Large superconducting wind turbine generators: Driving down the cost?

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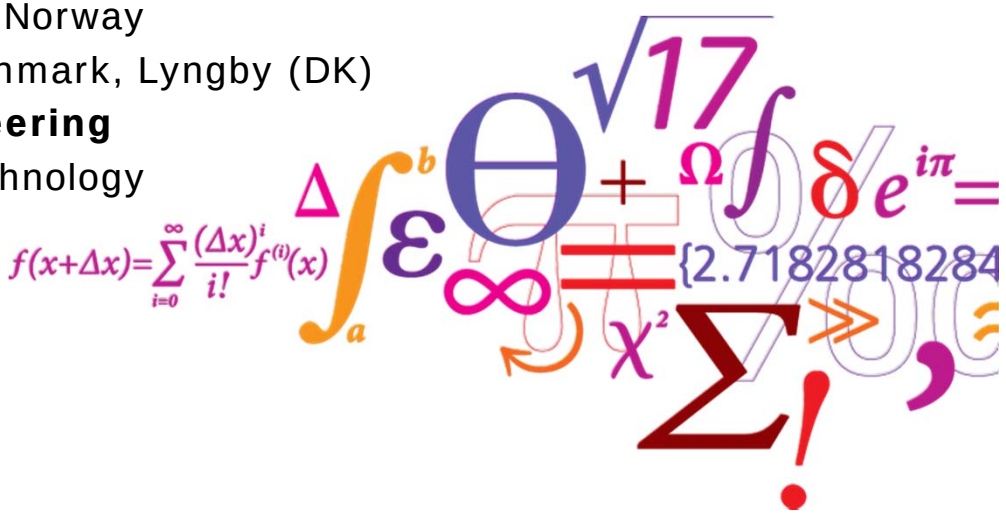

Deep Wind Offshore Wind R&D Seminar
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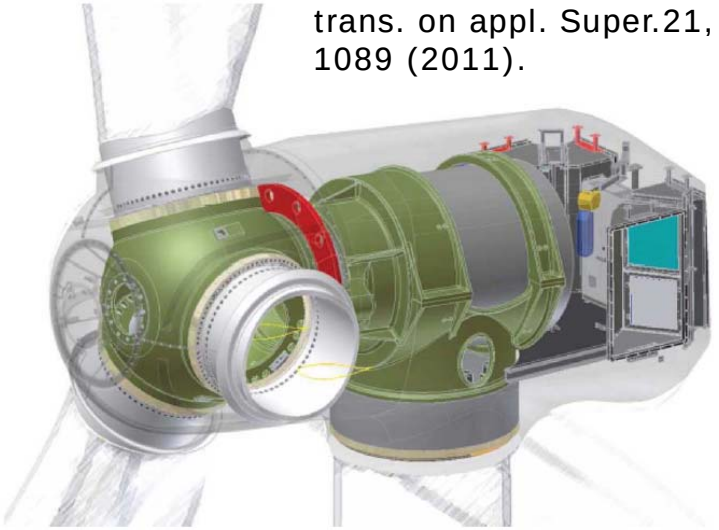
Session A1: New turbine technology

DTU Wind Energy
Department of Wind Energy

Outline

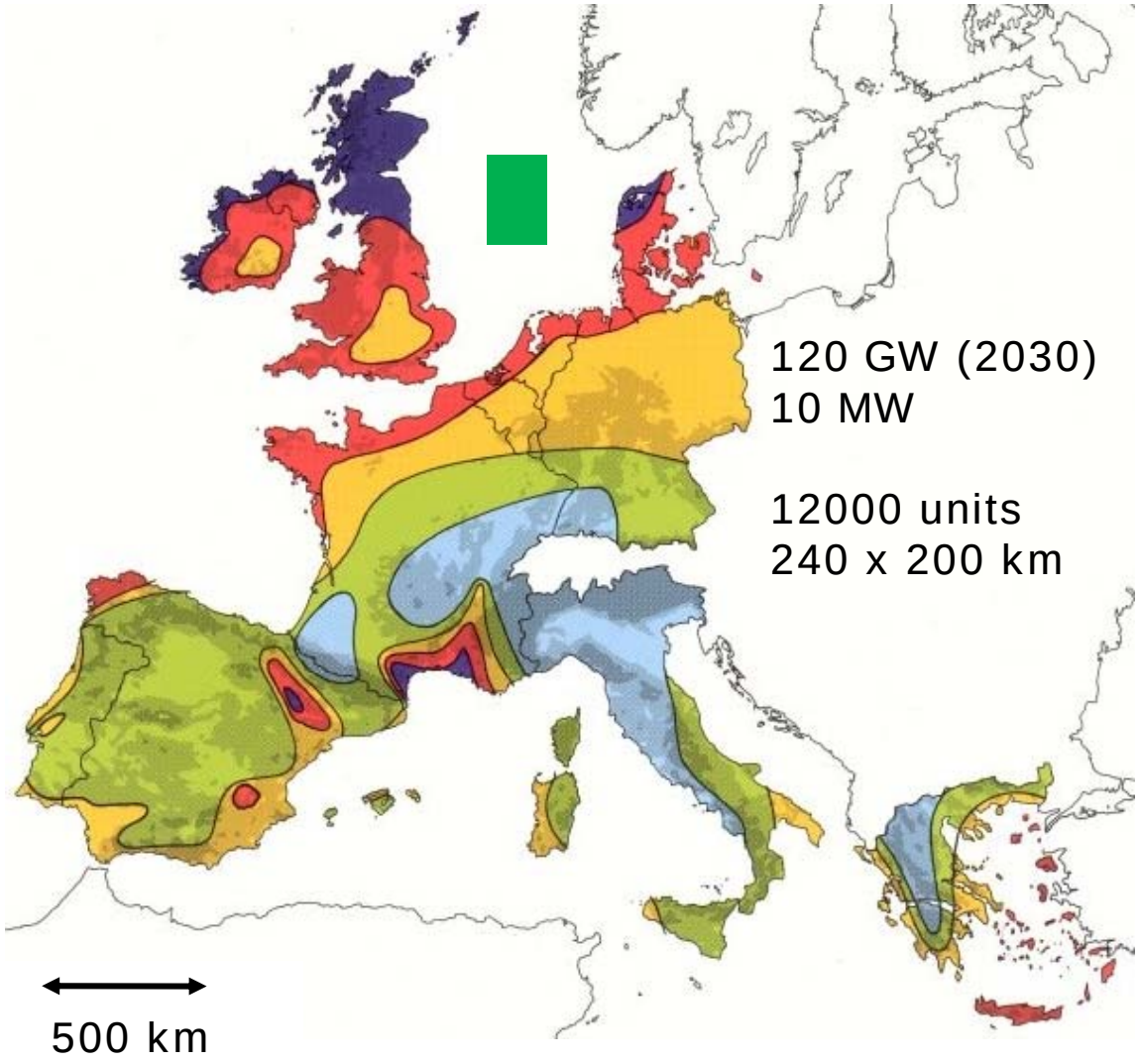
- Motivation for superconducting generators
- How to use superconductors in a generator?
- Superconductor wires and coils:
  - MgB_2, $Bi_2Sr_2Ca_2Cu_3O_{10+x}$ or $YBa_2Cu_3O_{6+x}$
- 5 MW generator to fit NREL reference turbine
  - Compare YBCO & MgB_2
- Superconducting wind turbine generator roadmap
- Conclusion

