Superconducting Generators in INNWIND.EU

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Outline

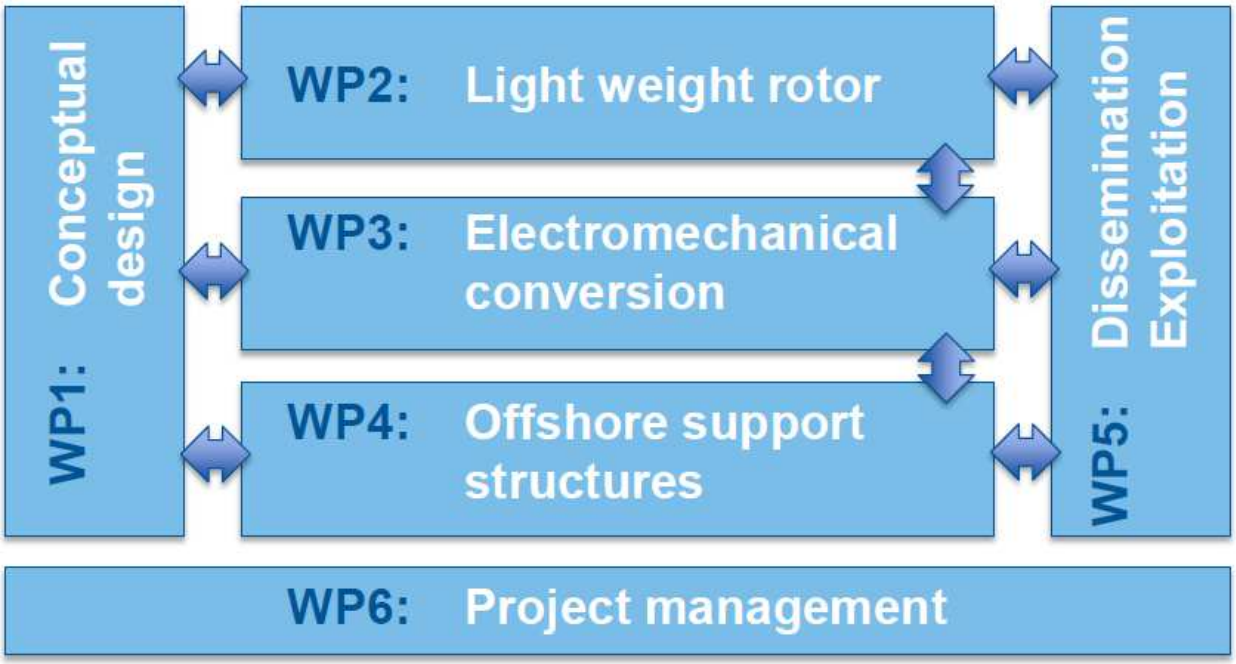
- INNWIND.EU concept 10-20 MW
- Choice of superconductors
- Siemens coil demonstration and generator design
- DTU/TUDelft/Sintef coil demonstration and generator design
- Potential
- Conclusion

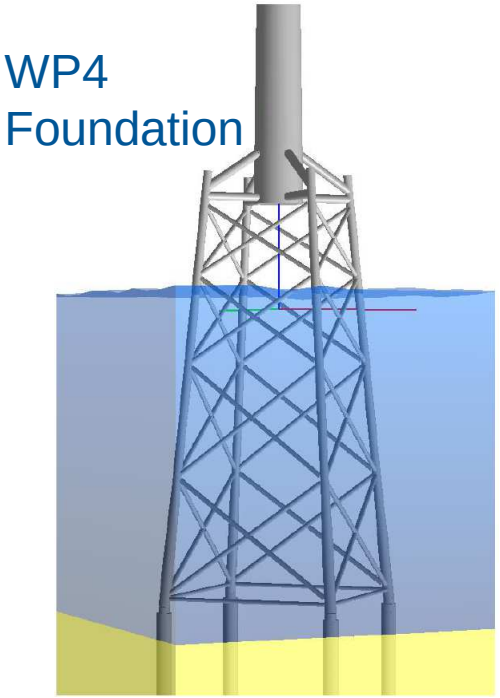
Acknowledgement

- This work is part of the INNWIND.EU project supported by the FP7 framework of EU, under Grant 308974.

