SHAKE THE FUTURE.

LHEEA CENTRALE NANTES

cnrs

FARWIND project:
Exploitation of the far-offshore wind energy resource

Aurélien Babarit
Jean-Christophe Gilloteaux

Motivation

Clean fuels are needed to achieve a carbon-neutral economy

Fuels will still represent at least 45% of the energy demand in the EU in 2050 according to the EC

Far-offshore wind energy resource is a tremendous yet-untapped renewable energy source

Issue: grid-connection, installation and moorings, maintenance costs at long distance & in very deep water

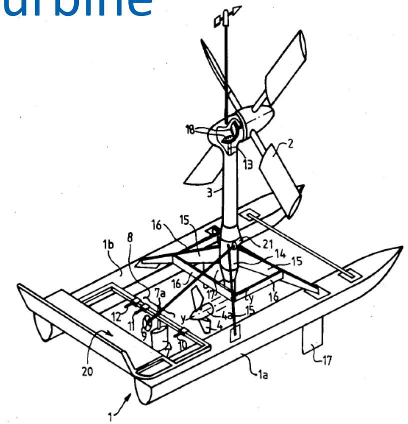
Can we convert far-offshore wind into clean fuels?

LHEEA CENTRALE NANTES cnrs

Possible enabling technologies

Sailing wind turbine

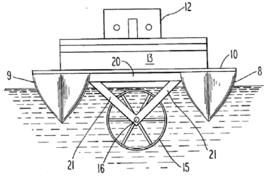
Vidal (1983)

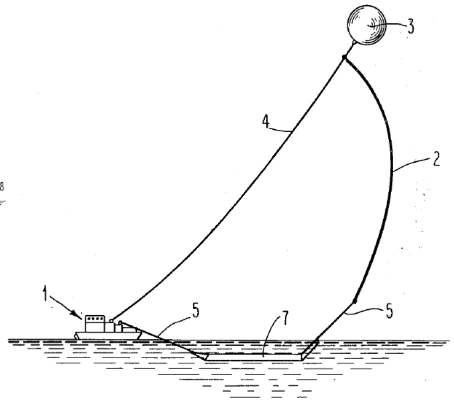


- Floating wind turbine neither moored nor anchored
- Propeller(s) & anti-drift planes for station-keeping
- Energy storage: onboard power-to-gas/liquid plant

Energy ship

Salomon (1982)





- Wind energy is used to propel a ship using sails
- Kinetic energy of the ship is converted into electricity using a water turbine
- Energy storage: onboard power-to-gas/liquid plant

LHEEA CENTRALE NANTES cnrs

(Very) limited state-of-the-art

Old patents

Sailing wind turbine: 1983 / energy ship: 1982

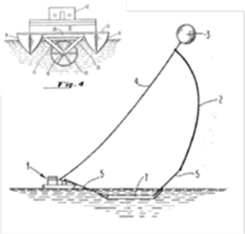
No attention until 2009

Platzer & Sarigul-Klijn (2009) ASME Int. Conf. On Energy Sustainability

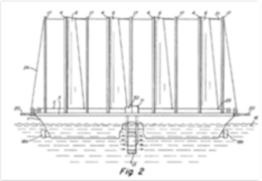
To date, 30 scientific publications

AEROHYDRO (USA), KRISO (South-Korea), KAIST (South-Korea), Univ. Of Tokyo (JP), TU Darmstadt (GE), Centrale Nantes (FR)

Does it work?

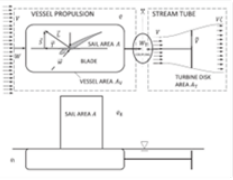


Salomon (1982)

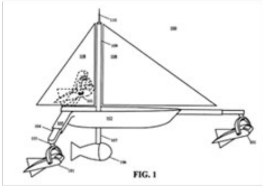


Meller (2006)

Kim & Park(2010)

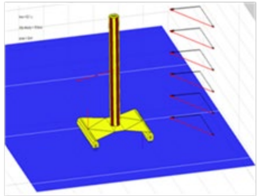


Pelz, Holz & Platzer (2016)



Gizara (2007)

Tsujimoto et al. (2009)



Gilloteaux & Babarit (2017)

