# New direct drive technologies of INNWIND.EU: Superconducting vs. Pseudo Direct Drive

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# New direct drive technologies of INNWIND.EU:

# Superconducting vs. Pseudo Direct Drive

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Wind Energy Denmark
Wednesday 26-27 October 2016

Battle of the wind generators workshop
26 October 14:00 – 15:15

DTU Wind Energy
Department of Wind Energy

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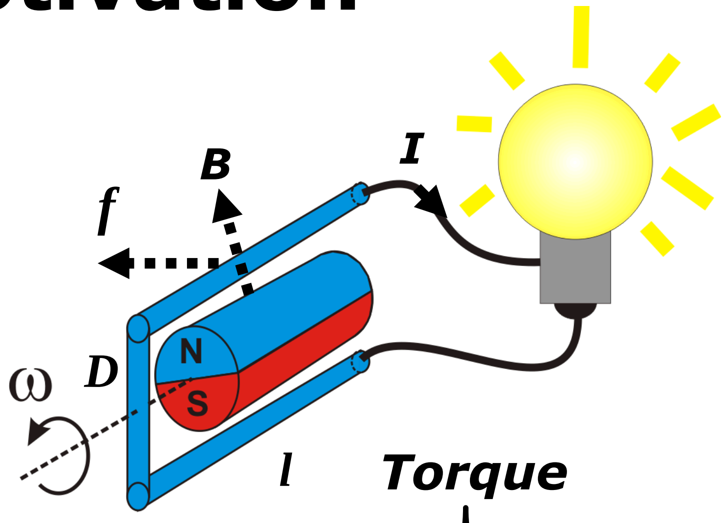
# Motivation




