
- In-field power cables are installed after the platforms
- Substation and export power cable is installed to coincide with start of operation of the first line of platforms



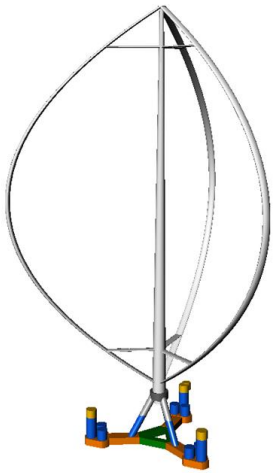
Total 210 MW Wind Farm CAPEX

HAWT Semi





VAWT TLP



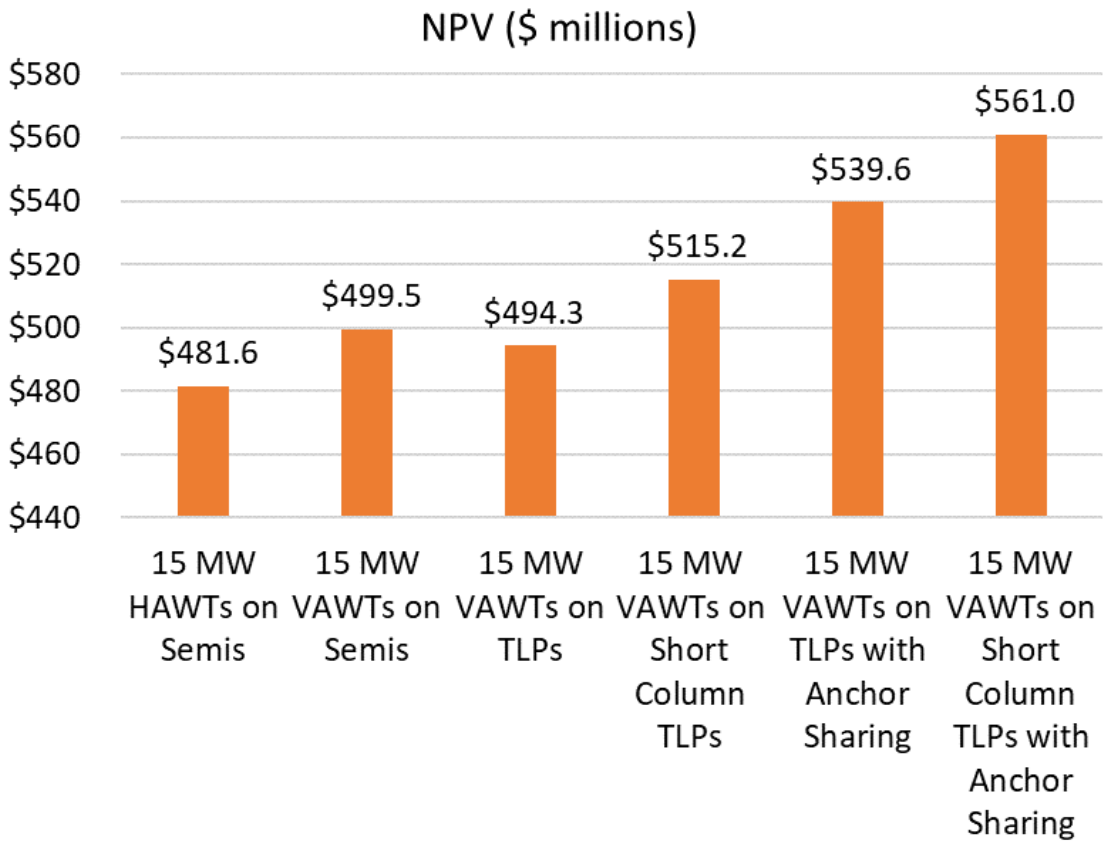
VAWT TLP with Short Column

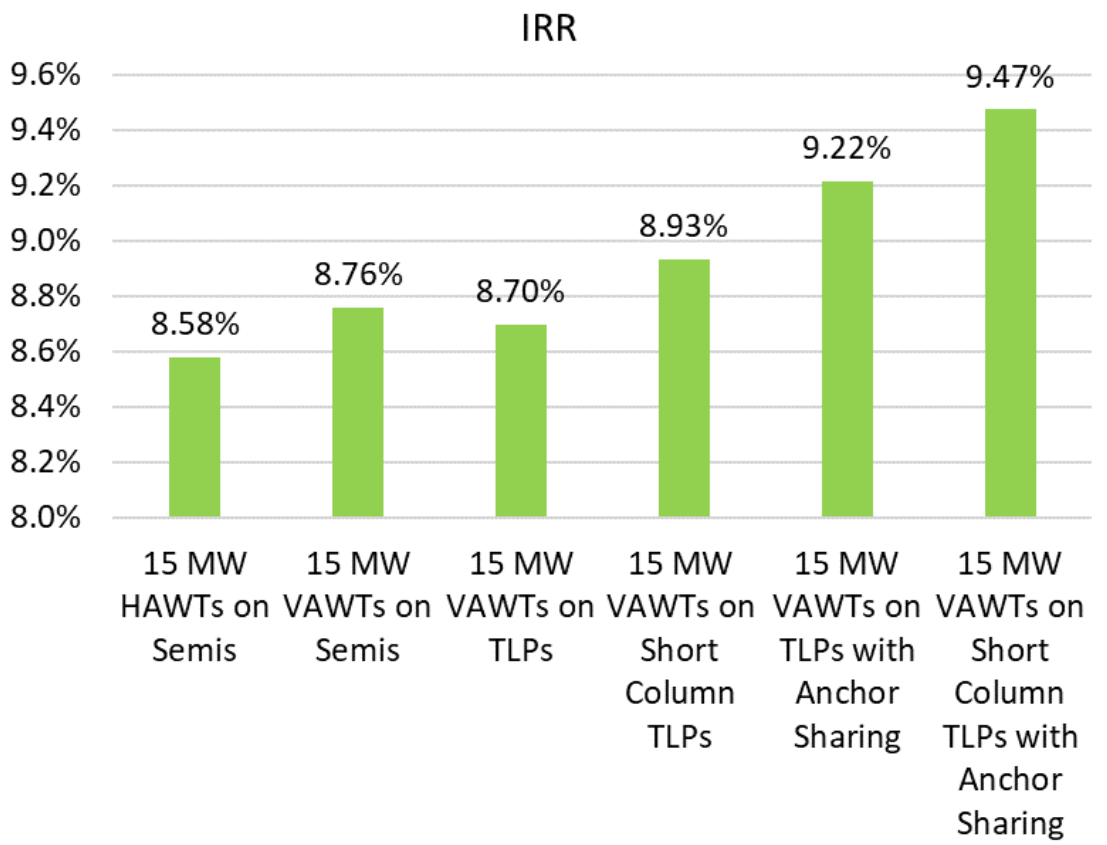
Financial Input Factors

	HAWT	VAWT
California Electricity Sales Price ($ / kWh)	$ 0.145	$ 0.145
Inflation Rate	4%	4%
Discount Rate	5%	5%
Operating Life (years)	25	25
Fixed O&M Cost ($ / kW year)	15	15
Variable O&M Cost ($ / kWh)	0.025	0.020
Capacity Factor	42.5%	42.5%
Annual Turbine Downtime	5%	5%

There are no government subsidies included.