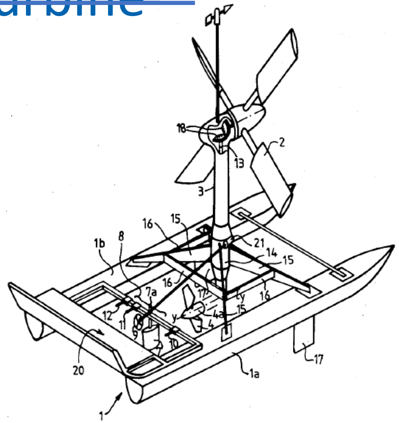
Ouchi & Henzie (2017)

LHEEA CENTRALE NANTES cnrs

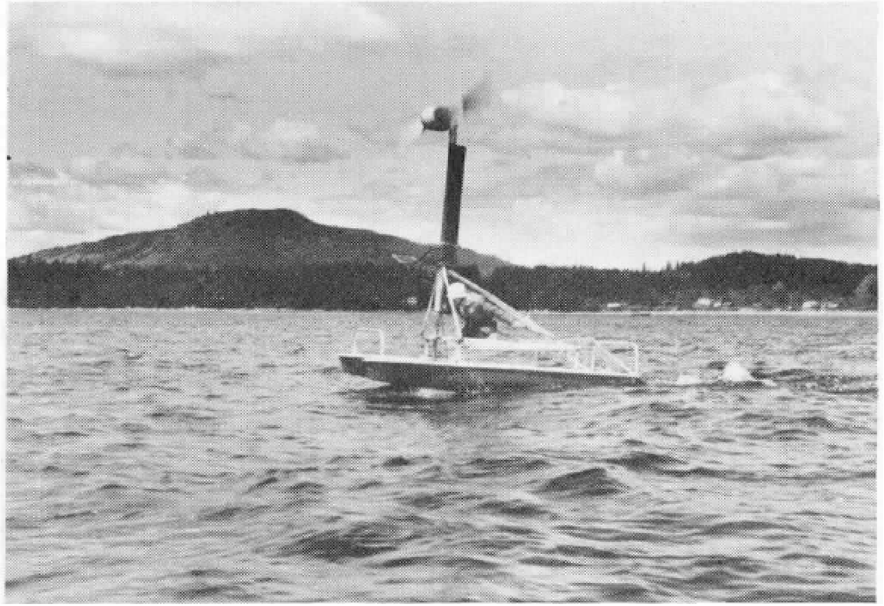
Enabling technologies: exp. proof of concepts (1/2)

~~Sailing wind turbine~~

Windmill boat



- 4 m windmill boat
- 3.8 m diameter turbine
- **Ship velocity ~ 0.5 true wind speed in straight upwind sailing conditions**



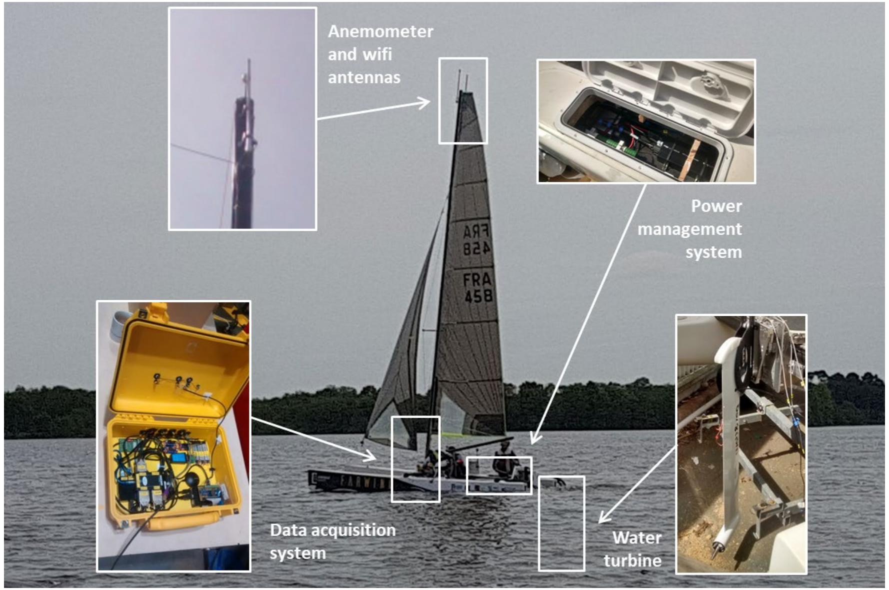
B.L. Blackford (1985) Optimal blade design for windmill boats and vehicles. Journal of ship research, Vol. 29(2), pp. 139-149