*Torque*

$$Power \propto \overbrace{BI\ D^2 l}^{Torque}\ \omega$$

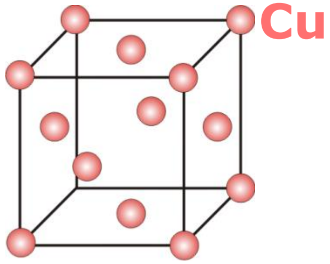
1G : Copper + Iron

2G : $R_2Fe_{14}B$ magnets + Fe

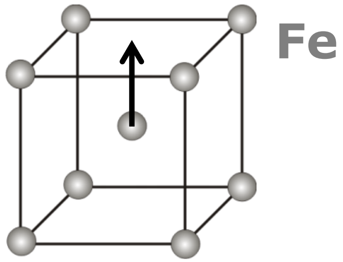
PM Direct Drive

Pseudo Direct Drive

3G : Superconductor + Fe

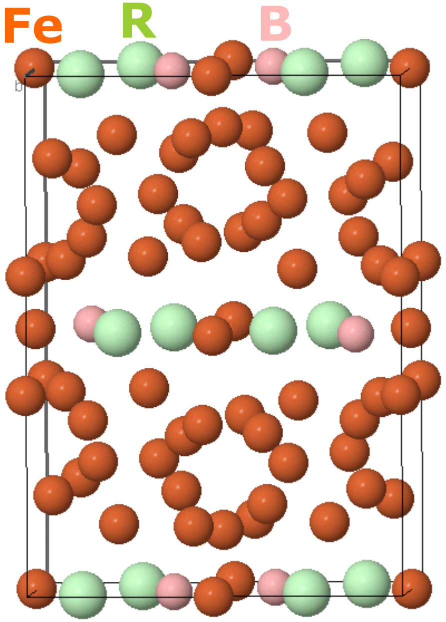



J ~ 2 A/mm²



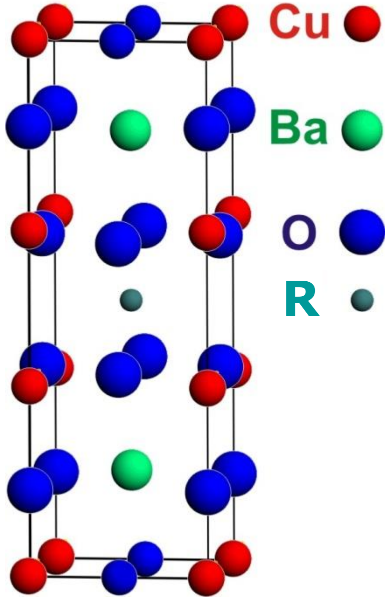

$T_C$ = 1043 K

$B_r$ ~ 0 Tesla




$T_C$ = 583 K

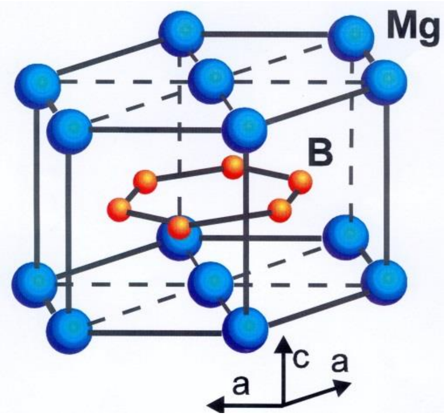
$B_r$ ~ 1.4 Tesla




$T_C$ = 93 K

$B_{c2}$ ~ 100 Tesla

J < 200 kA/mm²

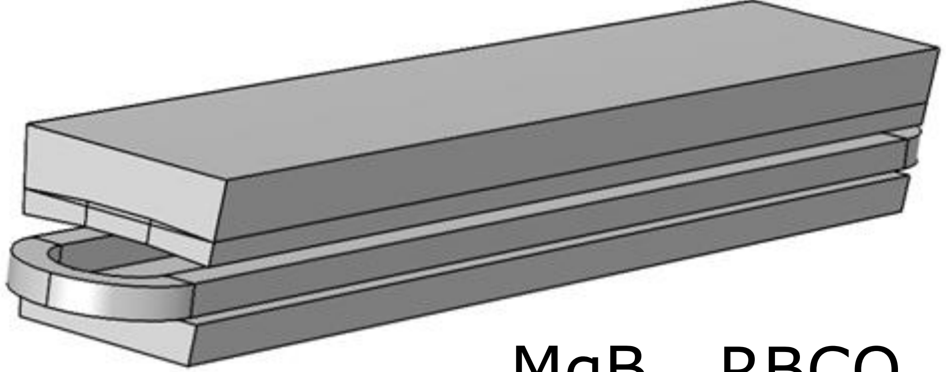



$T_C$ = 39 K