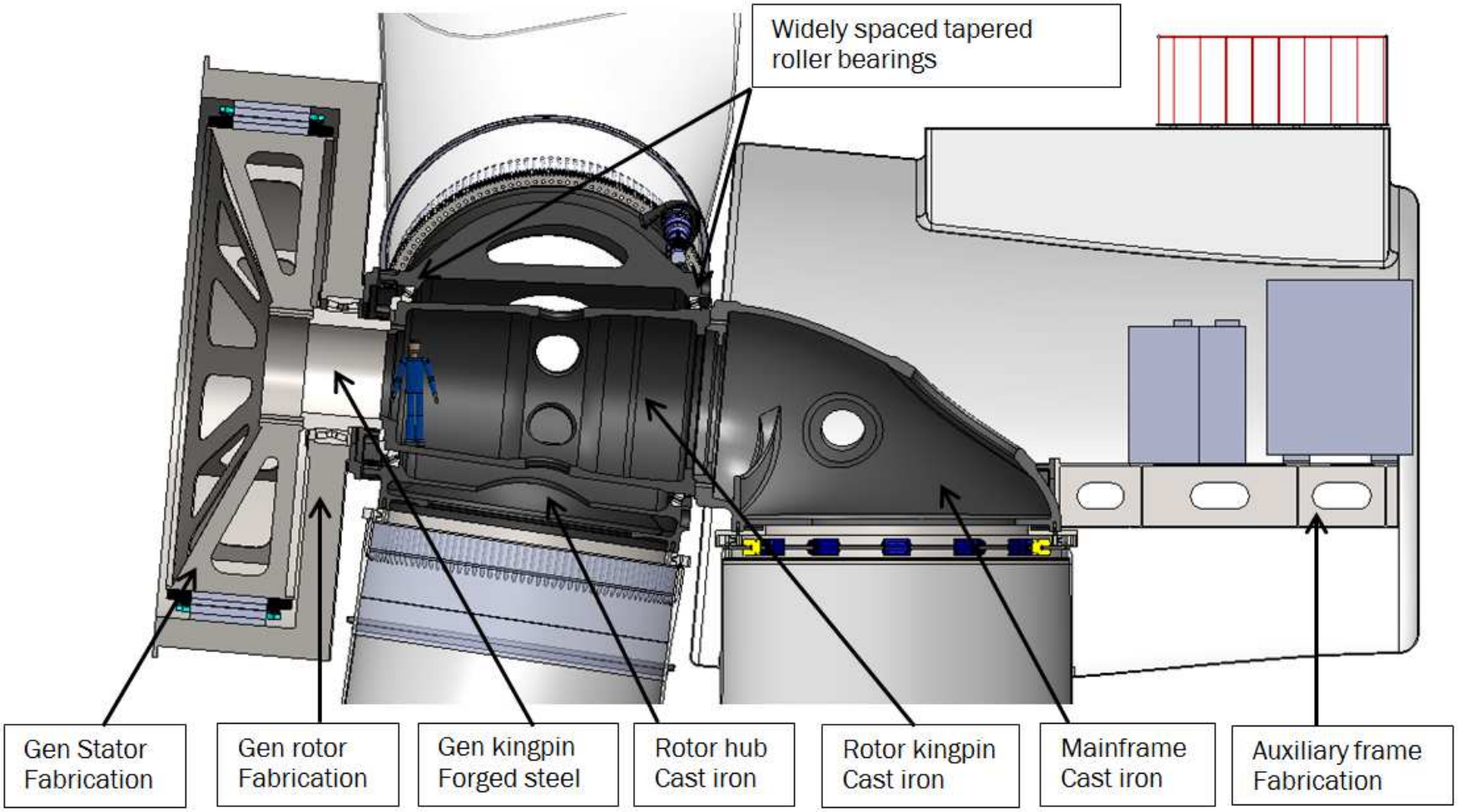
INNWIND project

- Upscaling to 10-20 MW
- How to beat the square-cube law?
- For EM conversion: SC and PDD