LHEEA CENTRALE NANTES cnrs

Enabling technologies: exp. proof of concepts (2/2)

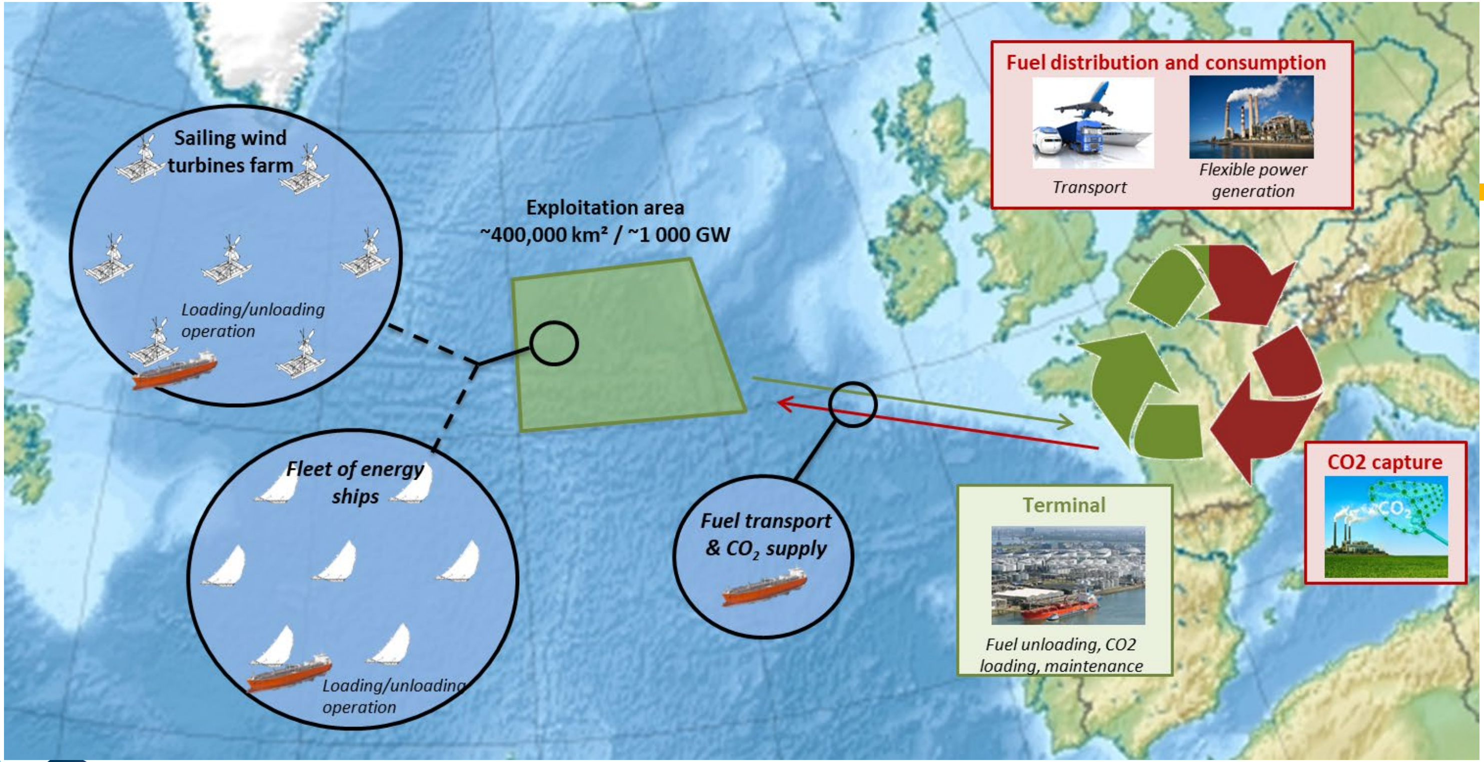
Energy ship

N. Abdul-Ghani, E. Brouillette, S. Delvoye, M. Weber, A. Merrien, S. Bourguet, A. Babarit (In preparation) A platform for the experimental testing of the energy ship concept.