$B_{c2}$ ~ 40 Tesla

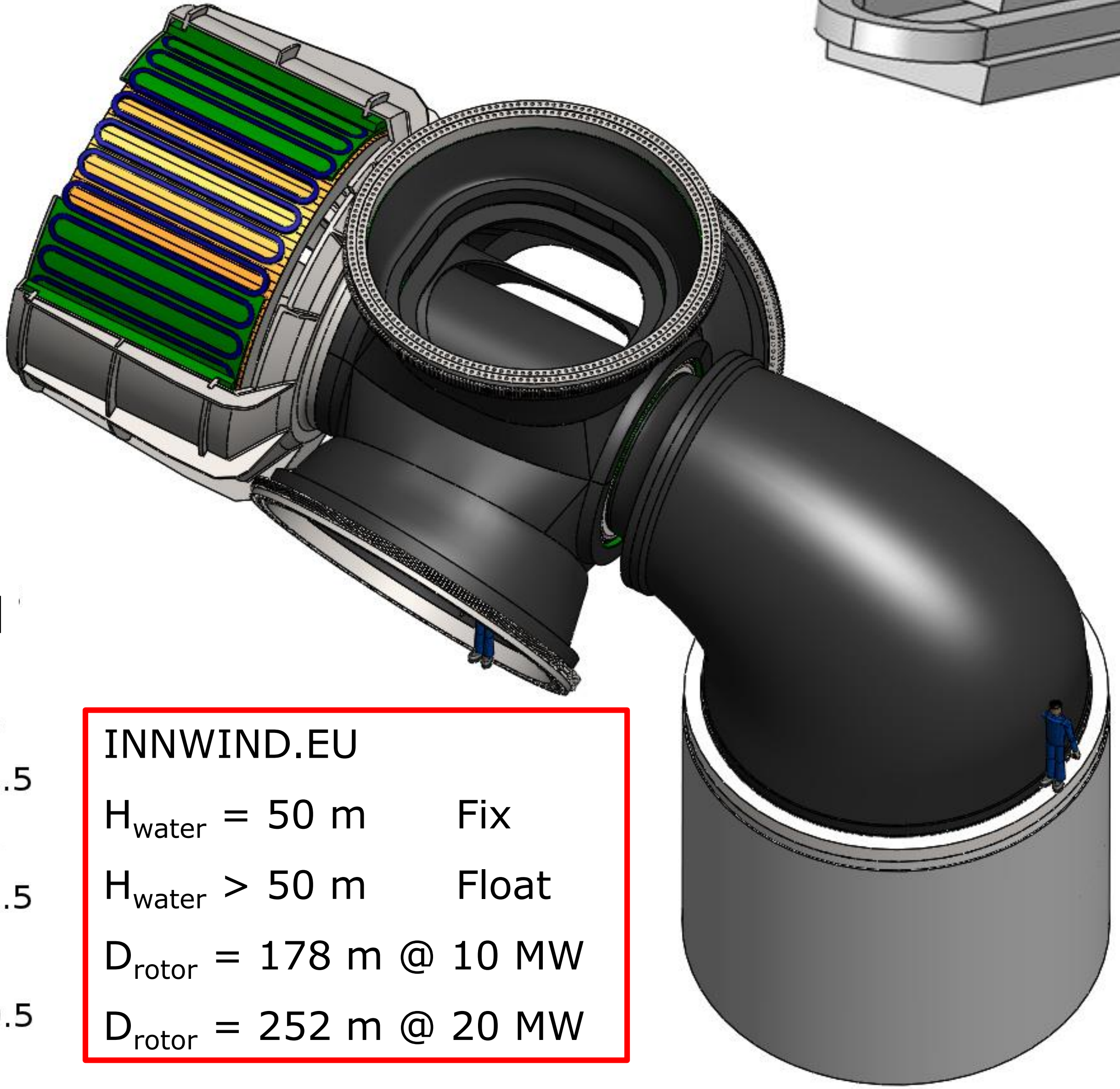
J < 20 kA/mm²

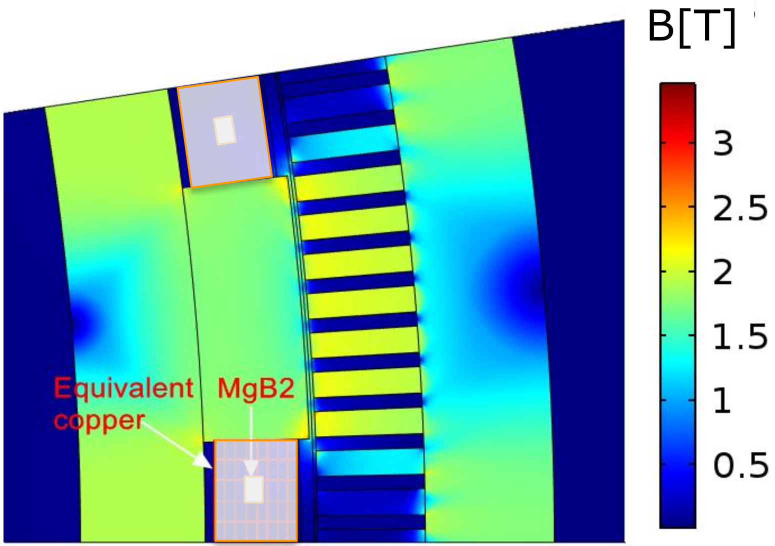
# Superconductor Direct Drive



**SC: J ~ 100-330 A/mm²**

**Cu: J ~ 2-3 A/mm²**






INNWIND.EU

$H_{water}$ = 50 m Fix

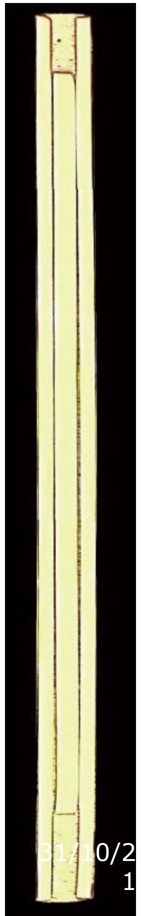
$H_{water}$ > 50 m Float

$D_{rotor}$ = 178 m @ 10 MW

$D_{rotor}$ = 252 m @ 20 MW

$MgB_2$ RBCO

-234 -180°C



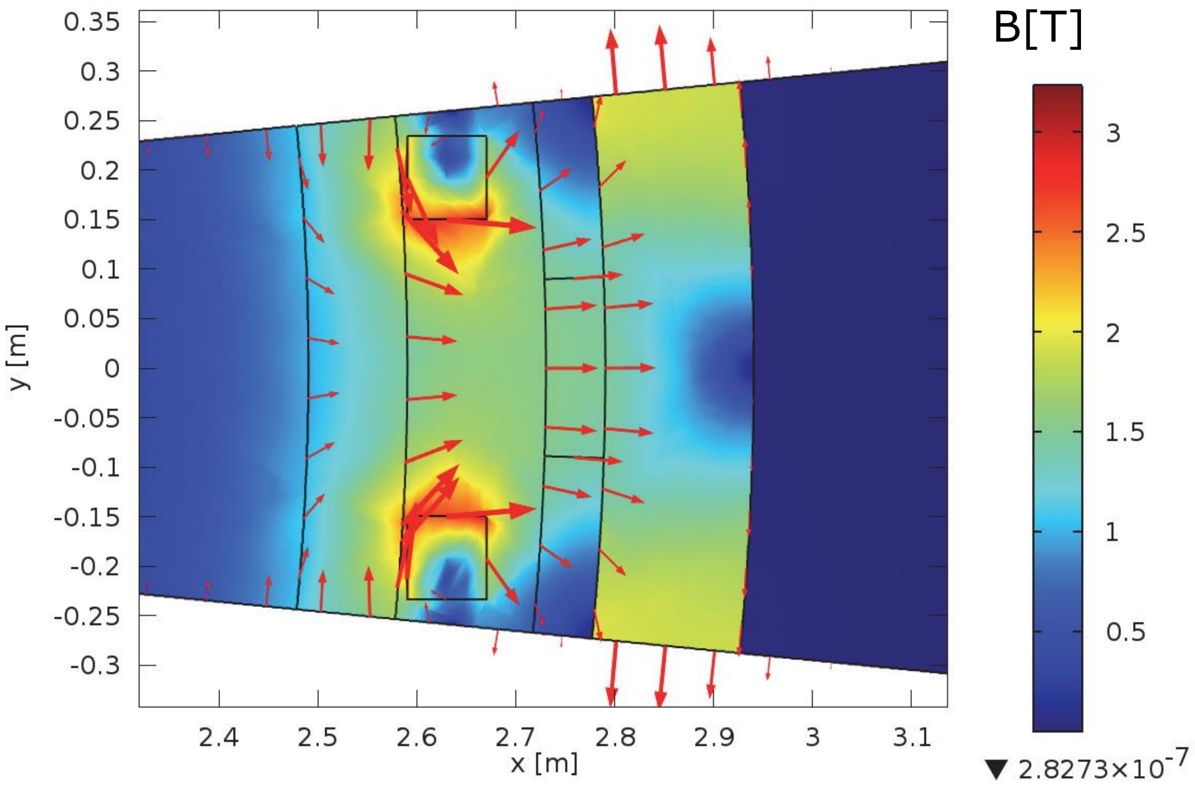
# Cost optimization

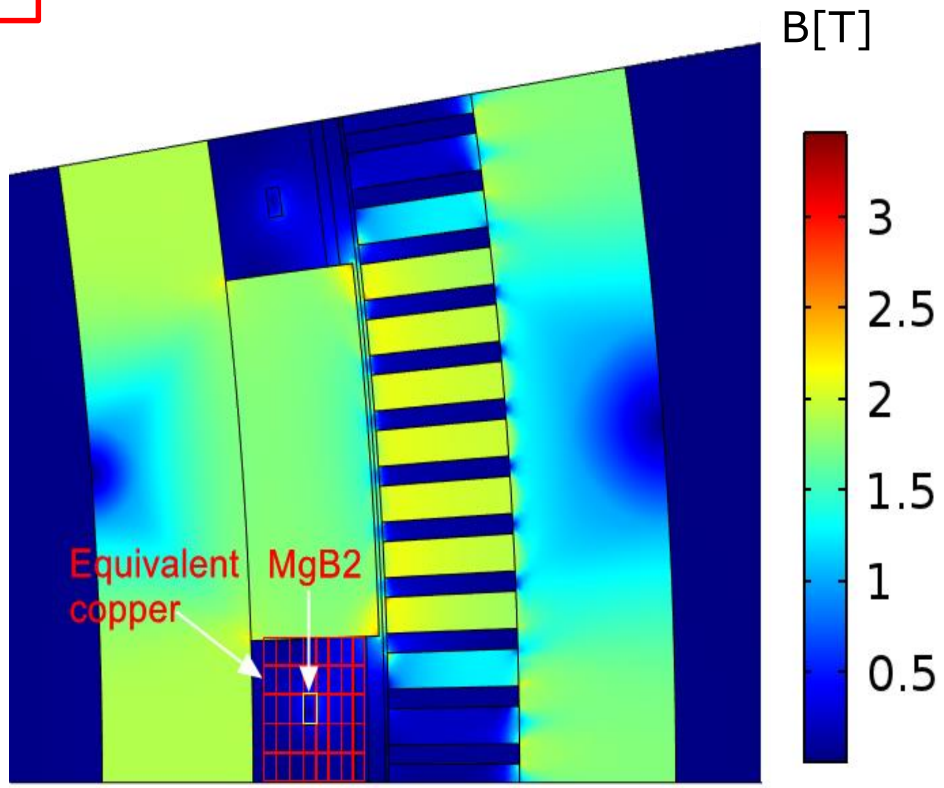
| | |
|---|---|
| Fe: 3 €/kg | $MgB_2$: 4 €/m |
| Cu: 15 €/kg | G10: 15 €/kg |