Nacelle integration INNWIND.EU

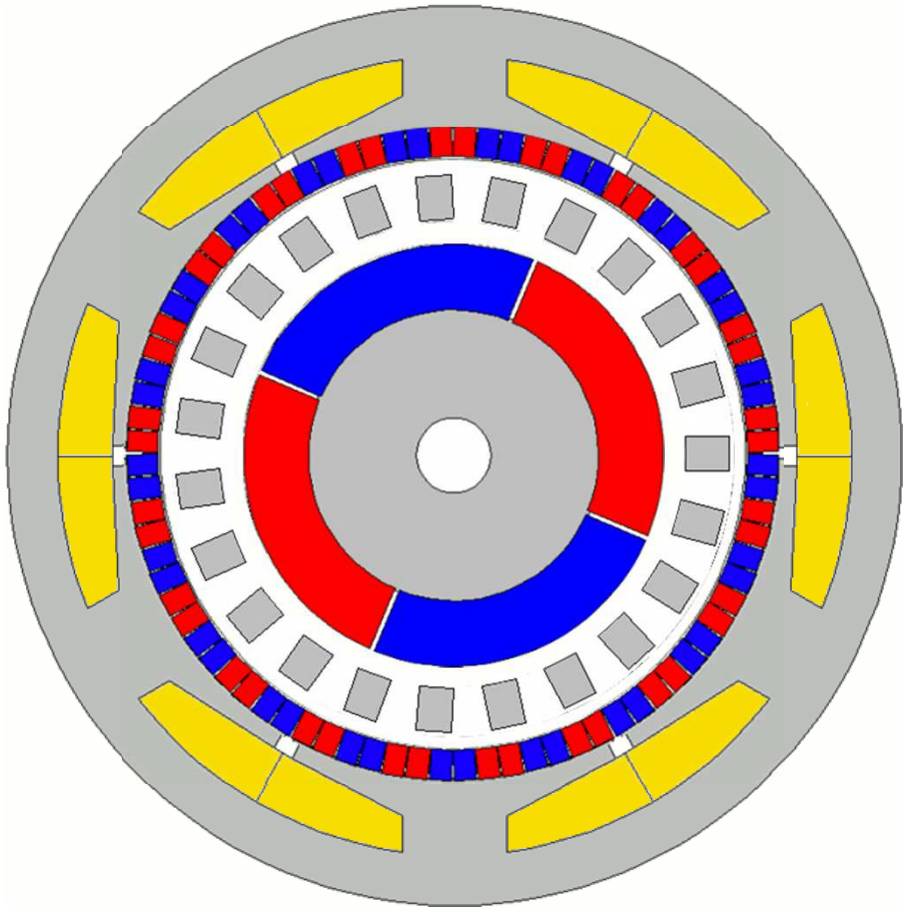


Mass and cost overview

	10MW 178m		10MW 198m	
Excluding generator	Mass [ton]	Cost [kEuro]	Mass [ton]	Cost [kEuro]
Blades	128	832	171	1112
Rest rotor (hub)	100	488	132	631
Nacelle	123	716	160	933
Total R&N structure	351	2036	463	2676

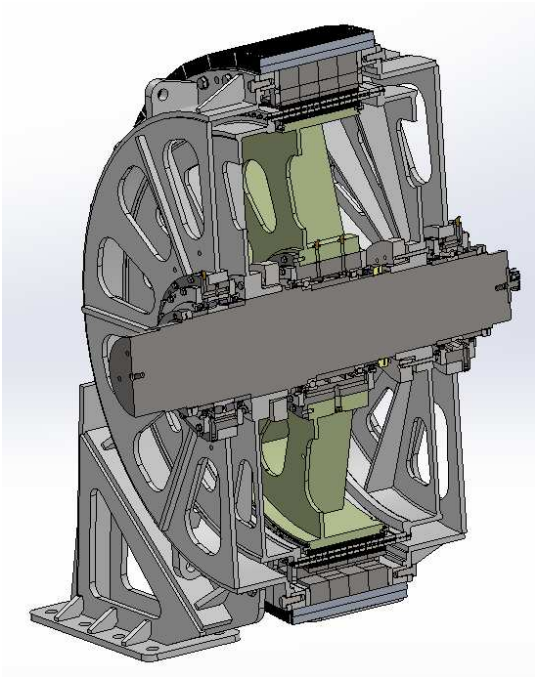
Magnetic Pseudo Direct Drive (PDD)

