ADVANCED PERFORMANCE HYDRAULIC WIND ENERGY

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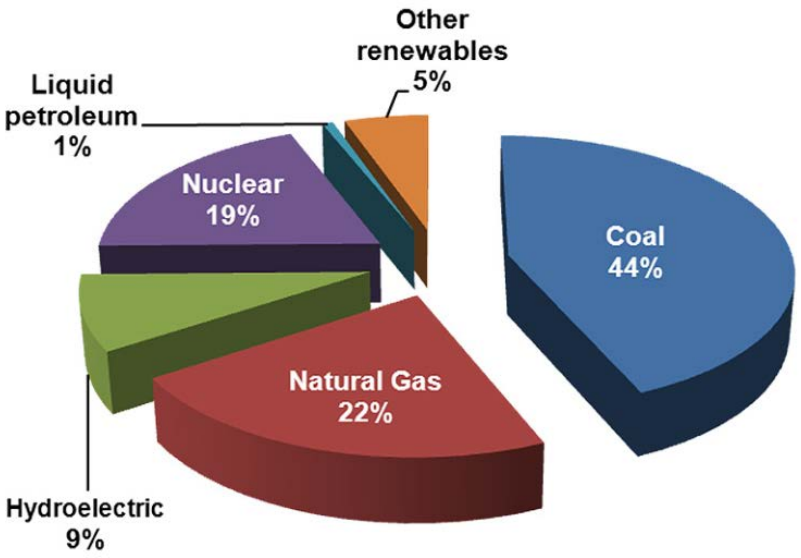
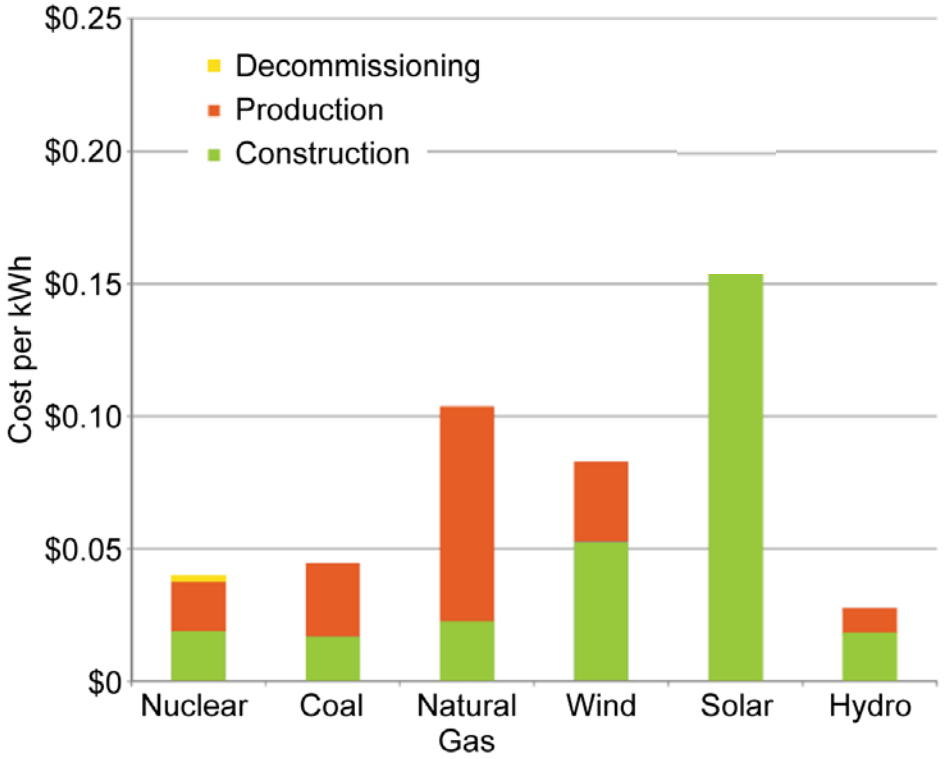
US Electrical Production and Costs





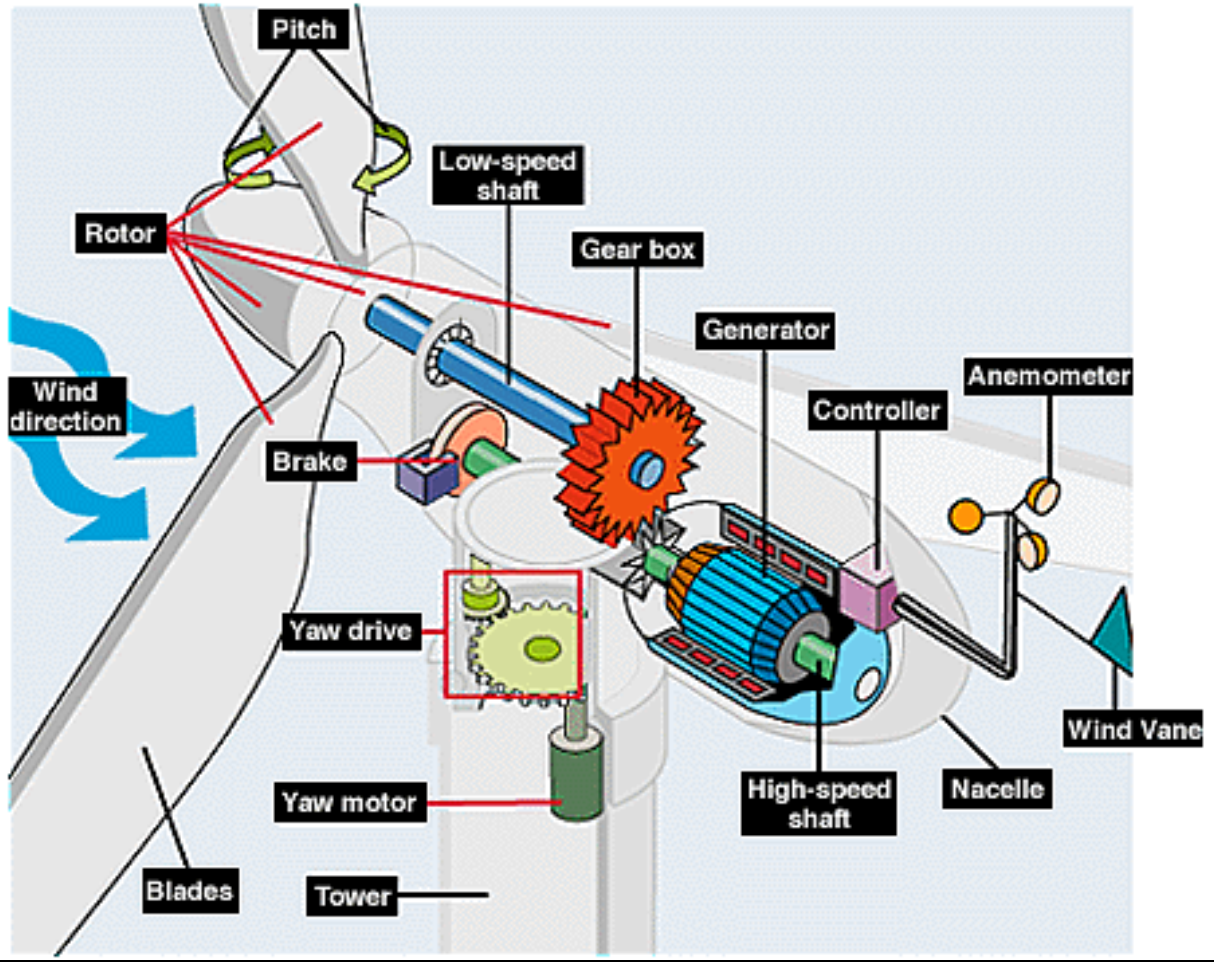
With hydroelectric and nuclear energy effectively maxed out, and cutbacks on coal and natural gas inevitable, *wind is presently leading the race for large amounts of low cost, low carbon energy.*