**10.6 MNm @ 9.7 rpm**

**D: 6.0 m L: 2.3 m**

**$m_{active}$ ~ 150 tons**




**$L_{MgB2}$ ~ 500 km**

**"Light weight & Expensive"**

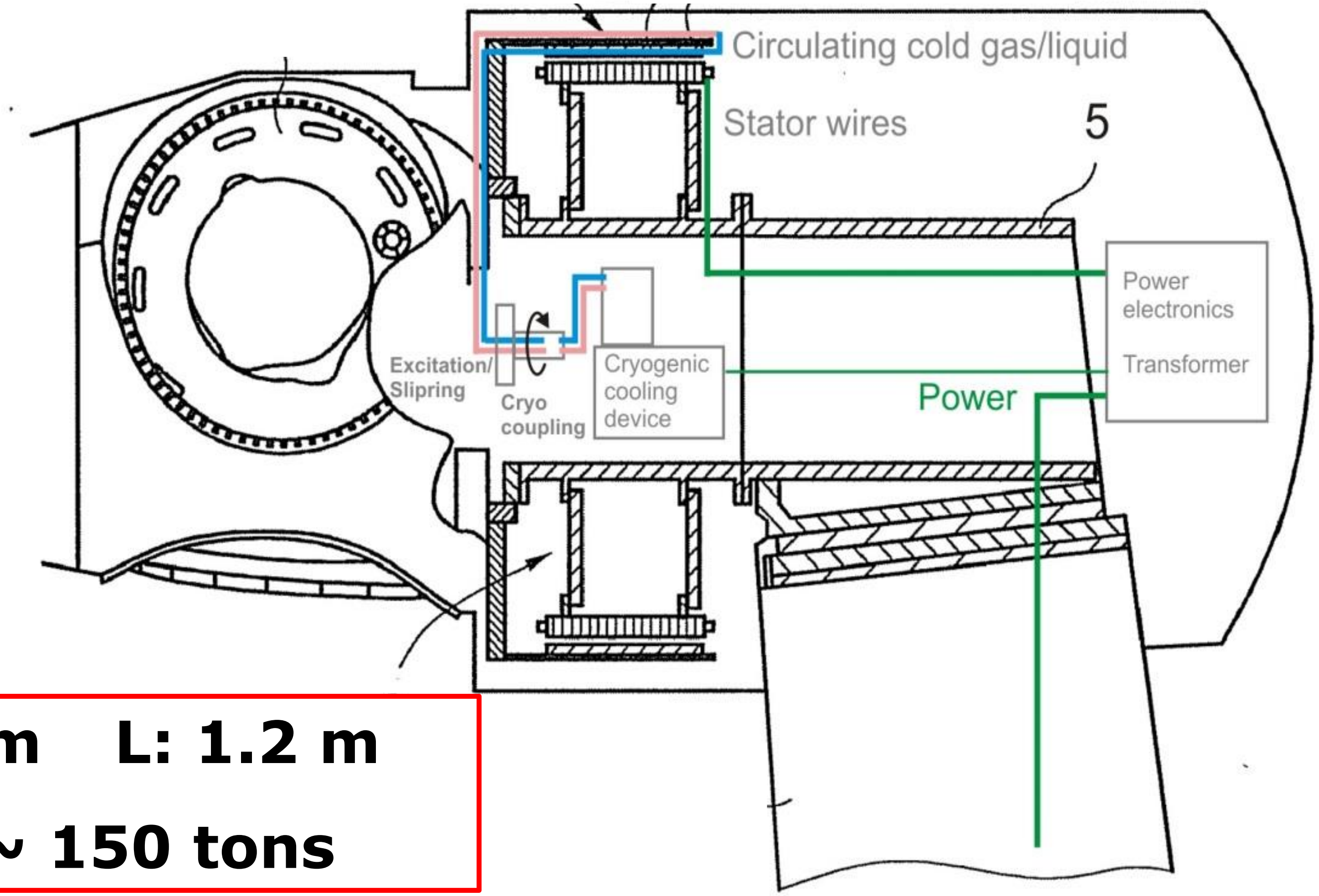
**$L_{MgB2}$ ~ 20 km**

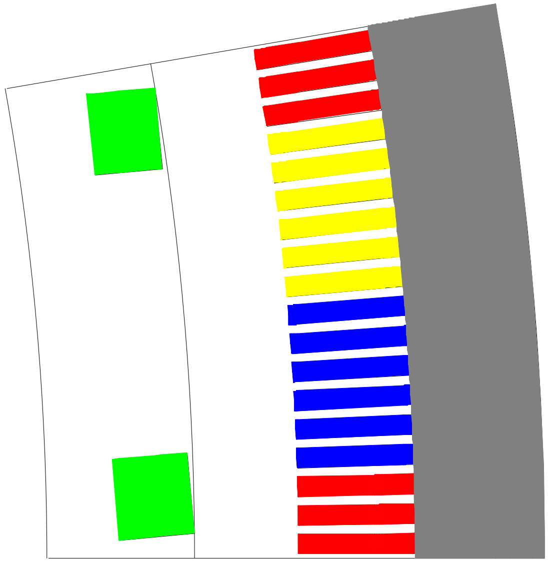
**"Cheap & Not too Heavy"**

# High temperature superconducting pole pair demo

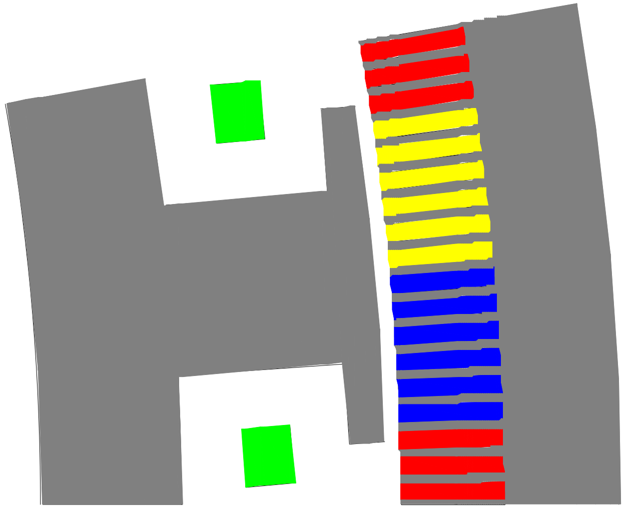
SIEMENS

**"As high operation temperature as possible → HTC"**



Air-core stator, air-core rotor



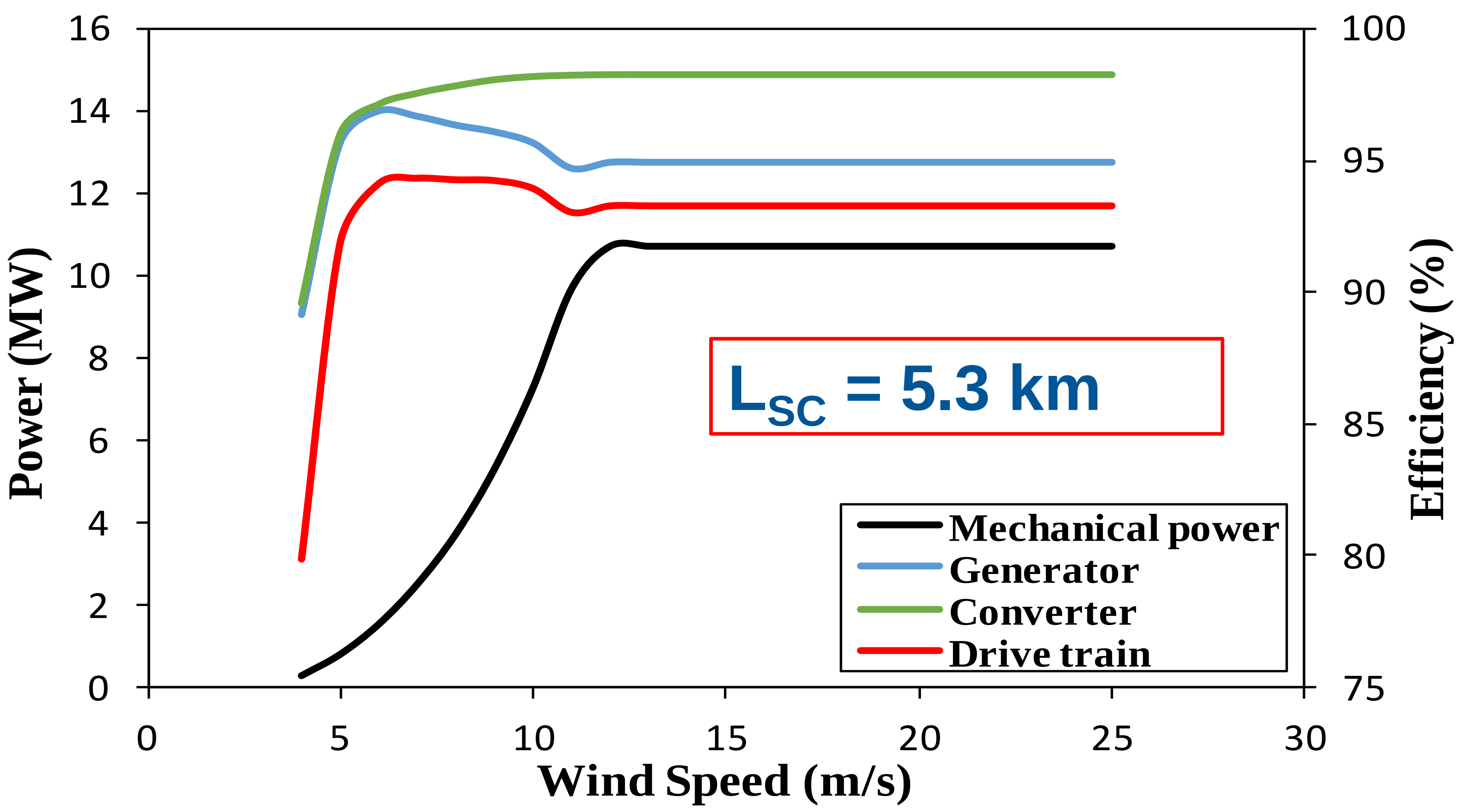
Iron-core stator, iron-core rotor

**D: 7.0 m L: 1.2 m**

**$m_{active}$ ~ 150 tons**

# 10 MW HTC SC direct drive

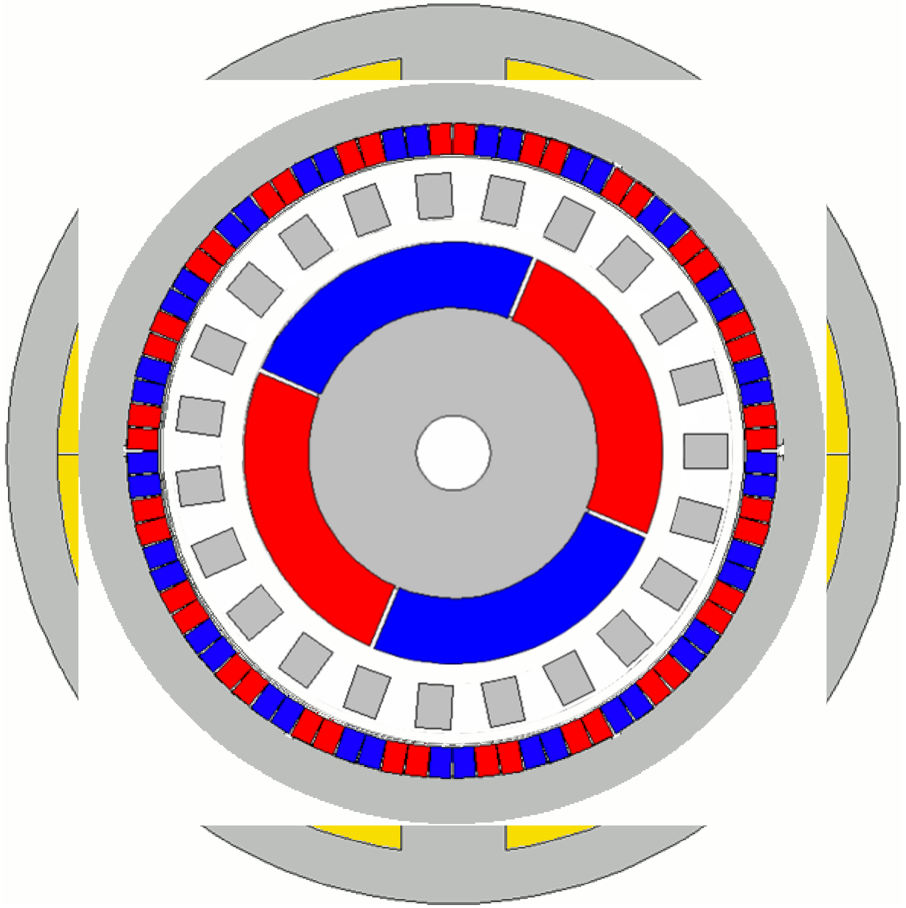
SIEMENS




| Component | Material | Cost (€) |
|---|---|---|
| Generator | Stator iron | 58188 |
| | Rotor iron | 53735 |
| | Copper | 117480 |
| | SC | 534896 |
| | Total | 764299* |
| Converter | Switches | 160314 |
| | Generator filter | 58084 |
| | DC Link | 152000** |
| | Grid filter | 89000** |
| | Cooling system | 143000** |
| | Mechanical support | 184000** |
| | Total | 786398 |
| Total drive train | Total | 1550697 |

* Without cooling system cost.
**Deliverable 3.3.2 - Converter designs based on new components and modular multilevel topologies.