Magnomatics®



Magnetic gear
+ Generator

- Compact
- No contact
- High efficiency



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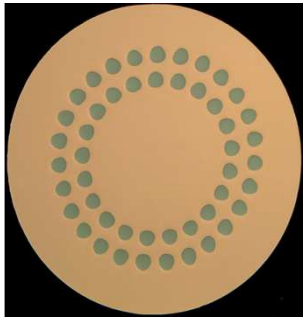
Choice of superconductors

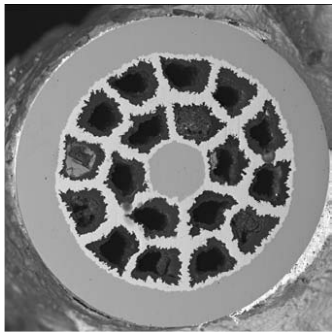


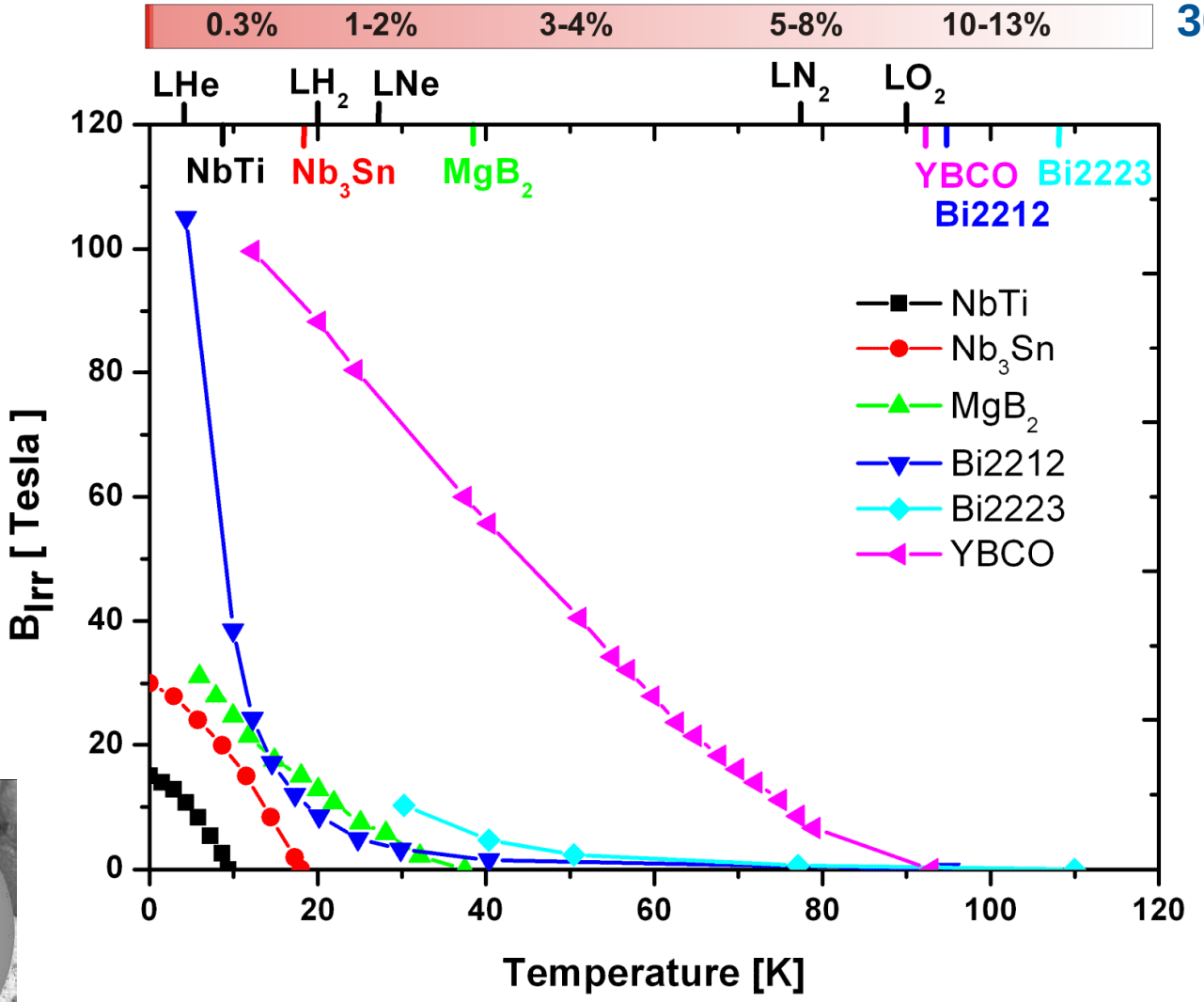
NbTi Bruker EST

0.4 €/m