Hydrokinetic and Wind Energy Production Potential in the United States

Type of Power	TW-Hr/Yr Potential in US
Ocean Waves	252
In-stream Tidal (Rivers, Tides, Gulfstream)	177
Offshore Wind	>4000
Onshore Wind	~37,000

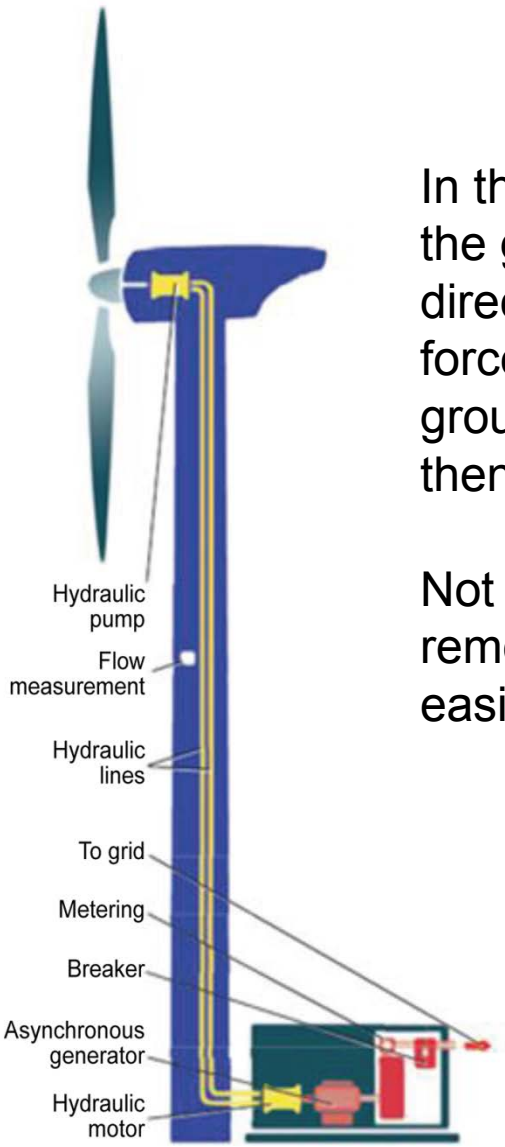
- The US presently uses about 4000 TW-Hr/Yr of Electricity
- Wind (Onshore and offshore), as well as Solar (not listed) are the only renewables in sufficient supply that can significantly reduce greenhouse gasses

CONVENTIONAL WIND TURBINE DESIGN



In the conventional wind turbine, a set of gears increases the RPM to the generator, which generates electricity. The gears represent a frictional loss that is very significant at lower speeds. The gears are also the most likely component to fail. Repairing gears or the generator requires expensive off-time to service the upper part of the wind turbine.

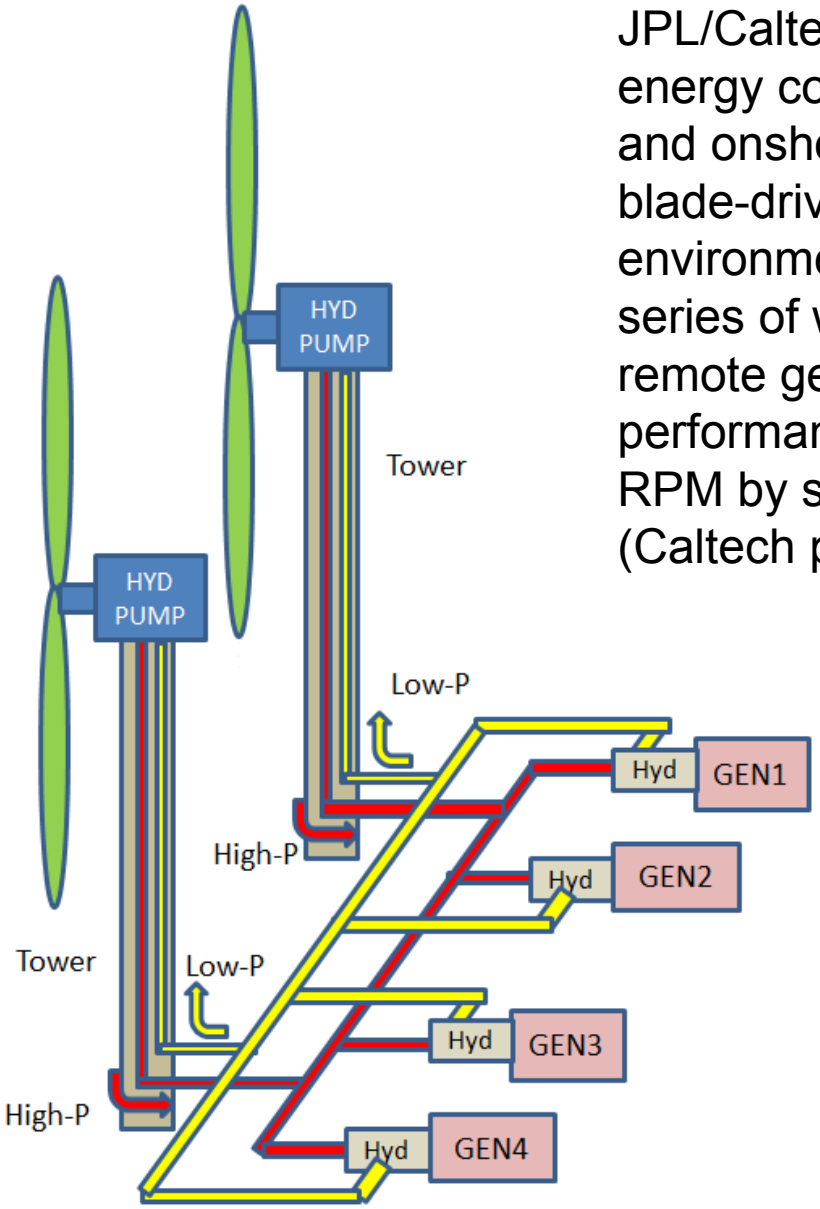
Conventional Hydraulic Wind Turbine



In the conventional hydraulic wind turbine, the gearbox is removed, and the blades directly turn a hydraulic pump. The pump forces high pressure hydraulic fluid into a ground-located hydraulic generator, which then generates electricity.

Not only is the expensive, failure prone gear removed, but all the electronics are at an easily serviceable ground level.