# Magnetic Pseudo Direct Drive (PDD)



**PDD =**

**Magnetic gear**

**+**

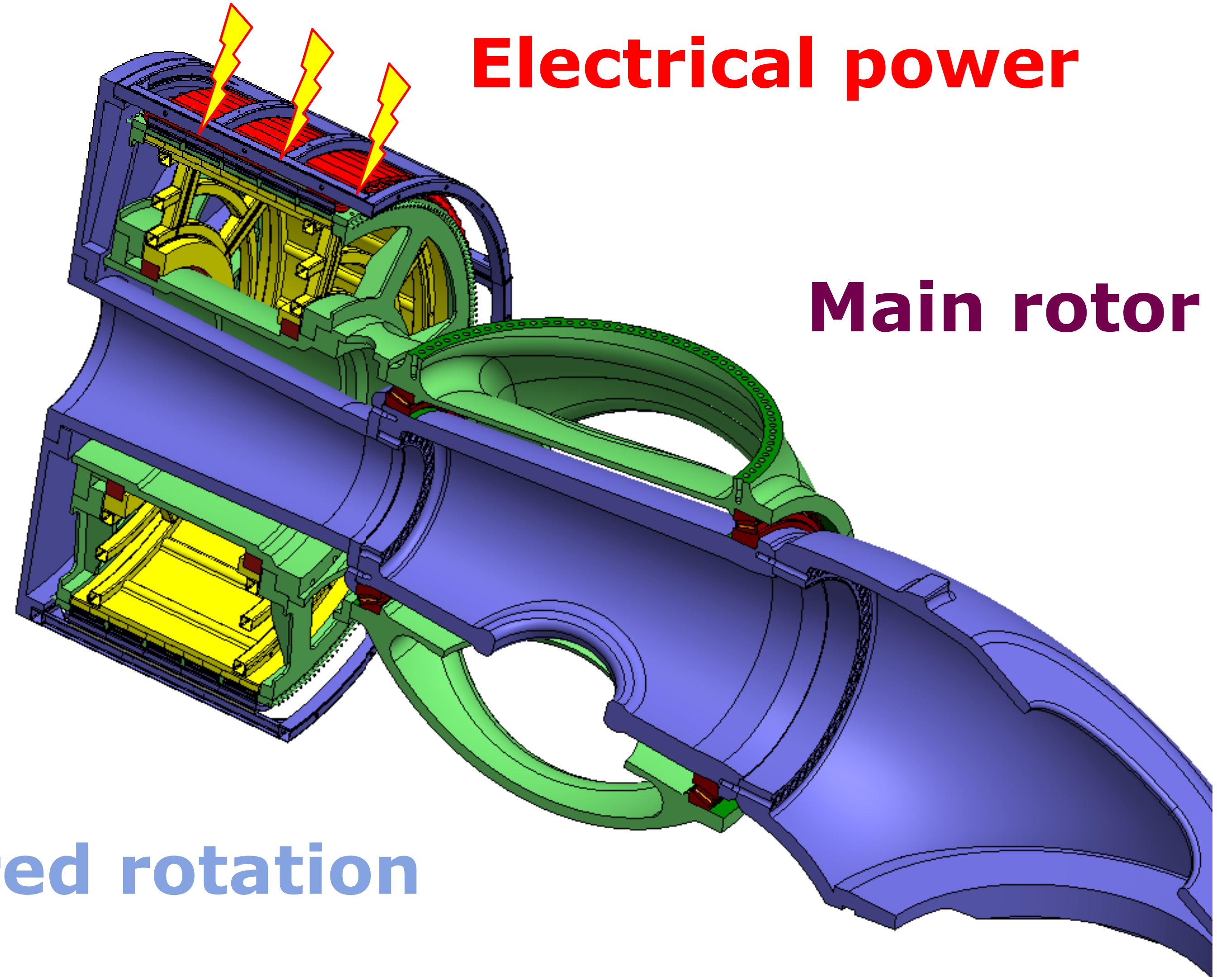
**Armature**

- **Compact**
- **No contact**
- **High efficiency**



Kirby, Calverley, Stehouwer & Hendriks EWEA 2014

# Integration into King-Pin nacelle

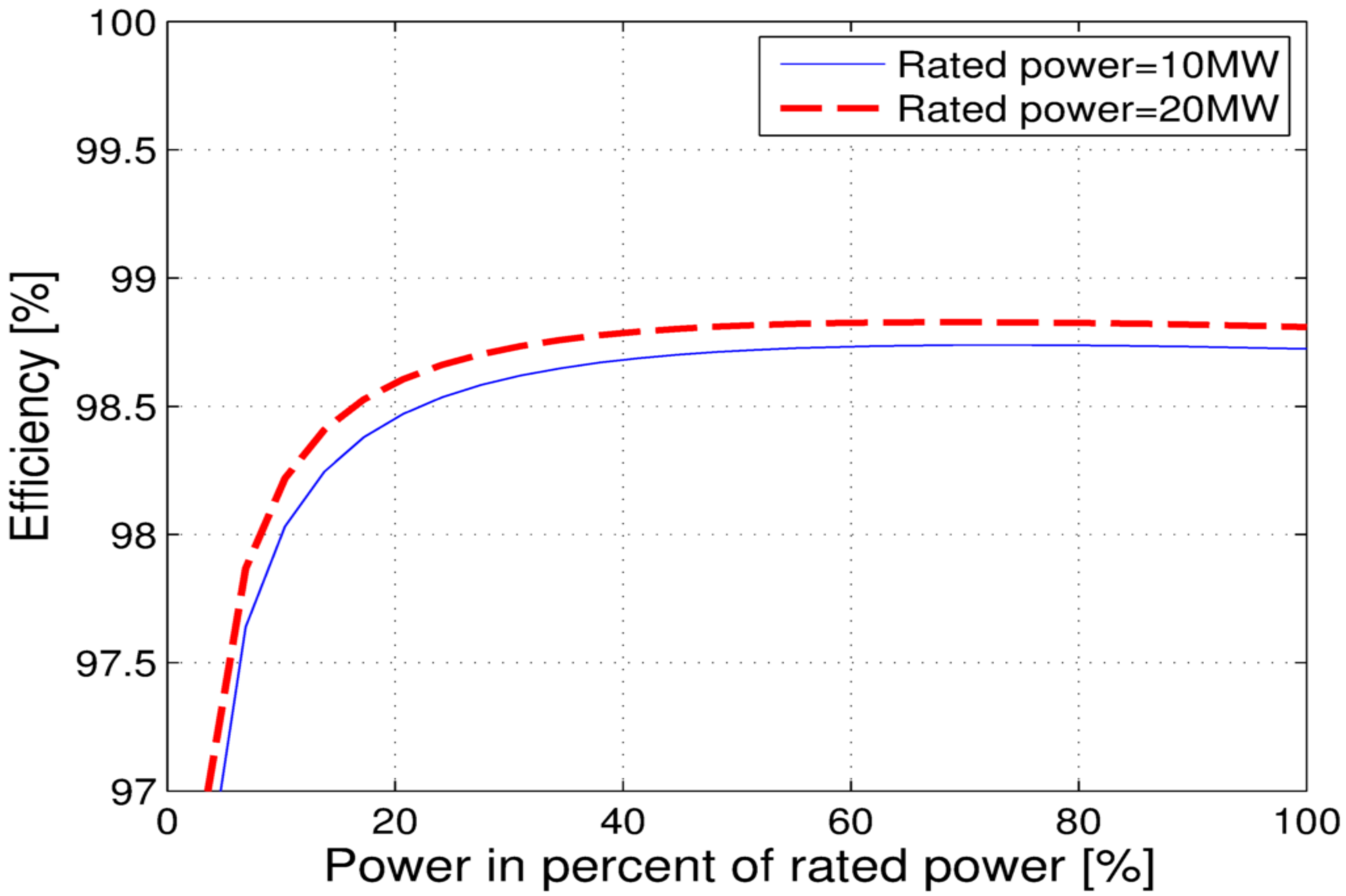



Kirby, Calverley, Stehouwer & Hendriks EWEA 2014

# PDD optimized for 10 and 20 MW

| Parameter | 10MW | 20MW |
|---|---|---|
| Airgap diameter | 6.0m | 8.5m |
| Active axial length | 1.66m | 2.35m |
| Permanent magnet mass | 13.5tons | 38.2tons |
| Copper mass | 7tons | 14tons |
| HS and PP rotor laminated steel mass | 14tons | 39.6tons |
| Stator laminated steel mass | 15.5tons | 45tons |
| Structural mass | 100tons | 383tons |
| Total mass | 150tons | 520tons |
| Cost of permanent magnets | 58.1 k€/ton | |
| Cost of copper material | 4.59 k€/ton | |
| Cost of laminated steel | 1.61 k€/ton | |
| Cost of structural material | 0.32 k€/ton | |
| Total material cost | 896 k€ | 2542 k€ |