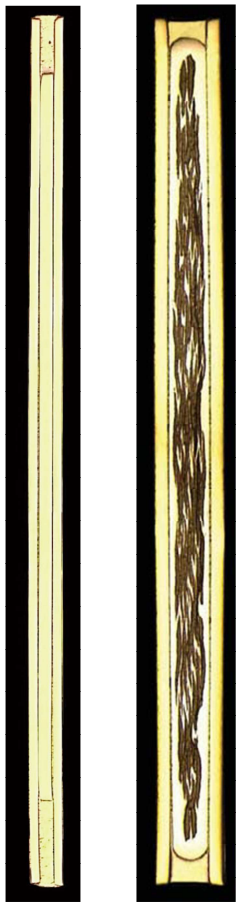
1-4 €/m

MgB_2 HyperTech





30 €/m **20 €/m**



YBCO Bi-2223
AmSC

Jensen, Mijatovic & Abrahamsen, J. Renewable Sustainable Energy 5, 023137 (2013)

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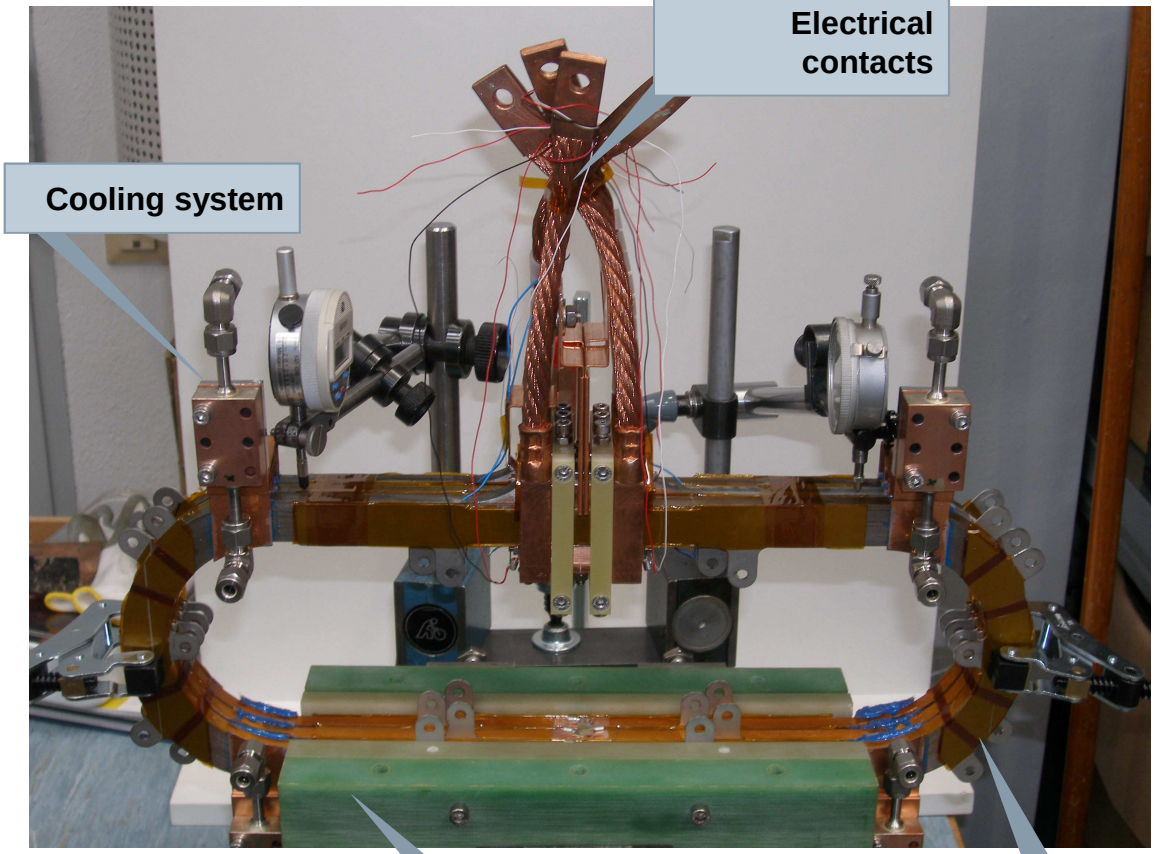
HTS coil demo SIEMENS