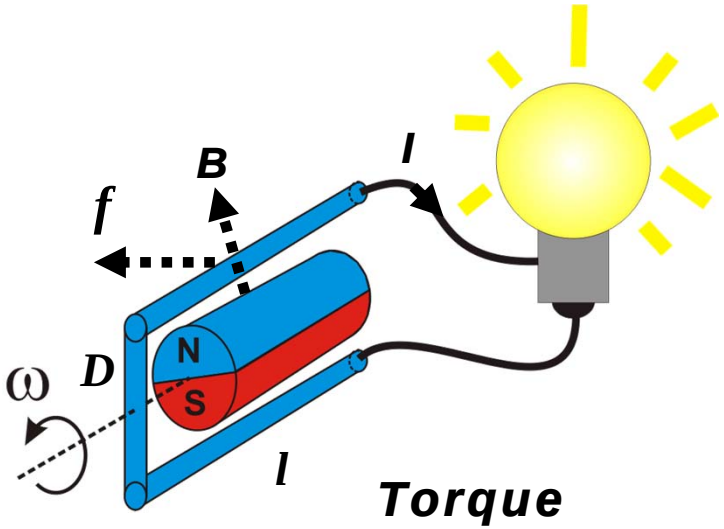
G. Snitchler et. al., IEEE trans. on appl. Super.21, 1089 (2011).