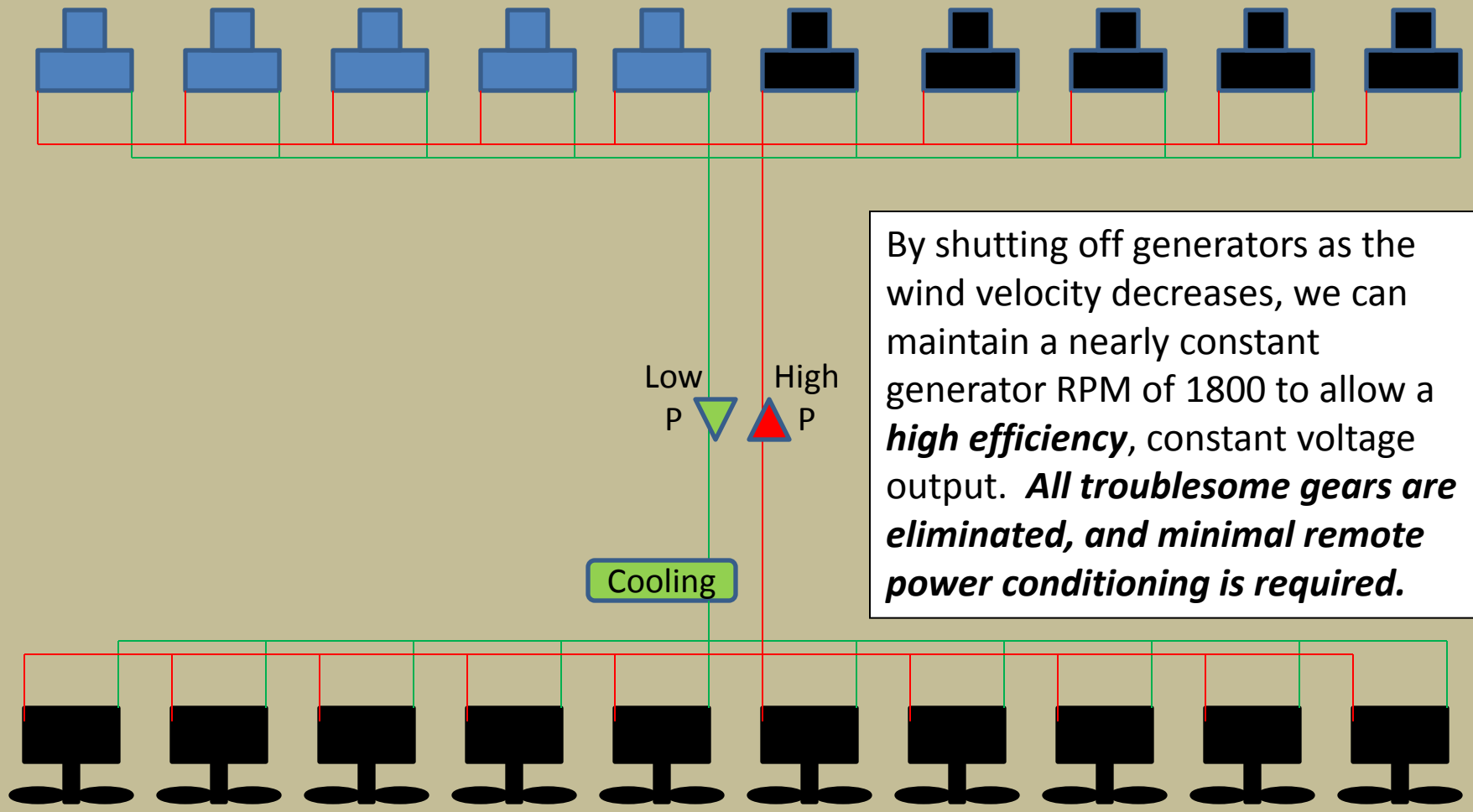
ADVANCED PERFORMANCE HYDRAULIC WIND ENERGY



JPL/Caltech improved the hydraulic wind energy concept significantly for both offshore and onshore applications. In this approach, blade-driven pumps are used to circulate an environmentally friendly hydraulic fluid from a series of wind towers directly to a series of remote generators. The generator performance can be maintained at an optimal RPM by shutting off some of the generators. (Caltech patents granted and pending)

Onshore Wind Turbine Power Generation

Remote Axial Piston Hydraulic Generators (~15 MW)

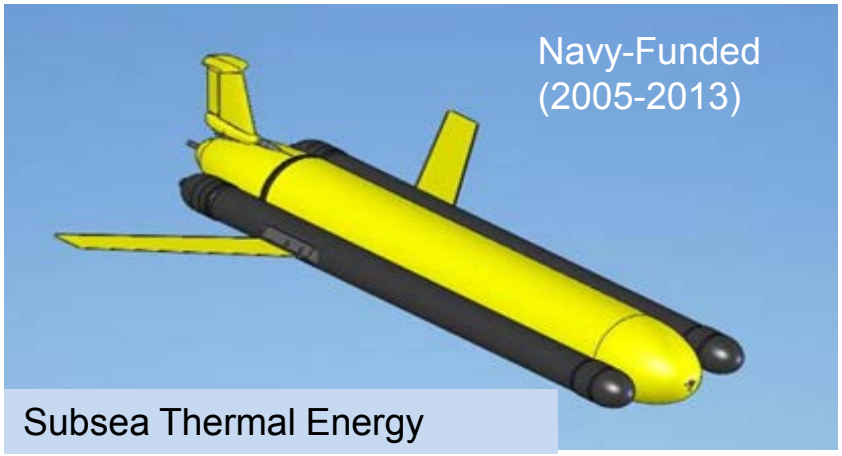


By shutting off generators as the wind velocity decreases, we can maintain a nearly constant generator RPM of 1800 to allow a ***high efficiency***, constant voltage output. ***All troublesome gears are eliminated, and minimal remote power conditioning is required.***

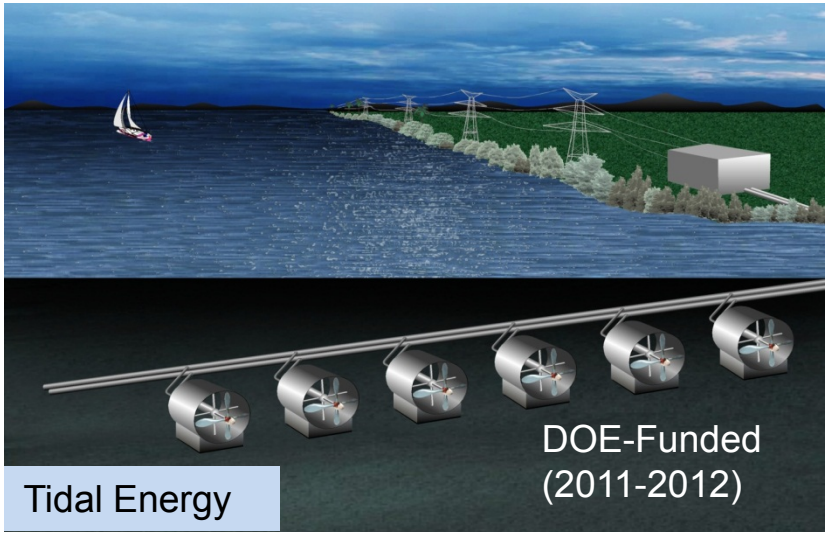
Blade Diameter = 58-m
RPM=18 at Max Velocity

Wind Turbine Radial Piston Hydraulic Pumps
(Fifteen Units, Bosch MB2400 @ 1.0 MW = 15 MW)