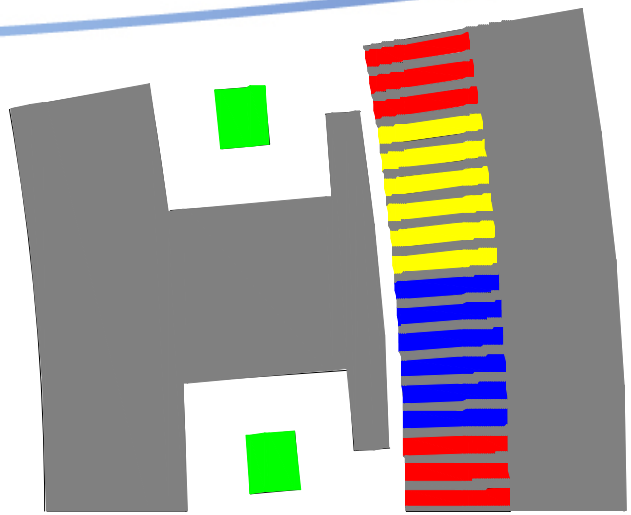


- As high temperature as possible
- HTS tapes
- 3 pancake stacked
- T = - 243 ºC (LNe)
- I = 474 A
- AC losses determined

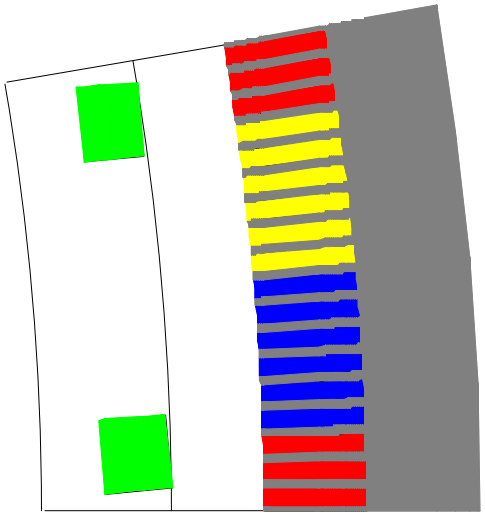
  @ $I_{AC} < 100$ A &

  $I_{DC} < 300$ A
- Industrialization of coil manufacturing needed

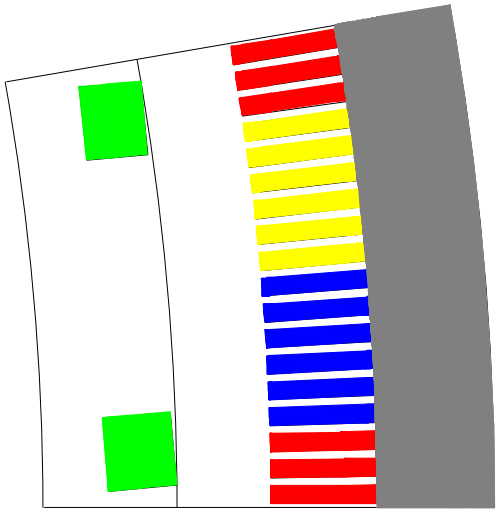
Topologies SIEMENS



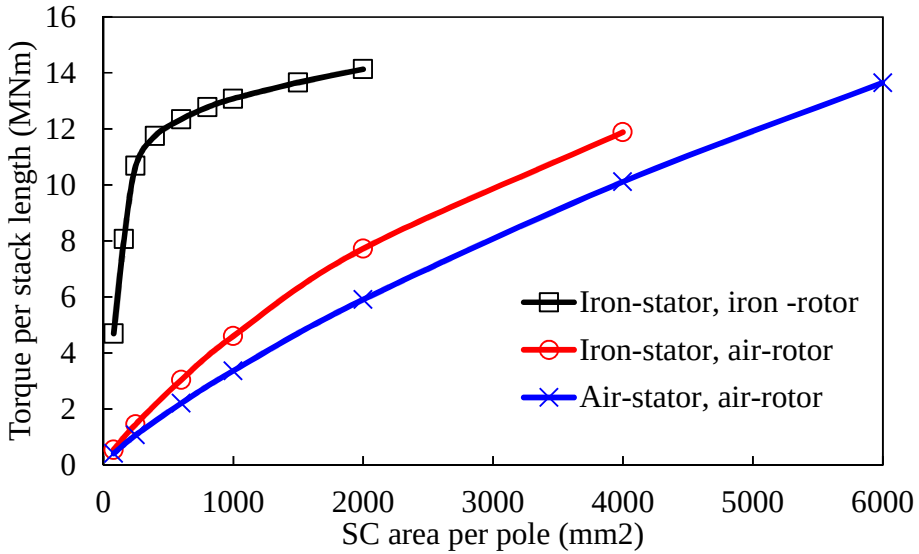