Generator: P = 10 MW
D ~ 5 m, L ~ 5 m
m = 180 tons

Motivation for superconducting generator





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

1G : Copper + Iron

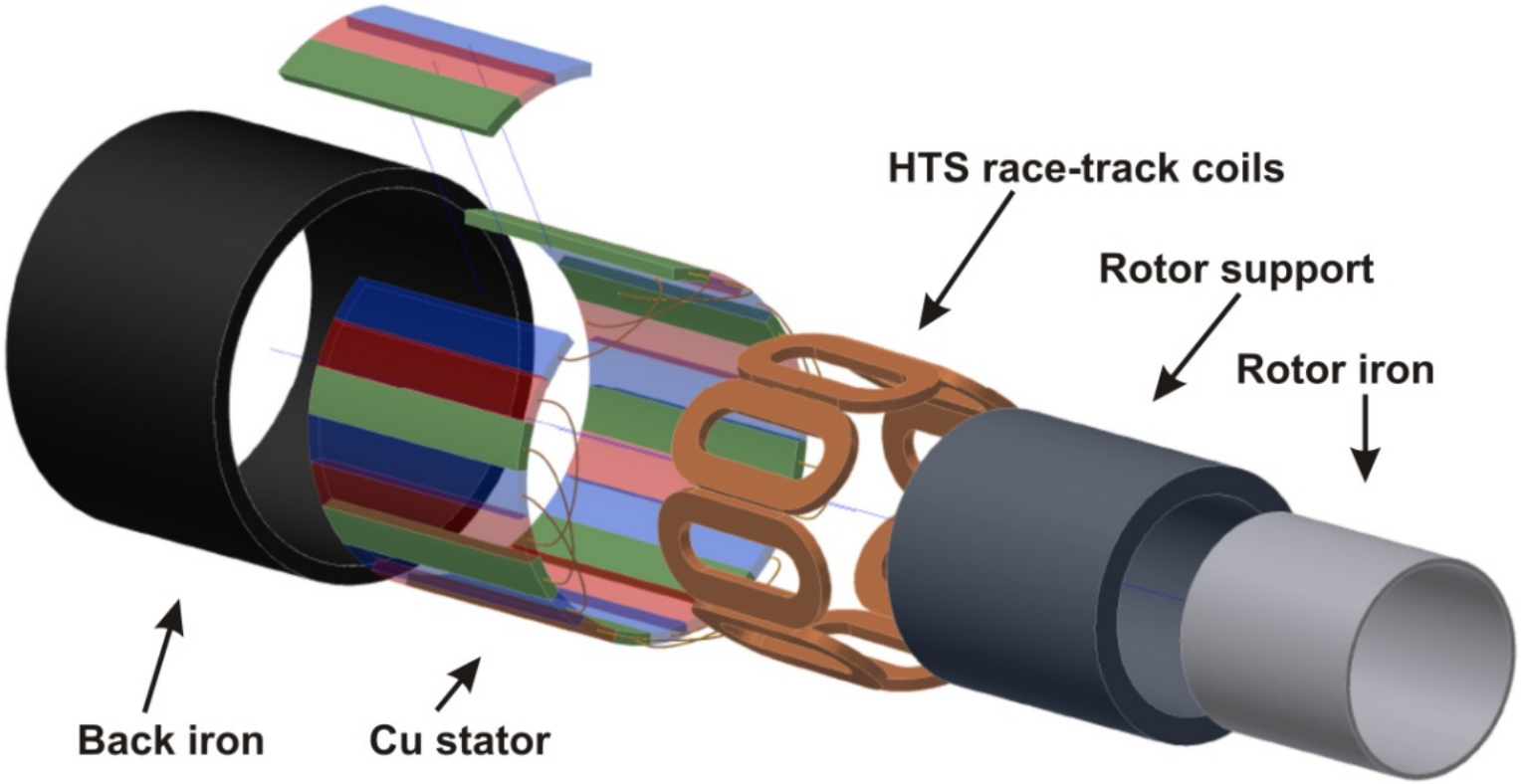
2G : $R_2Fe_{14}B$ magnets+Fe
10 MW ~ 6 tons PM

3G : $RBa_2Cu_3O_{6+x}$ HTS + Fe
10 MW ~ 10 kg RBCO

Superconducting direct drive

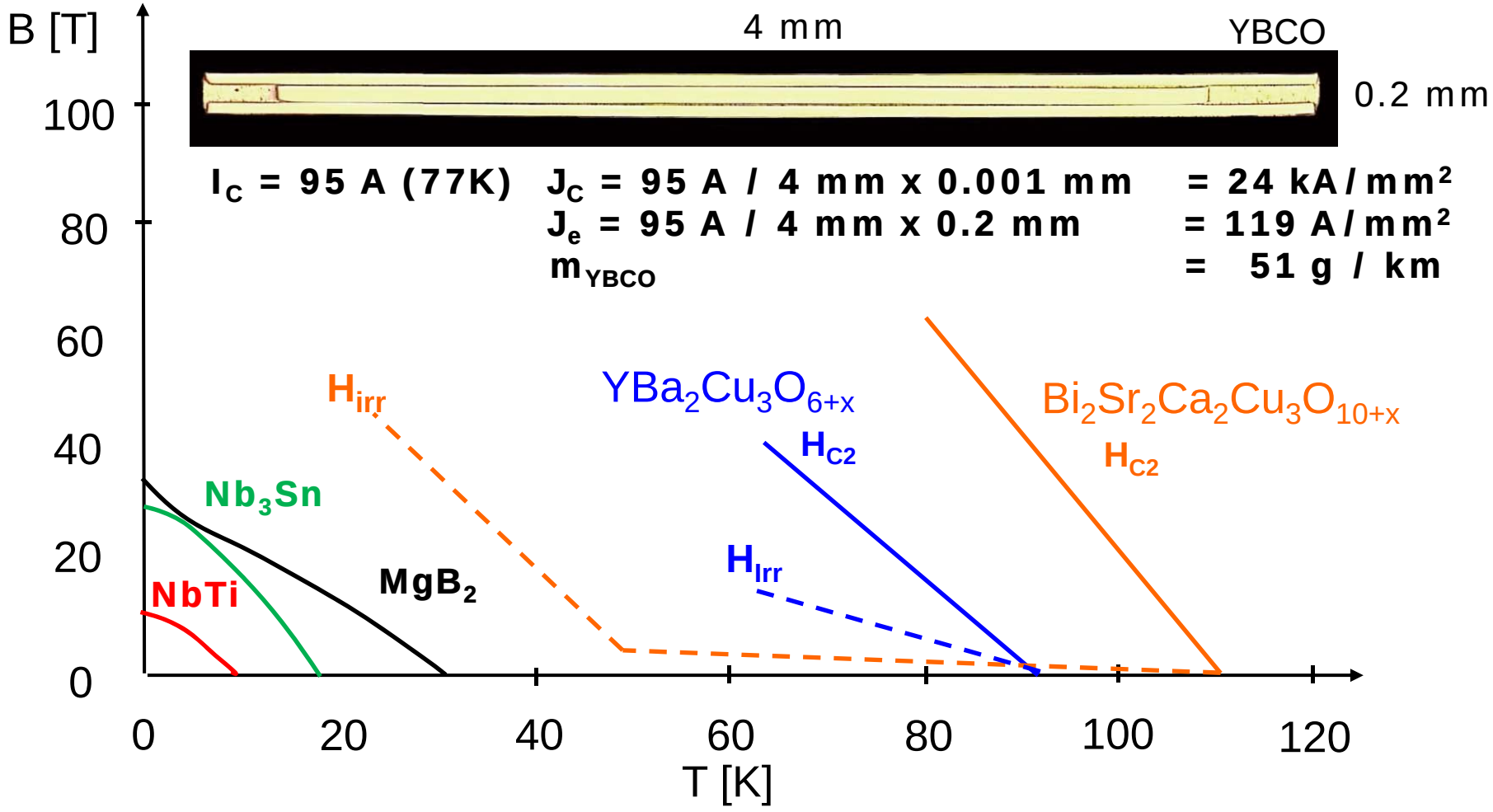
Magnetic flux		$\Phi = LI$
Joule loss	Cu:	$P = R\,I^2$
	SC:	$P = U_0 (I/I_C)^n I$