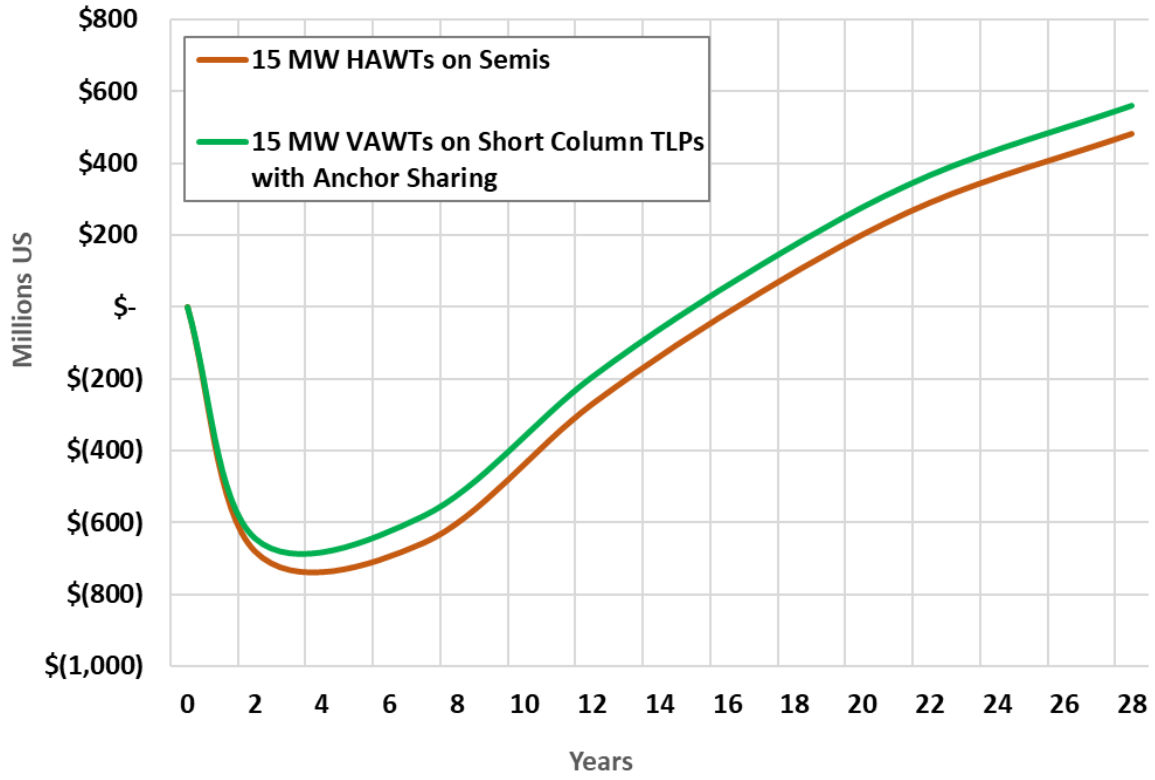
NPV and IRR


NPV ($ millions)
$580
$560
$540
$520
$500
$480
$460
$440
$481.6
$499.5
$494.3
$515.2
$539.6
$561.0
15 MW HAWTs on Semis
15 MW VAWTs on Semis
15 MW VAWTs on TLPs
15 MW VAWTs on Short Column TLPs
15 MW VAWTs on TLPs with Anchor Sharing
15 MW VAWTs on Short Column TLPs with Anchor Sharing