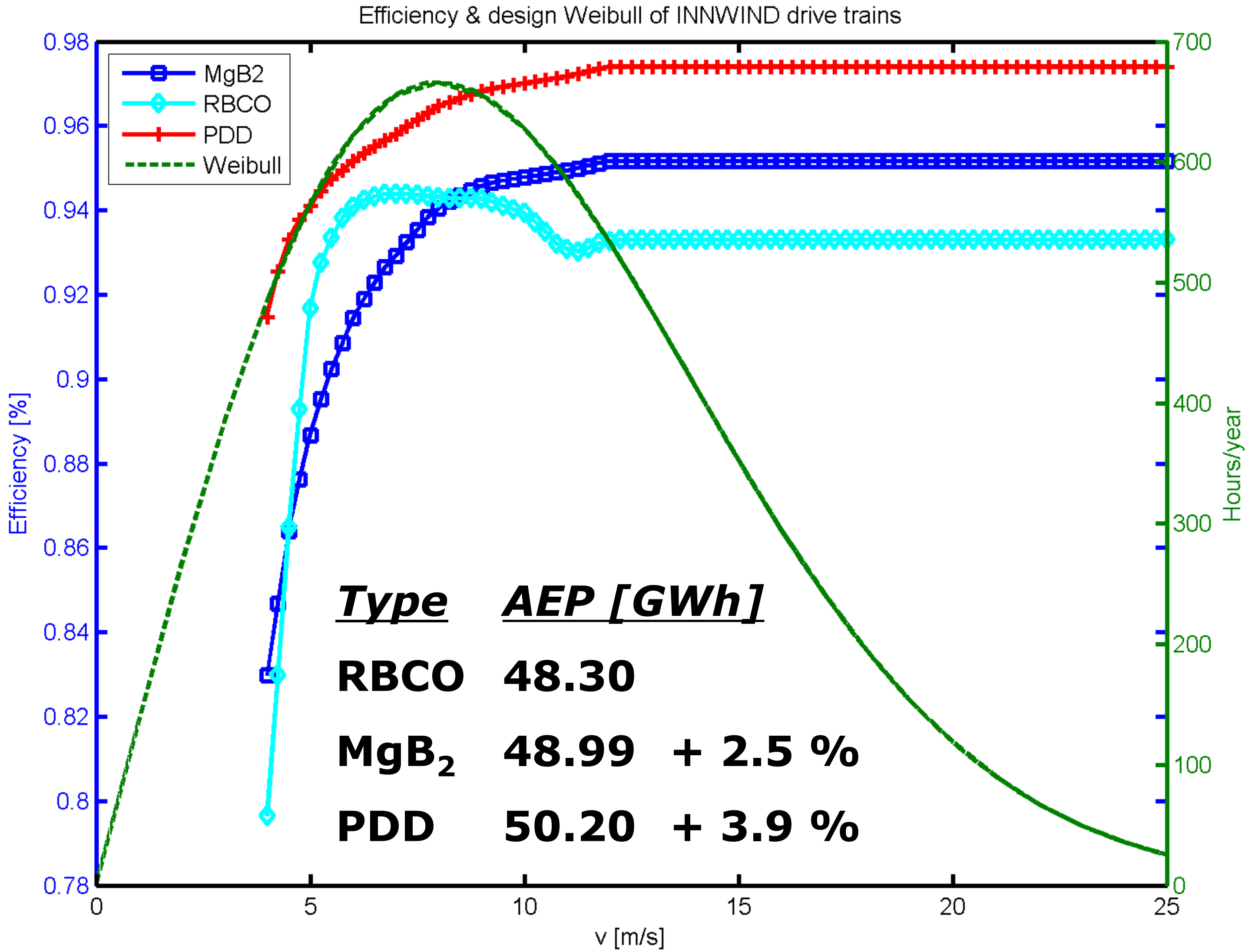
Variation of efficiency



# Cost of Energy (CoE) @ 10 MW

$$CoE = \frac{C_D + C_R + O}{AEP \cdot LT}$$

$$\sim \frac{C_R + O}{AEP \cdot LT}$$




| ***Type*** | ***AEP [GWh]*** | |
|---|---|---|
| **RBCO** | **48.30** | |
| **$MgB_2$** | **48.99** | **+ 2.5 %** |
| **PDD** | **50.20** | **+ 3.9 %** |

| ***Type*** | ***Cost* [M€]*** | |
|---|---|---|
| **PDD** | **1.7** | **+ 6 %** |
| **RBCO** | **1.6** | |
| **$MgB_2$** | **2.3** | **+ 44%** |

| ***Type*** | ***ΔCoE [%]*** |
|---|---|
| **PDD** | **~ - 4** |
| **RBCO** | **~ + 0** |
| **$MgB_2$** | **~ - 1** |

***Preliminary**

**$C_R$ ~ 30 M€, O ~ 35 M€ LT = 25 years**

# Conclusion

- Innovative non-contact drive trains investigated

- Superconducting Direct Drive
  - RBCO: Race track coil demonstrated. ΔCoE ~ + 0 %
  - $MgB_2$: Race track coil under construction ΔCoE ~ - 1 %
  - Both will have a hard time beating the PM direct drive
  - Both will remove dependency of Rare Earth Elements

- Magnetic Pseudo Direct Drive (PDD)
  - Demonstrated: T = 5 & 16 kNm. Next step 200 kNm
  - Superior in term of efficiency and cost. ΔCoE ~ -4 %
  - Increased Rare Earth Elements dependency compared to permanent magnet direct drive

# Contributions to work package Electro-Mechanical conversion of INNWIND.EU


D. Liu & Henk Polinder, Delft University of Technology (NL)

N. Magnuson, SINTEF (N)

A. Thomas & Z. Azar, Siemens Wind Power (DK / UK)

E. Stehouwer & B. Hendriks, DNV GL (NL)

A. Penzkofer & K. Atallah, University of Sheffield (UK)

Dragan, Meyers, Clark & Todd, Magnomatics (UK)