Gearless Hydraulic Energy Transfer



Subsea Thermal Energy

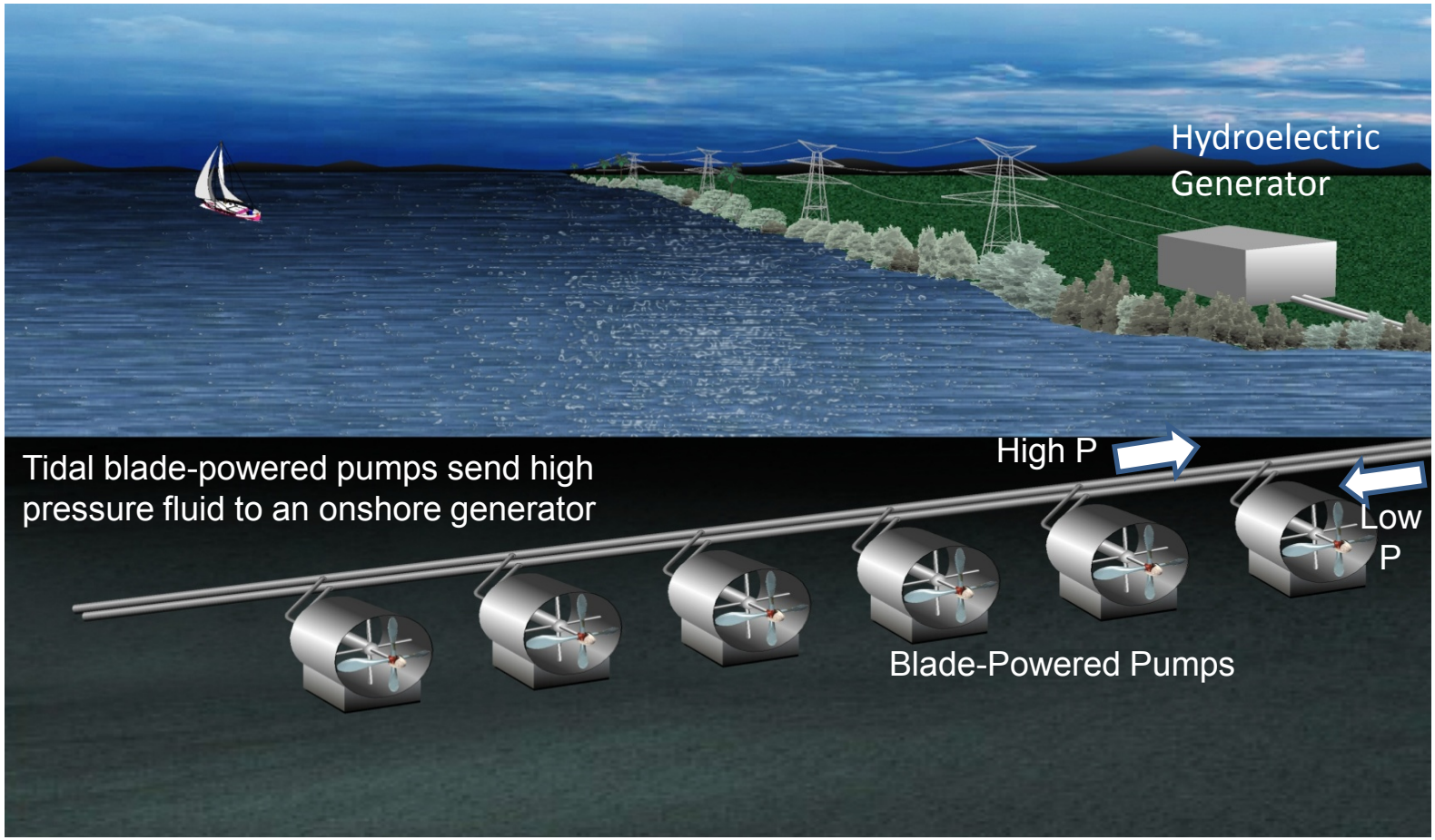


Tidal Energy

Wind Energy

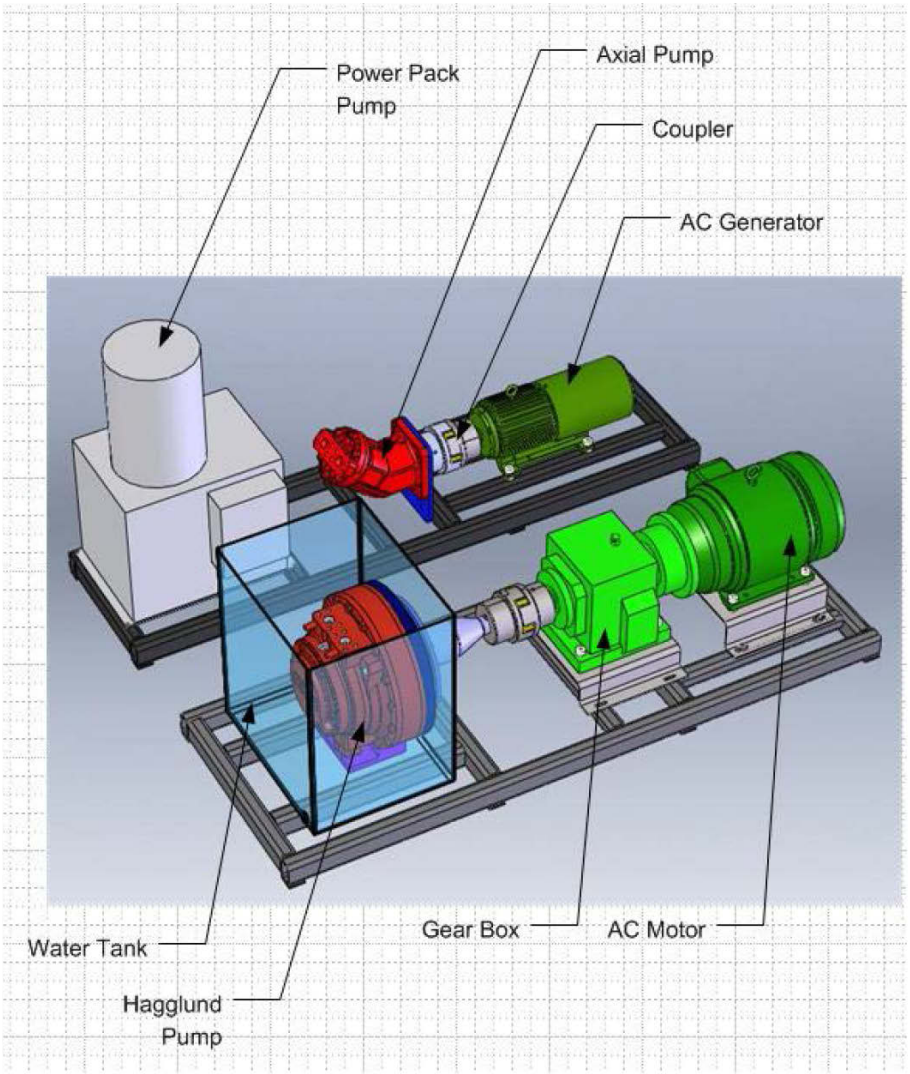
JPL has developed numerous gearless hydraulic energy transfer concepts, with Sunlight Photonics joining in the tidal energy and wind energy systems.