$B_{air\ gap}$ can exceed saturation of iron



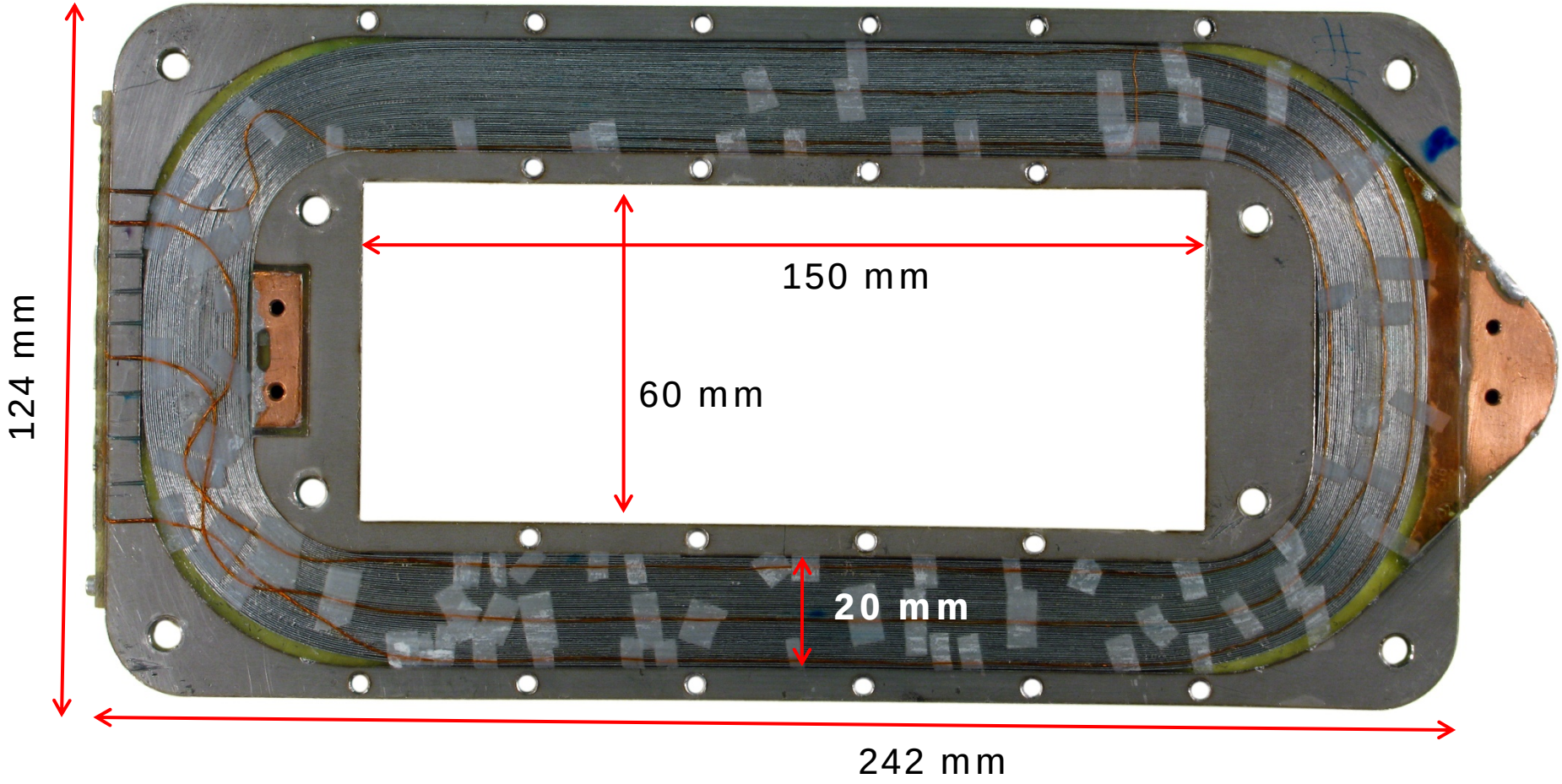
Abrahamsen et. al., SUST23(2010),034019

Critical fields & Temperature

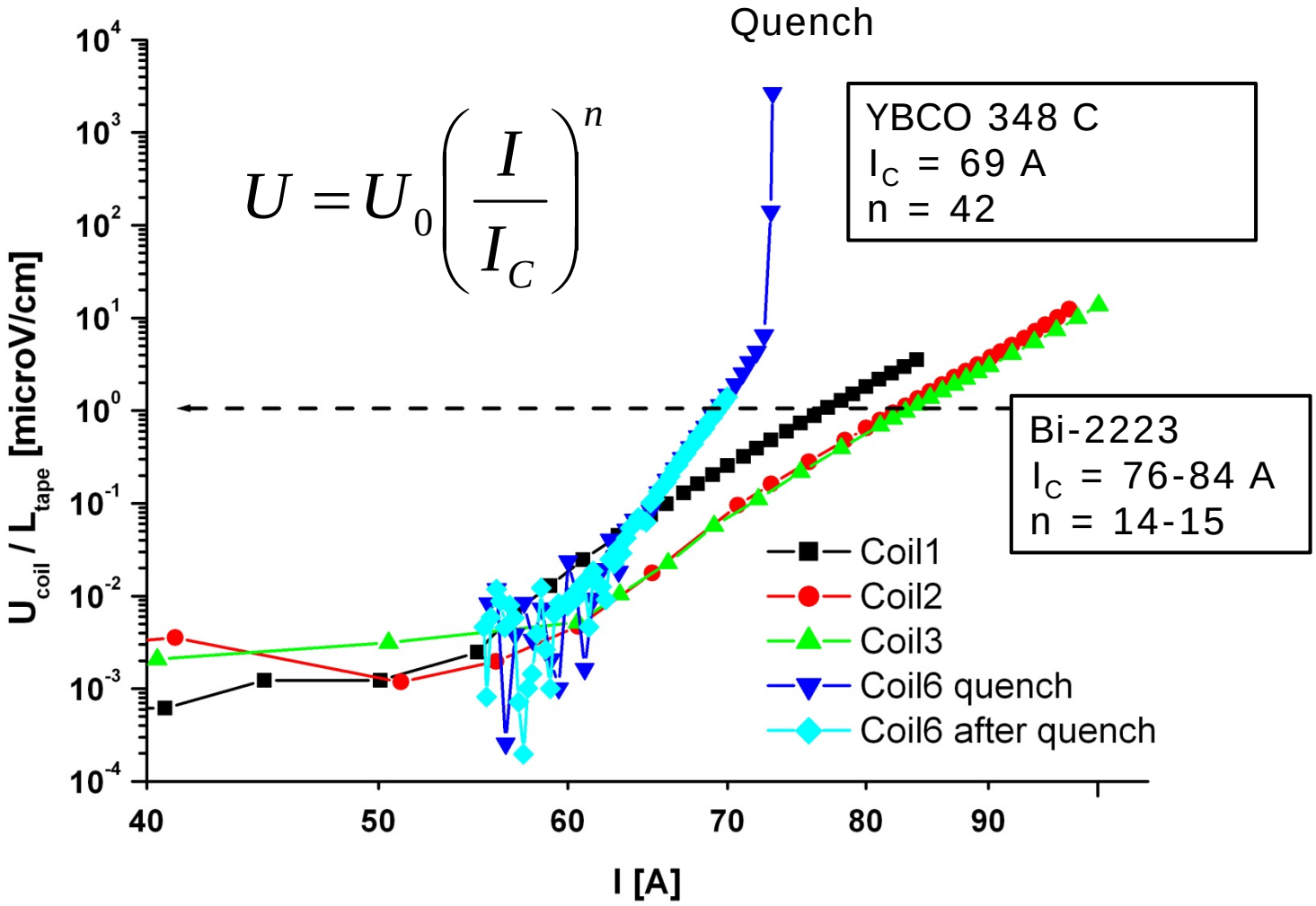


Superwind.dk DTU

Race track coils

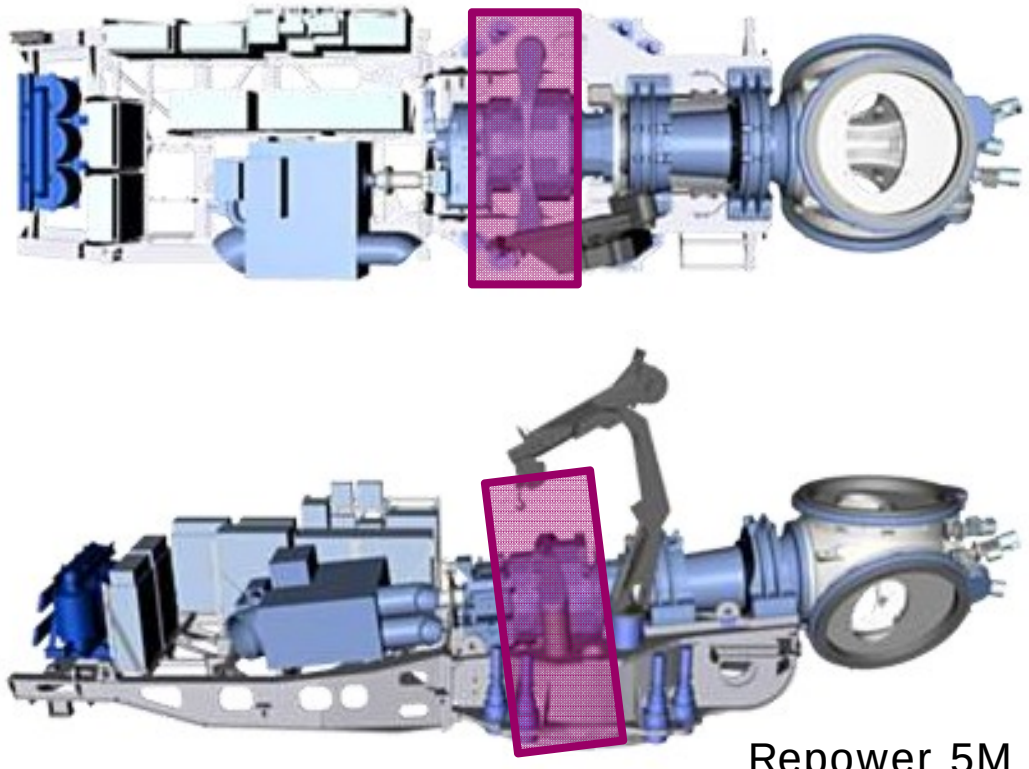