- 5.5m long sailing catamaran equipped with a 600 W water turbine (240 mm diameter)
- **75 W @ 2.7 m/s TWS 90° TWA → 1 200 kW @ 10 m/s TWS (scale 1/14)**

Possible concept of operations



Energy vector: methanol

Design examples

Sailing wind turbine

2MW floating wind turbine

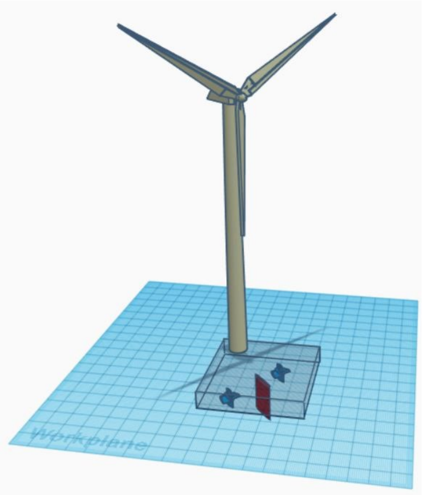
40 m x 40 m barge

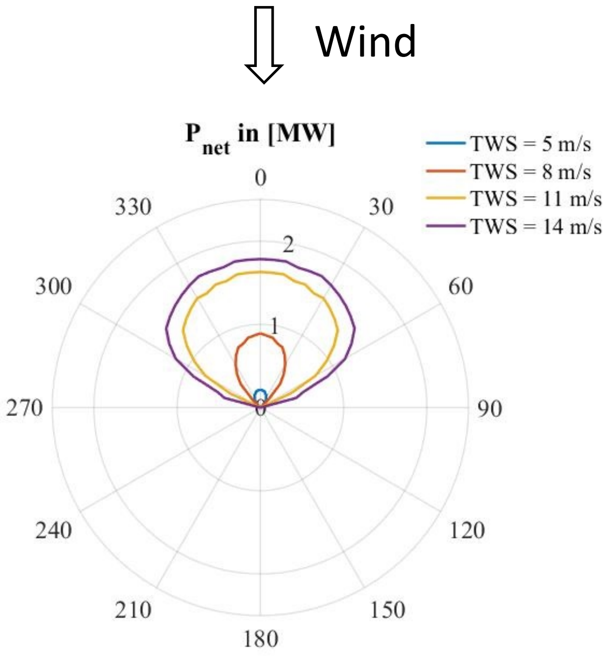
2 x 6 m diameter propellers

15 m² keel

Propellers control: V_{mg} = 0 m/s

P_{net} ~ 1.7 MW @ 11 m/s TWS & 0° TWA





R. Alwan, A. Babarit, T. Choisnet, J-C. Gilloteaux (In preparation) Investigation of the sailing wind turbine concept for the harvesting of the far-offshore wind energy resource.