Advanced Hydraulic Tidal Energy

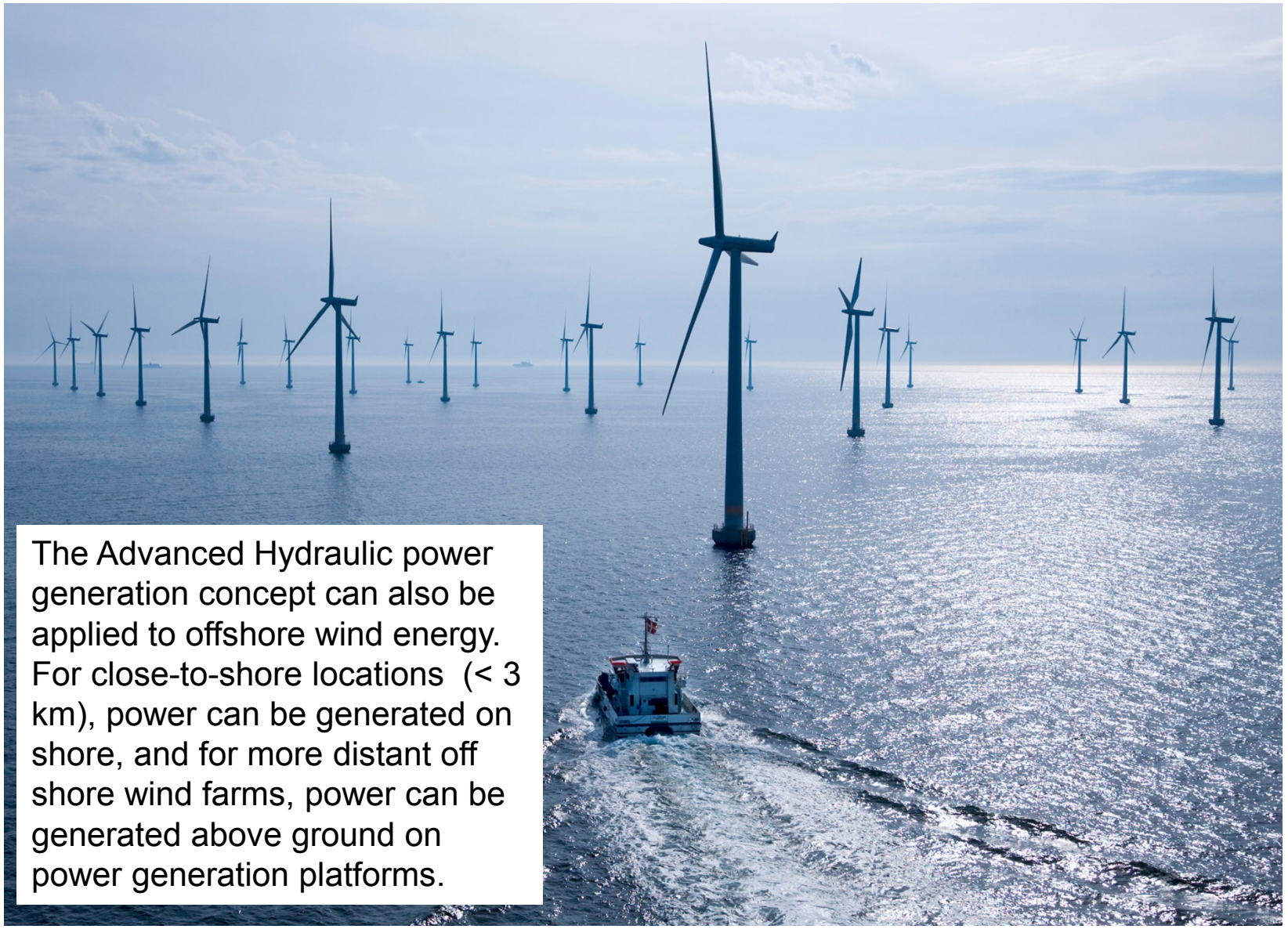


The same advanced hydraulic process can be applied to tidal energy, and all power generation can be relocated to onshore. In FY'12, DOE funded a successful theoretical analysis and laboratory demonstration by Sunlight Photonics, JPL, Atlantis Resources, Maine Maritime Academy, and Rutgers University.