IV curves of coils @ 77 K in liquid nitrogen



Abrahamsen *et. al.*,"Feasibility of 5 MW superconducting wind turbine generator", Physica C471, 1464 (2011)

Superconducting 5 MW direct drive?



Repower 5M

$m_{gear+gen.}$ = 17 tons + 63 tons = 80 tons

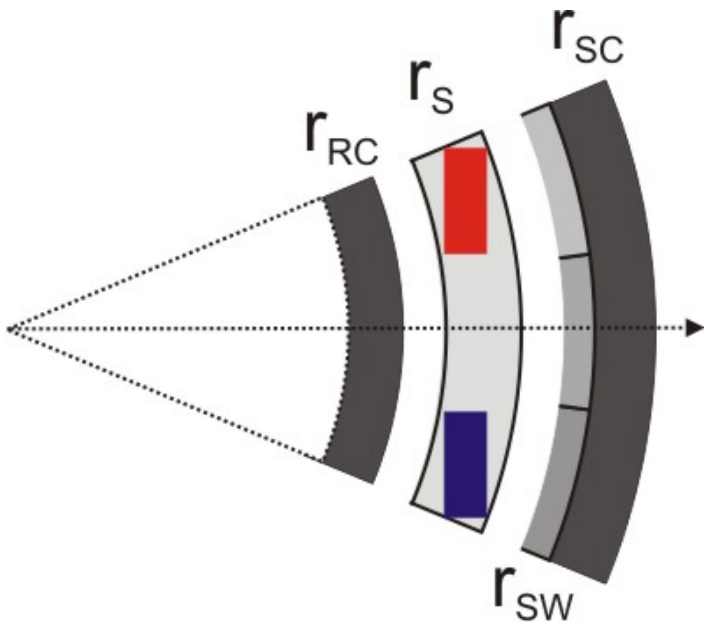
m_{active} < 40 tons
D ~ 4.2 m
L_{active} ~ 1.5 m

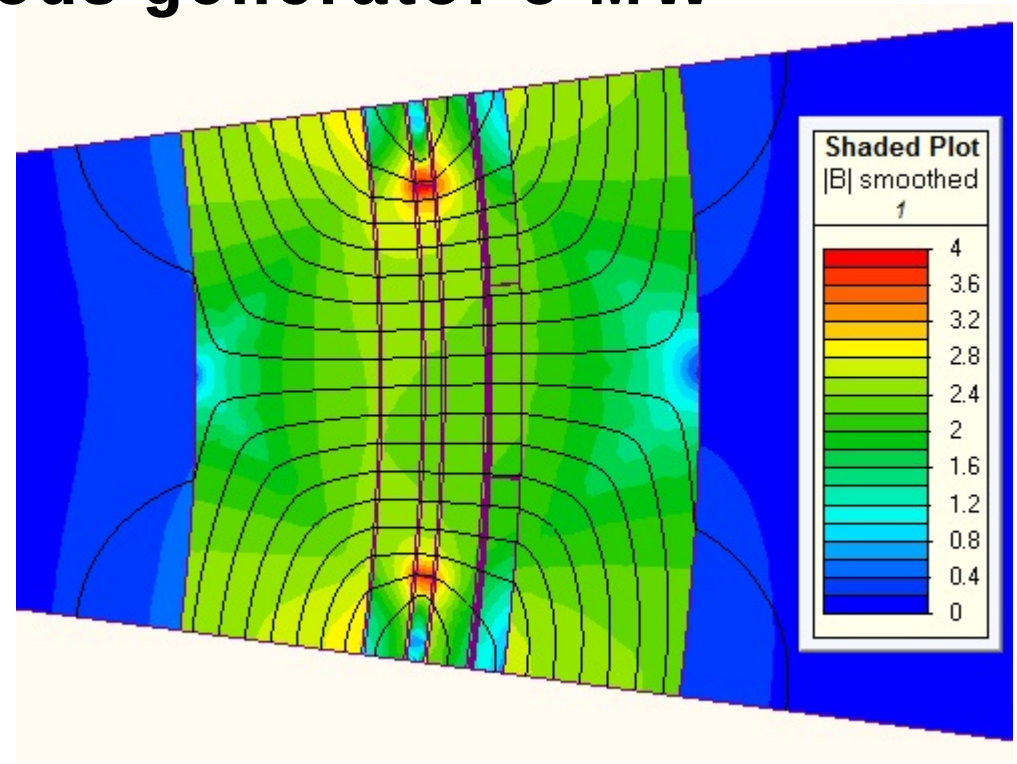
Price:	2 M€/MW
	10 M€
Turbine:	1/3
Drive train:	1/2
Max:	1.65 M€

<u>YBCO Coated conductors</u>
30 €/m ~ 55 km (2012)
8 €/m ~ 200 km ?