F. Deng & Z. Chen, Aalborg University (DK)

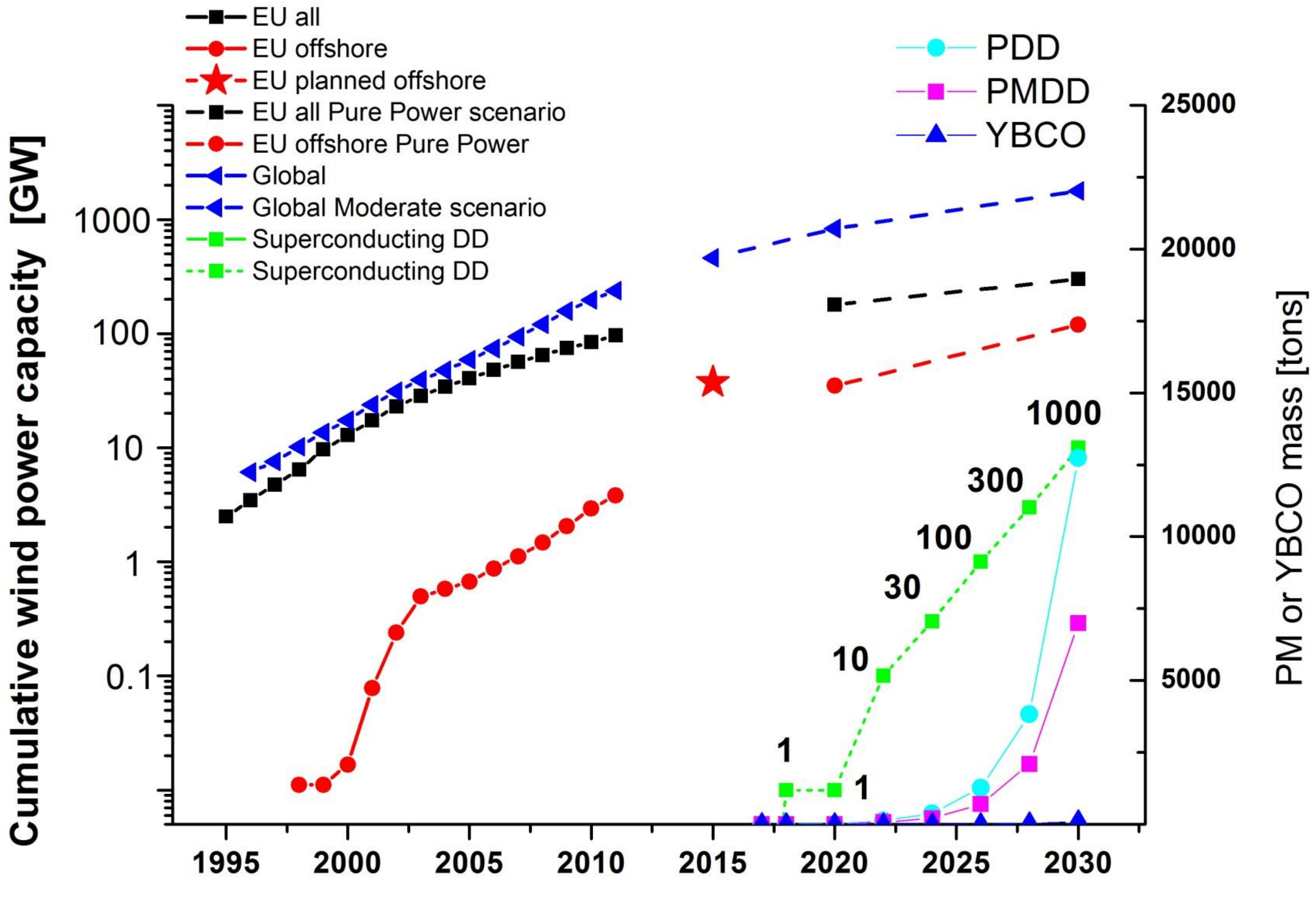
D. Karwatzki & A. Mertens, University of Hannover(D)

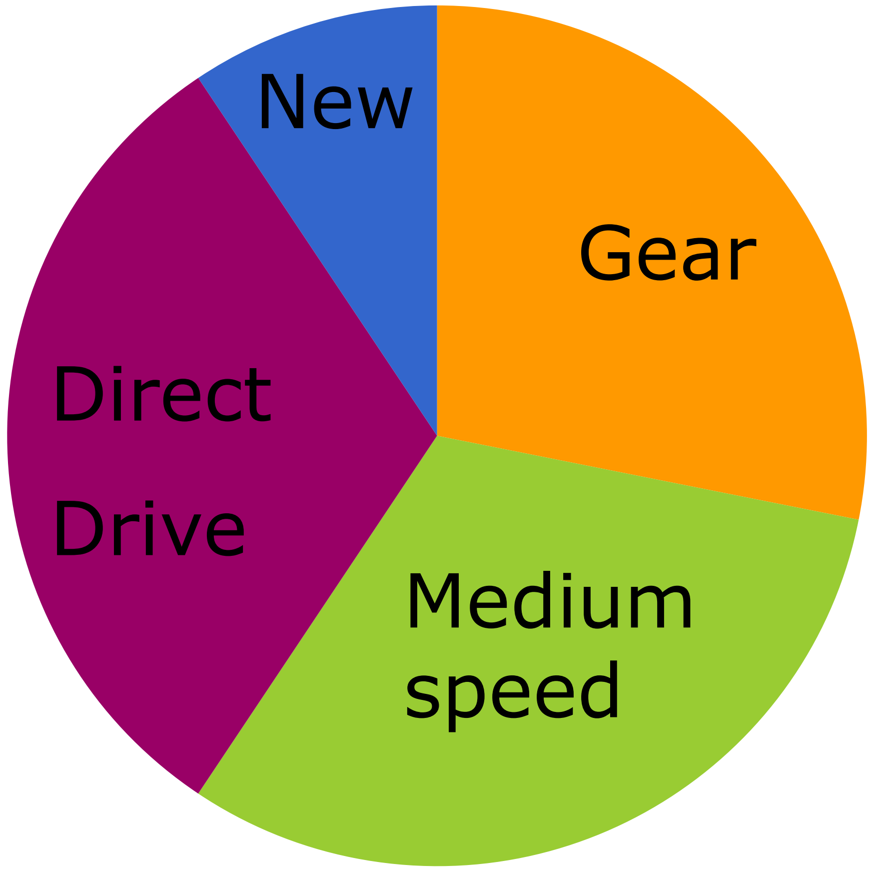
M. Parker & S. Finney, University of Strathclyde

Asger B. Abrahamsen (asab@dtu.dk), DTU Wind Energy (DK)


Project website: www.innwind.eu

# Drive train mix in 2030?




**Abrahamsen and Jensen , "Wind Energy Conversion System: Technology and Trend", ISBN 978-1-4471-2200-5, Springer 2012.**