Tidal Energy Laboratory Demonstration

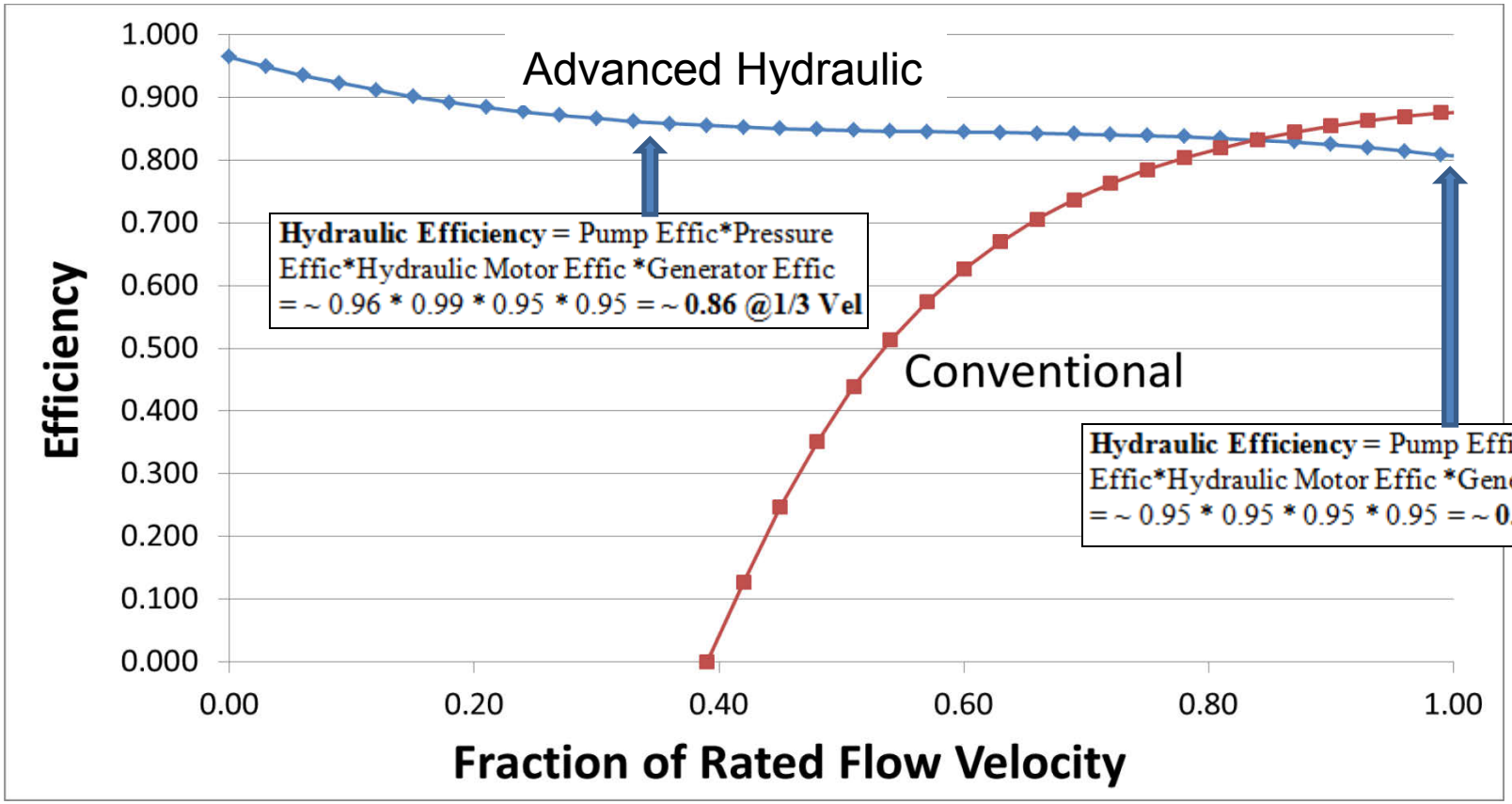


Offshore Wind Energy



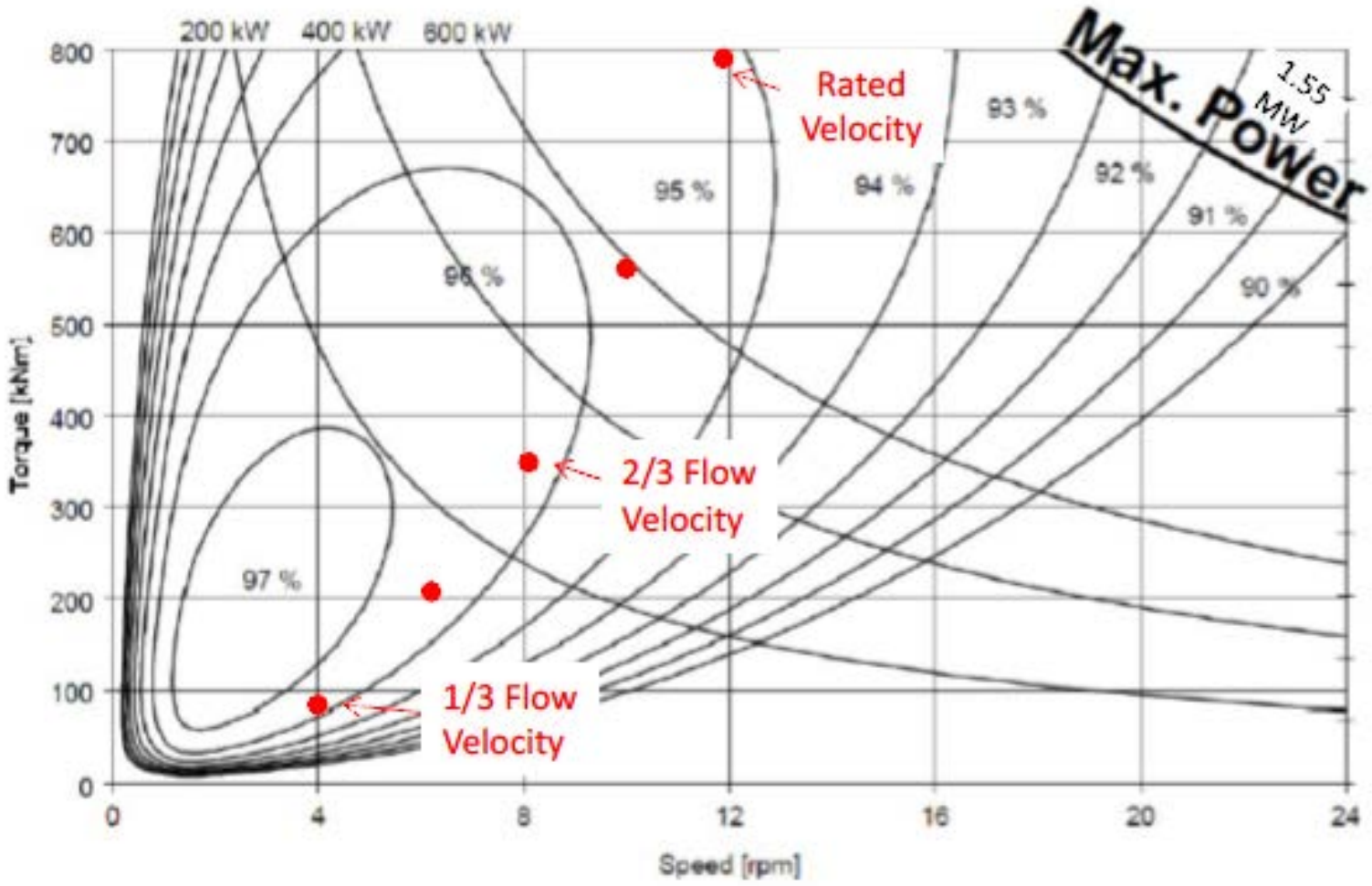
The Advanced Hydraulic power generation concept can also be applied to offshore wind energy. For close-to-shore locations (< 3 km), power can be generated on shore, and for more distant off shore wind farms, power can be generated above ground on power generation platforms.

Advanced Hydraulic vs. Conventional Wind Efficiency



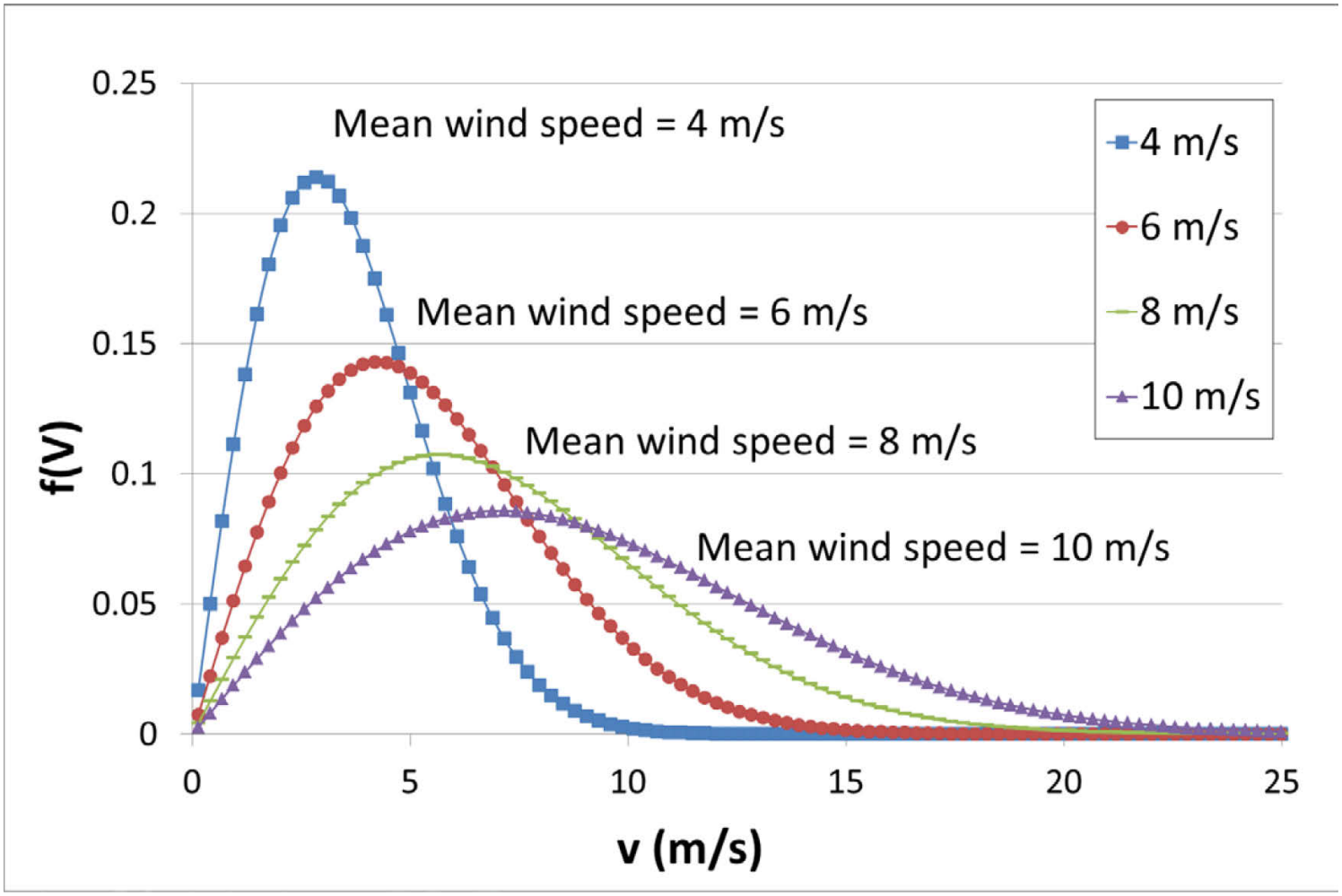
At speeds below about 90% of rated speed, the hydraulic energy transfer system is more efficient than conventional wind turbines. Conventional wind turbines drop efficiency fast due to generator and gearbox inefficiencies, while hydraulic wind turbines increase pump and pressure drop efficiencies with lower speeds, and can keep generator efficiencies constant by dropping out unused generators.