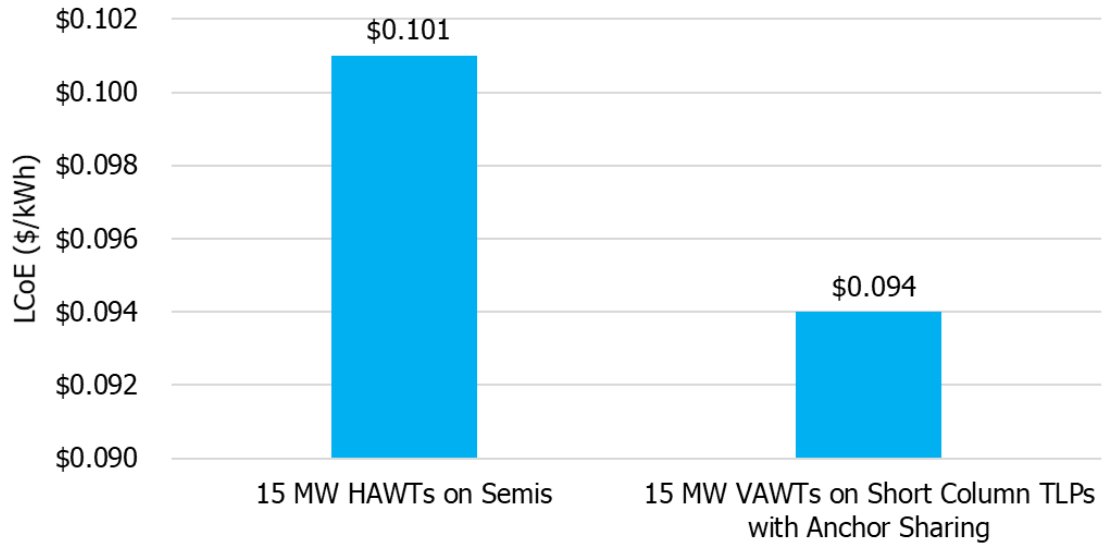

IRR
9.6%
9.4%
9.2%
9.0%
8.8%
8.6%
8.4%
8.2%
8.0%
8.58%
8.76%
8.70%
8.93%
9.22%
9.47%
15 MW HAWTs on Semis
15 MW VAWTs on Semis
15 MW VAWTs on TLPs
15 MW VAWTs on Short Column TLPs
15 MW VAWTs on TLPs with Anchor Sharing
15 MW VAWTs on Short Column TLPs with Anchor Sharing

NPV and LCoE Ranges

NPV over Project Life



LCoE Value Range



Summary for a 210 MW California Wind Farm

- 15 MW modular floating platforms for California offshore are commercially and technically feasible
- A modular approach allows for series production of components within existing infrastructure on the West Coast
- LCoE values range between $0.094 to $0.101 /kWh
- IRR ranges from 8.5% to 9.5% without any government subsidies of any kind
- VAWT configured wind farms will see reductions in spacing offshore and reduced operating maintenance expenditures compared to HAWT configurations.
- The IEA 15MW HAWT has been highly optimized with several years of effort while the UT-Dallas VAWT is in early stages of engineering development. It is expected that the 15MW VAWT loads will be further reduced resulting in a lighter hull and additional reductions in LCoE.

Questions / Contact

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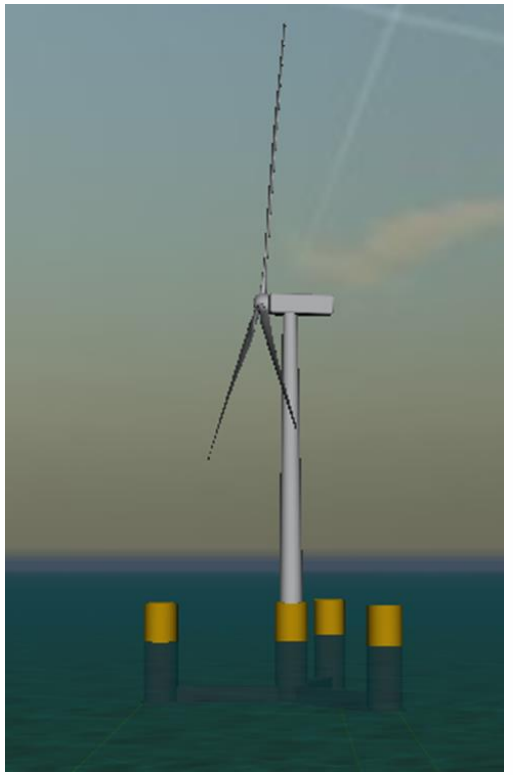
ARPA-E ATLANTIS
FloatVAWT TLP



VLO Y-Wind Semi