LHEEA CENTRALE NANTES cnrs

Design examples

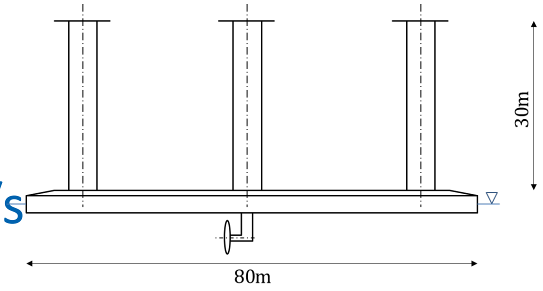
Energy ship

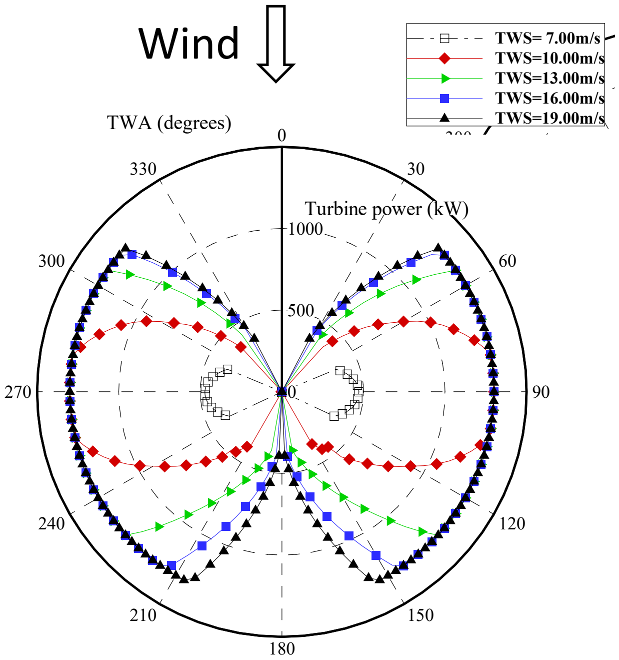
80 m long catamaran

3 x 30 m tall Flettner rotors

6 m diameter water turbine

P_{net} = 1.3 MW @ 10 m/s TWS & 90° TWA





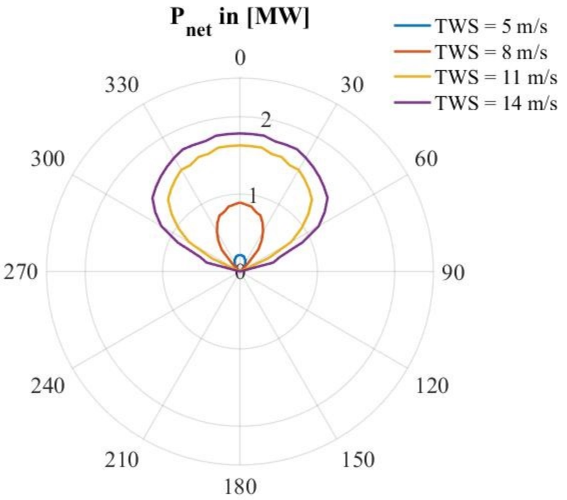
A. Babarit, G. Clodic, J-C. Gilloteaux (Submitted) A new energy system for sustainable methanol production from the far-offshore wind energy resource

Sailing wind turbine vs energy ship

Sailing wind turbine

Best performance when facing the wind

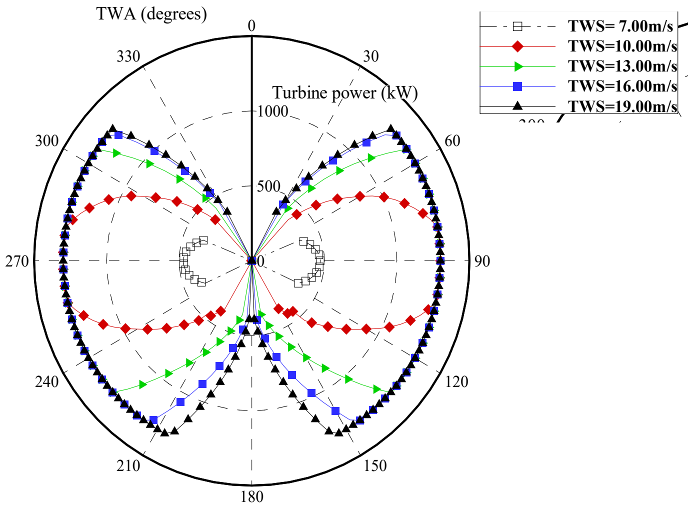
Stationary (V_{mg} ~0 m/s)