1 MW Pump Efficiencies



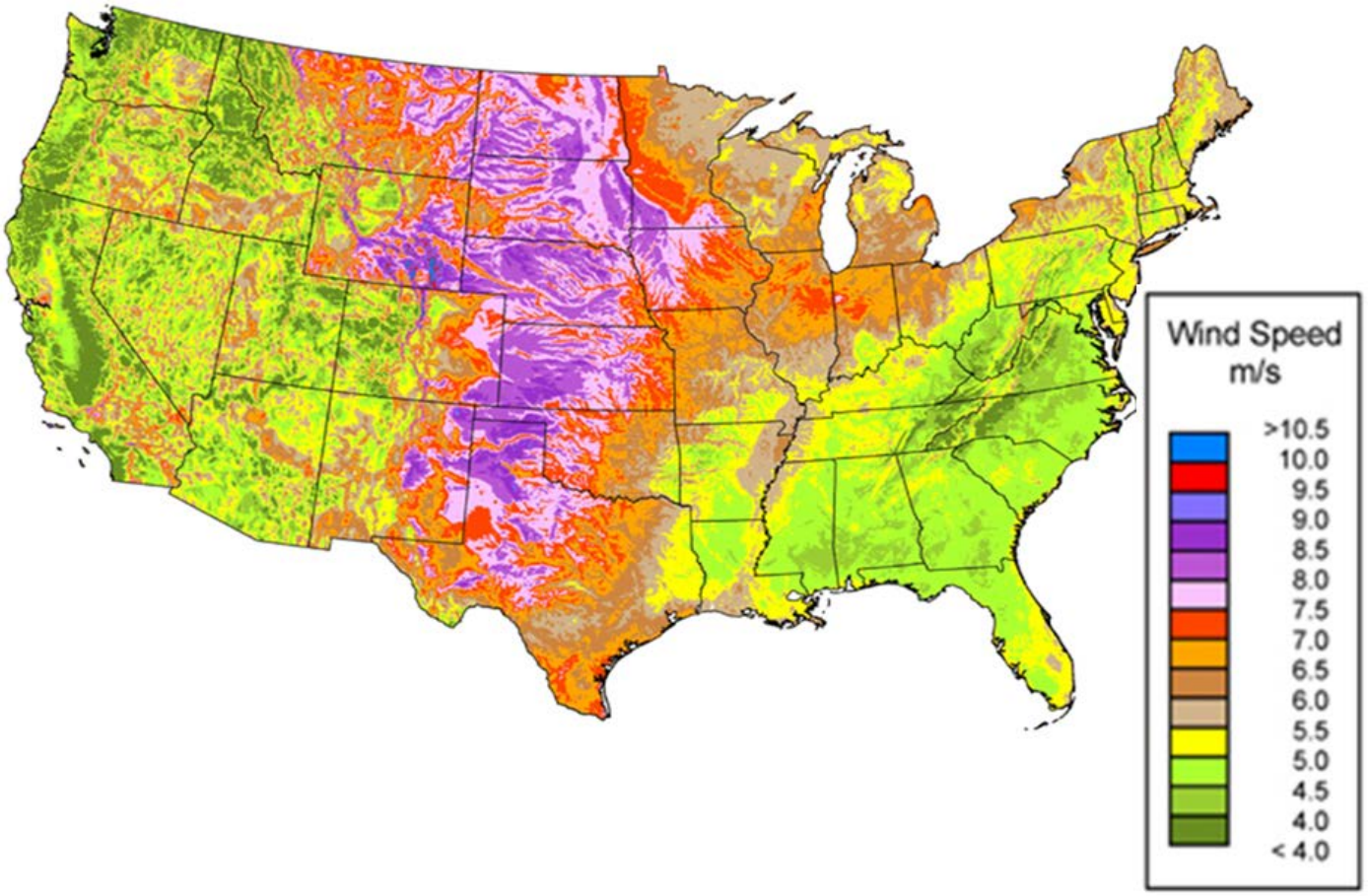
Efficiency curves for Bosch Rexroth MB 2400 hydraulic pump (1 MW rating for 5-year life) show improved efficiency as the wind flow velocity decreases.

Weibull Wind Distributions



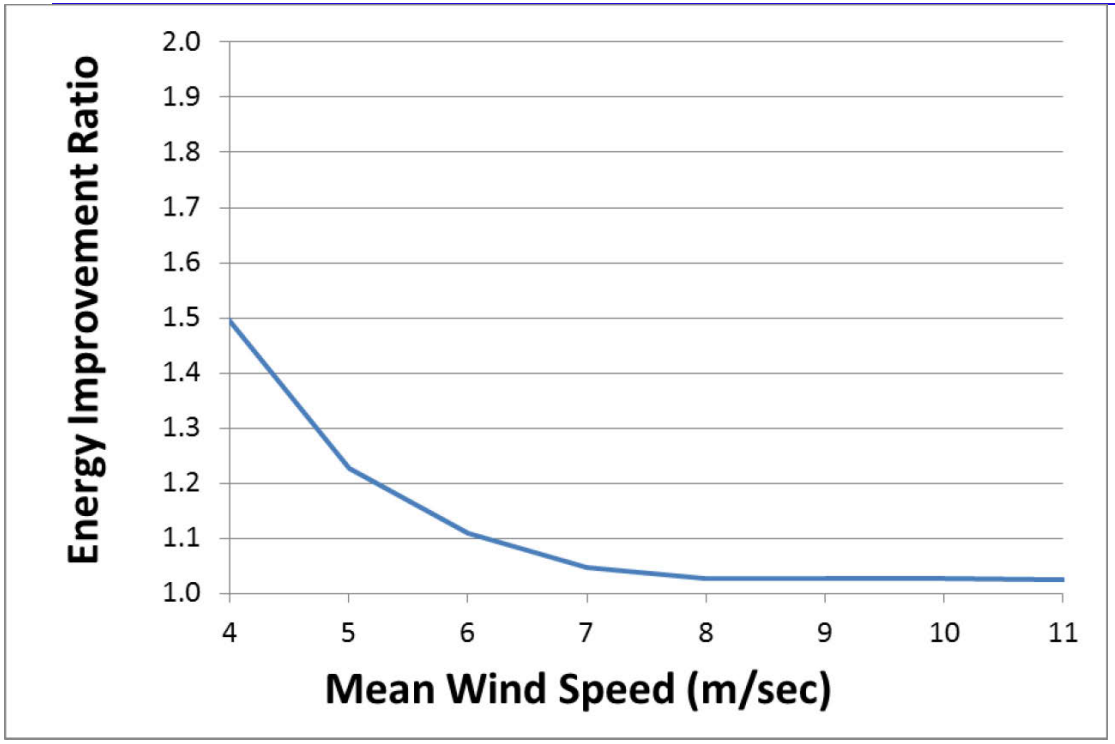
Most wind distributions follow a typical “Weibull” curve, where f(V) is the amount of time that a certain wind velocity occurs.