<u>MgB_2 wire/tape</u>
3-5 €/m ~ 410 km (2012)
1-2 €/m ~ 1650 km (2015)

Multi-pole synchronous generator 5 MW





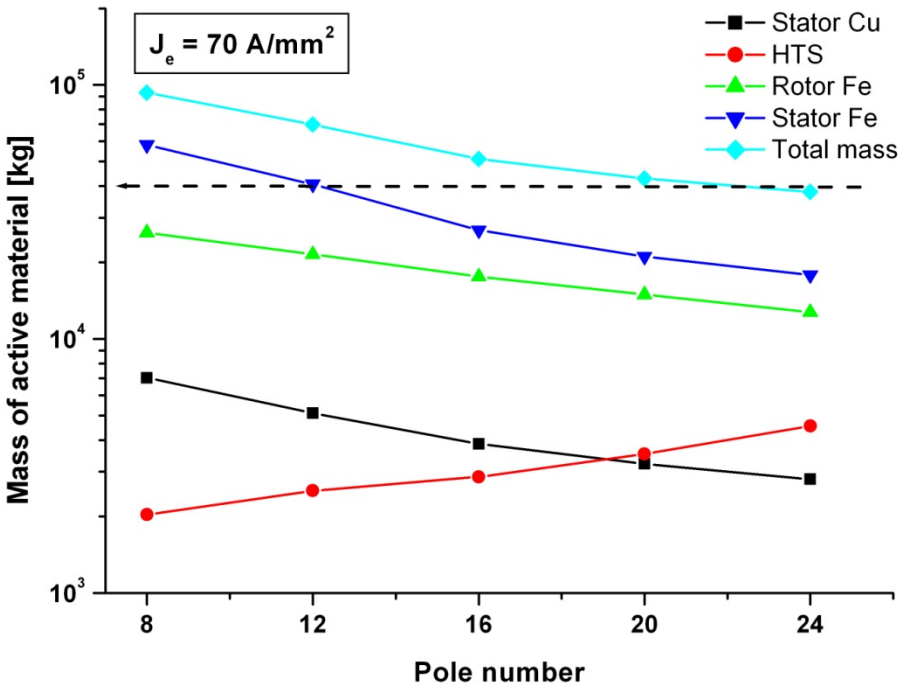
Warm rotor and stator Fe
$t_{cryostat}$ ~ 4 cm

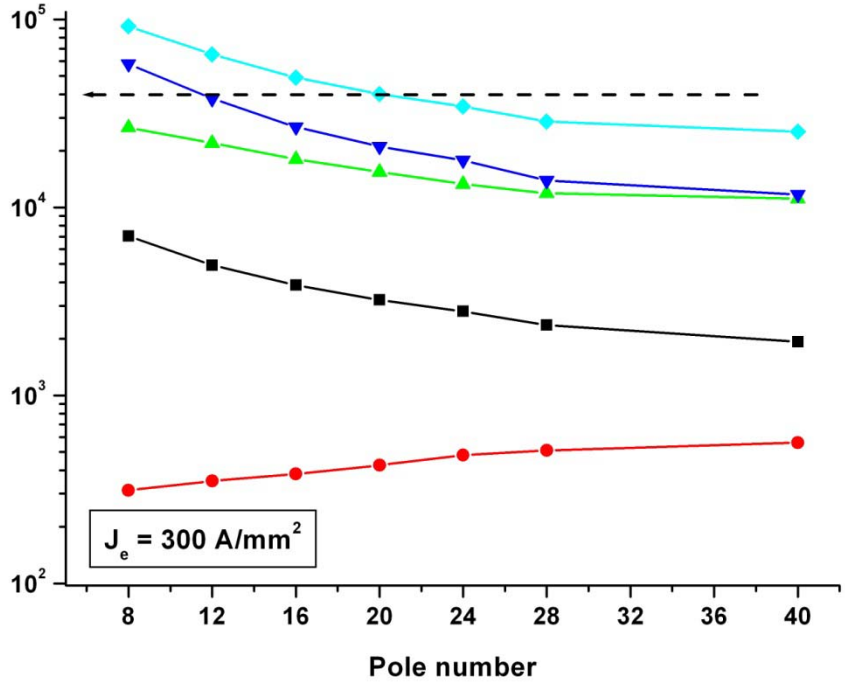
B_{airgap} ~ 2.3 Tesla
B_{Fe} < 2.5 Tesla
A_{stator} ~ 90 kA/m
Cu loss ~ 5 %

D = 4.2 m L = 1.5 m

ρ_{FE} = 7600 kg m^{-3}
ρ_{Cu} = 8940 kg m^{-3}
$\rho_{AmSC\ 348\ +\ insu}$ = 6546 kg m^{-3}
$\rho_{SP4050+\ insu}$ = 4982 kg m^{-3}