Energy ship

Best performance when sailing beam wind

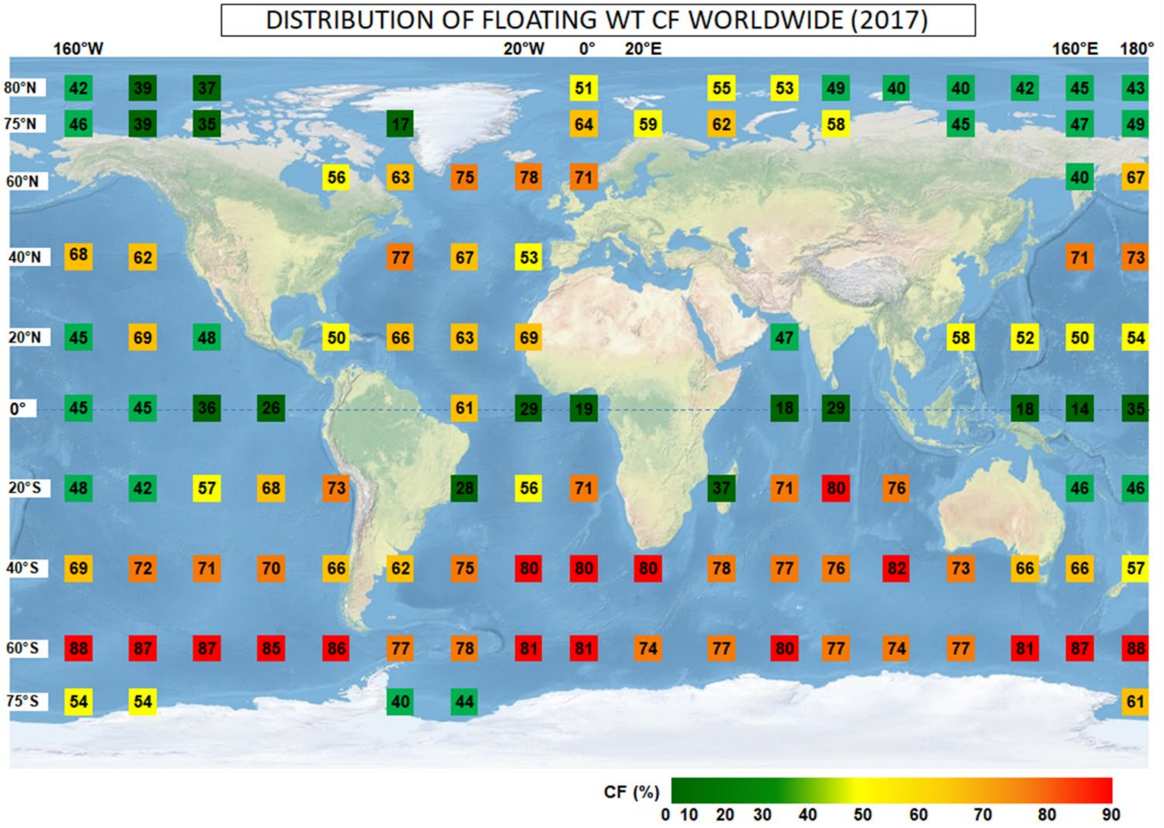
Sails relatively fast (20 knots)



Capacity factor

Hypothetical stationary floating wind turbines

70 – 80% capacity factor may be achieve



LHEEA CENTRALE NANTES cnrs

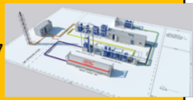
R. Abd-Jamil, J-C. Gilloteaux, P. Lelong, A. Babarit (2019) Comparison of the capacity factor of stationay wind turbines and weather-routed energy ships in the far-offshore. In Proc. Of the EERA DeepWind' conference, Trondheim, Norway

Energy vector

Methanol

A. Babarit, J-C. Gilloteaux, G. Clodic, M. Duchet, A. Simoneau, M.F. Platzer (2018) *Techno-economic feasiility of fleets of far offshore hydrogen-producing wind energy converters. International Journal of Hydrogen Energy.*

A. Babarit, J-C. Gilloteaux, E. Body, J-F. Hétet (2019) *Energy and economic performance of the FARWIND energy system for sustainable fuel production from the far-offshore wind energy resource. In Proc. Of the 14th EVER conference, Monaco*

Energy vector	H_2	CH_4	CH_3OH	$(-CH_2-)_n$	NH_3
Process	Electrolysis $2H_2O \rightarrow 2H_2 + O_2$	Electrolysis $2H_2O \rightarrow 2H_2 + O_2$ Methanation $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$	Electrolysis $2H_2O \rightarrow 2H_2 + O_2$ CO_2 hydrogenation $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$	Electrolysis $2H_2O \rightarrow 2H_2 + O_2$ Fischer-Tropsch synthesis $nCO_2 + 3nH_2 \rightarrow (-CH_2-)_n + 2nH_2O$	Electrolysis $2H_2O \rightarrow 2H_2 + O_2$ Haber-Bosch process $N_2 + 3H_2 \rightarrow 2NH_3$
TRL	9 	8 	5-8 	5 	4-7 
Energy efficiency	60%	55%	49%	39%	47%
Efficiency inc. transport	36%	50%	47%	37%	43%
State & energy density in STP	Gas ~0.003 kWh/L	Gas 0.01 kWh/L	Liquid ~4 kWh/L	Liquid ~10 kWh/L	Gas ~0.004 kWh/L
Market value (€/MWh_{th})	30 – 150	~20	~20-90	~30-60	~20-90
Market (G€)	~100	~600	~25	~4,000	~25