US Mean Wind Speeds



Except in the Midwest, most mean wind speeds in the continental United States are about 4-6 m/sec.

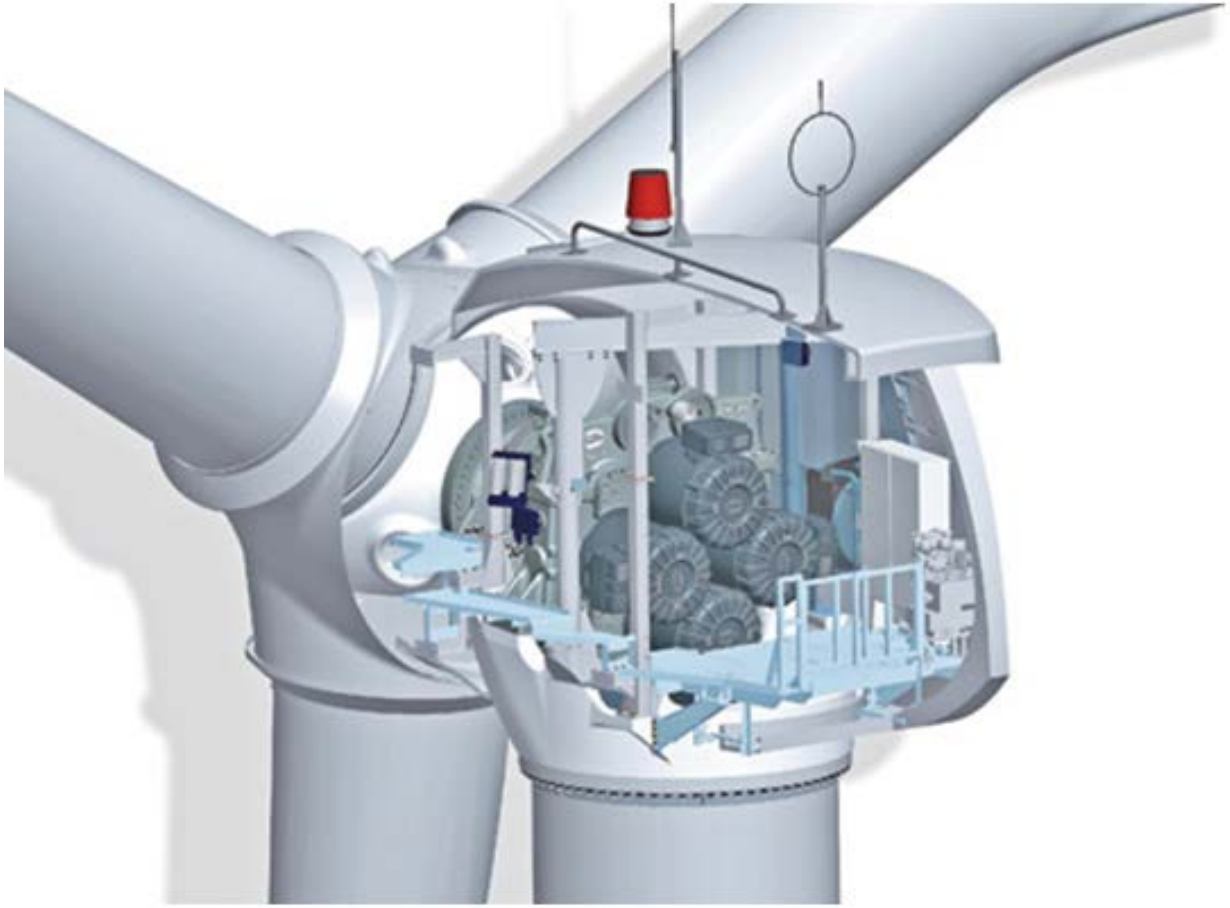
Efficiency Improvement with Advanced HET



Except for the Midwest, the Advanced Hydraulic Energy Transfer (HET) wind cycle will improve efficiencies by about 10% @ 6 m/sec and up to about 50% at 4 m/sec. For an average wind speed of 5 m/sec, the typical improvement of performance is about 23%.

Mean Wind Speed (m/s)	Energy Ratio	Optimal Rated Speed (m/s)	
		Conventional	HET System
4	1.496	11	11
5	1.227	11	11
6	1.109	11	11
7	1.048	11	11
8	1.027	11	12
9	1.028	13	14
10	1.026	14	15
11	1.024	15	17

Torque-Splitting Allows Power to 4 MW and Above



The Clipper Liberty uses torque splitting to run four generators simultaneously. With a 1/1 speed ratio gear, we can power up to 4 MW and above using the Advanced HET power cycle.

Levelized Cost of Energy (LCOE)

Component	Cost ($/kW-hr)
Conventional LCOE	0.097
Tax rebate	-0.022
Efficiency	–(0.097*0.11) = -0.011 @ 6 m/sec wind [-(0.097*0.23) = -0.022 @ 5 m/sec wind]
Maintenance	-(0.010*0.6) = -0.006 (ground maintenance, no gears)
Hydraulic conversion	+0.020 (pipes, fluids, pumps, motors)
Reduced capital costs	-0.035 (no gears, less tower, hub, shaft, power conv.)
TOTAL HET COSTS	0.043 $/kW-hr (4.3 cents per kW-hr)

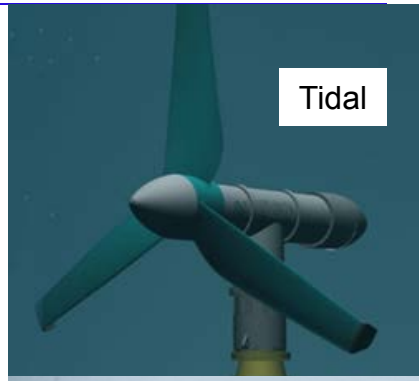
With 6 m/sec winds, total Advanced HET costs, with tax rebate, are about equal to coal, and costs are less than natural gas, even without a tax rebate. Relative costs are even lower for more common 5 m/sec winds.

Environmental Impacts

The carbon footprint and environmental impacts will largely mirror those of current COTS wind turbine systems and towers. The preferred hydraulic fluid is HEPG (polyethylene glycol), a non-toxic, environmentally friendly, biodegradable oil which is used as a food additive and is fully miscible with water. Testing has shown HEPG has no adverse effects on organisms even at levels of 1%.

Advanced HET Design Summary

- For Advanced HET, blade-driven pumps are used to circulate an environmentally friendly hydraulic fluid from a series of wind towers directly to a series of remote generators.
- All failure-prone gears are eliminated, and the electronics are moved to a central, more easily maintained, ground-level power generating station.
- Constant generator RPM results in higher efficiency and no power conditioning.
- Typical efficiency increase of 11-50% with Levelized costs decreased by at least about 30%.
- Similar hydraulic power transfer systems can be used with offshore tides, ocean currents, ocean waves, offshore wind and onshore wind (Caltech Patents granted and pending).



Goals for Wind Energy Development

- **We are looking for a wind energy industrial partner to join for to join for proposal of DOE funds on hydraulic wind power development.**

- Demonstrate small scale, in situ models of hydraulic energy transfer for a number of wind turbines (Total Power < 100 KW)

- Pass technology to private industry to commercially develop large scale use of hydraulic energy transfer for wind turbines

WIND ENERGY