Active mass of 5 MW direct drive generators





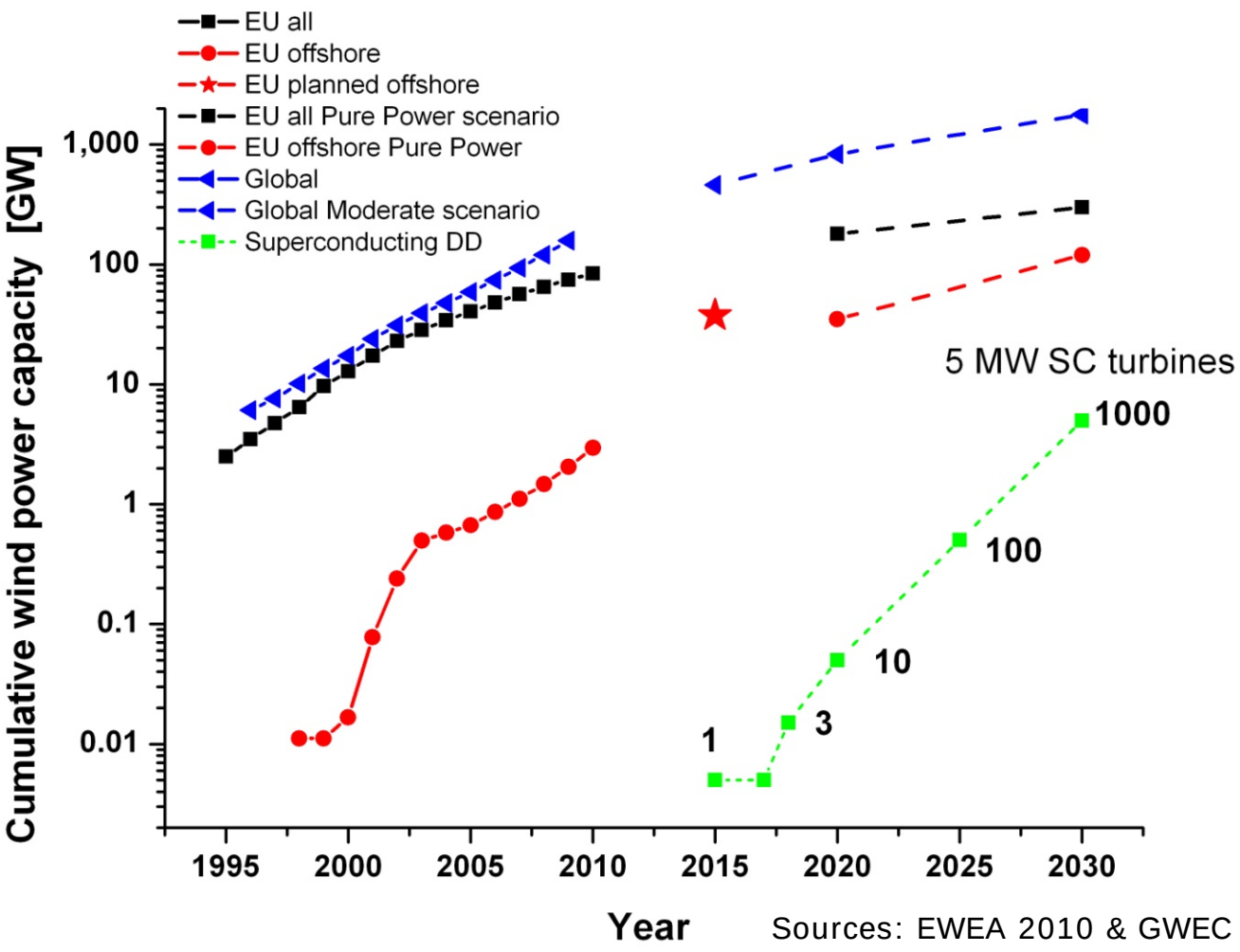
YBCO: 24 pole L = 550 km
T = 40 K Price: 16.5M€ (30 €/m)

24 pole L = 130 km
T = 40 K Price: 3.9 M€ (30 €/m)

MgB_2: 16 pole L = 330 km
T = 20 K Price: 1.0M€ (3 €/m)
Price: 0.3M€ (1 €/m 2015)

24 pole L = 130 km
T = 20 K Price: Not ready
Price: 130 k€
(1 €/m 2015)

Superconducting drive train road map



Needed

130000 km tape
6000 cryocoolers
1000 cryostats

YBCO production
2000 km/year ↑

MgB_2 (2015)
10000 km/year

a) Prod. vol.
b) Price
c) Reliability

Sources: EWEA 2010 & GWEC 2009 statistics, EWEA "Pure power" and GWEC "Global wind energy outlook 2010" reports. Abrahamsen et. at., "Wind Energy Conversion System: Technology and Trend", book chapter, Springer 2012.

Conclusion

- Superconducting direct drive offers higher torque in the same package
- Air gap flux density higher than saturation of iron is possible
- Race track coils of high temperature superconductors obtained
- Superconductor properties extrapolated to 5 MW direct drive generator
- Electromagnetic - thermal – structural design challenge
  - Trade off between high operation temperature, high current density and cost
  - YBCO: T = 40 K J_e ok Cost: Too high
  - MgB_2: T = 20 K, J_e close Cost: Close – Promising
- SC roadmap: Start addressing reliability as production volume is scaled up!