Cost of energy

No grid-connection cost
No moorings and installation cost
Planned maintenance at port

} 50% of cost of energy of floating offshore wind

High capacity factor — Say +10-20% / moored OWT

Lower overall energy efficiency
(elec. to fuel conversion losses) — 50% energy loss

PtL plant — +500 – 1000 €/kW

Cost similar to grid-connected floating offshore?

Challenges

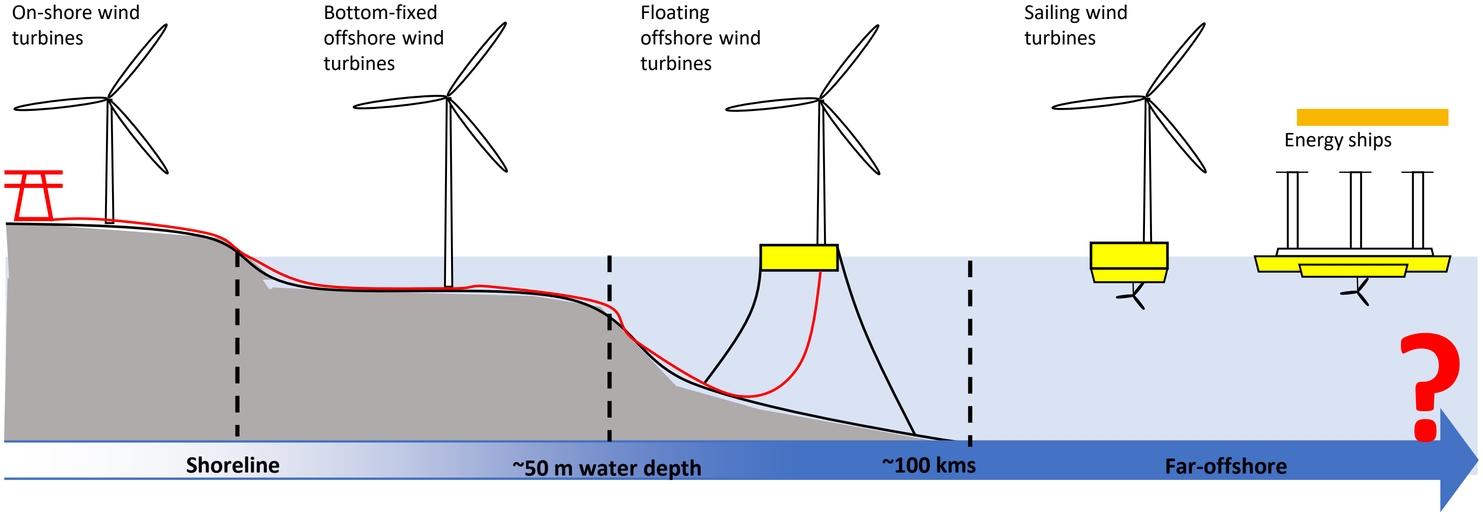
- Models, tools and methods for the design, performance assessment and optimization of far-offshore wind energy converters
- Medium and high fidelity

- Development of key subsystems including
- Autonomous power-to-gas/liquid plants for offshore energy storage
- Control systems for autonomous far-offshore wind energy converters
- Water turbine for energy ships
- Wind turbine for sailing wind turbines

- Non-technical barriers
- Resource assessment
- Legal status of energy produced far-offshore with autonomous converters
- Environmental impacts
- Conflicts of uses/synergies

- Cost-effective converters including logistics for fuel collection

Thank you for your attention



LHEEA CENTRALE NANTES
cnrs
aurelien.babarit@ec-nantes.fr
Jean-christophe.gilloteaux@ec-nantes.fr

Financial support:
ADEME – Agence de l'Environnement et de la Maîtrise de l'Energie
WEAMEC – Research, Education & Innovation in Pays de la Loire FOR MARINE ENERGY
Région PAYS DE LA LOIRE
Nantes Métropole