Iron-core stator, iron-core rotor



Iron-core stator, air-core rotor

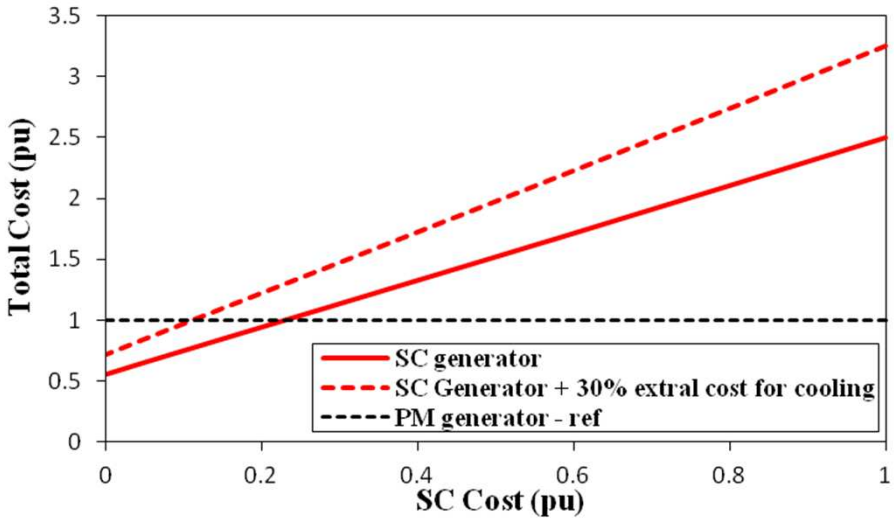


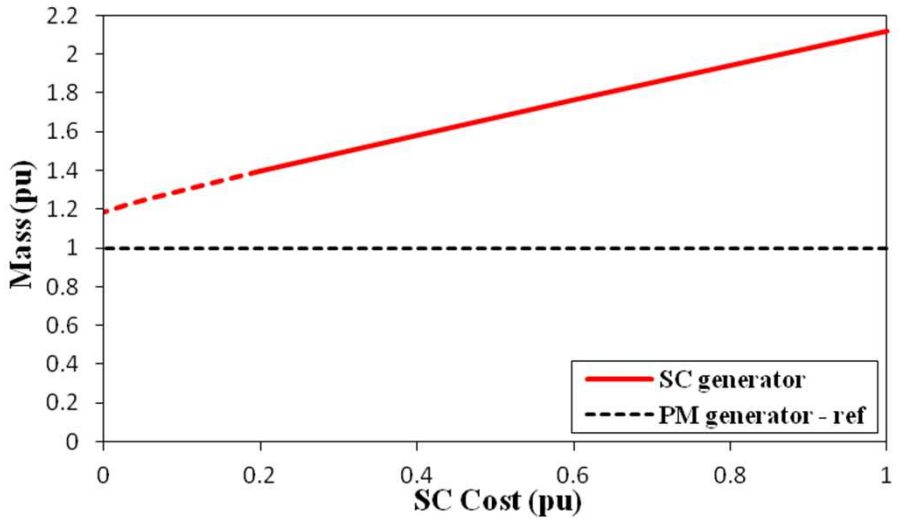
Air-core stator, air-core rotor



PM vs superconducting SIEMENS

- To be cheaper than PM, SC cost must decrease 90%
- SC is not expected to be lighter than PM for this topology





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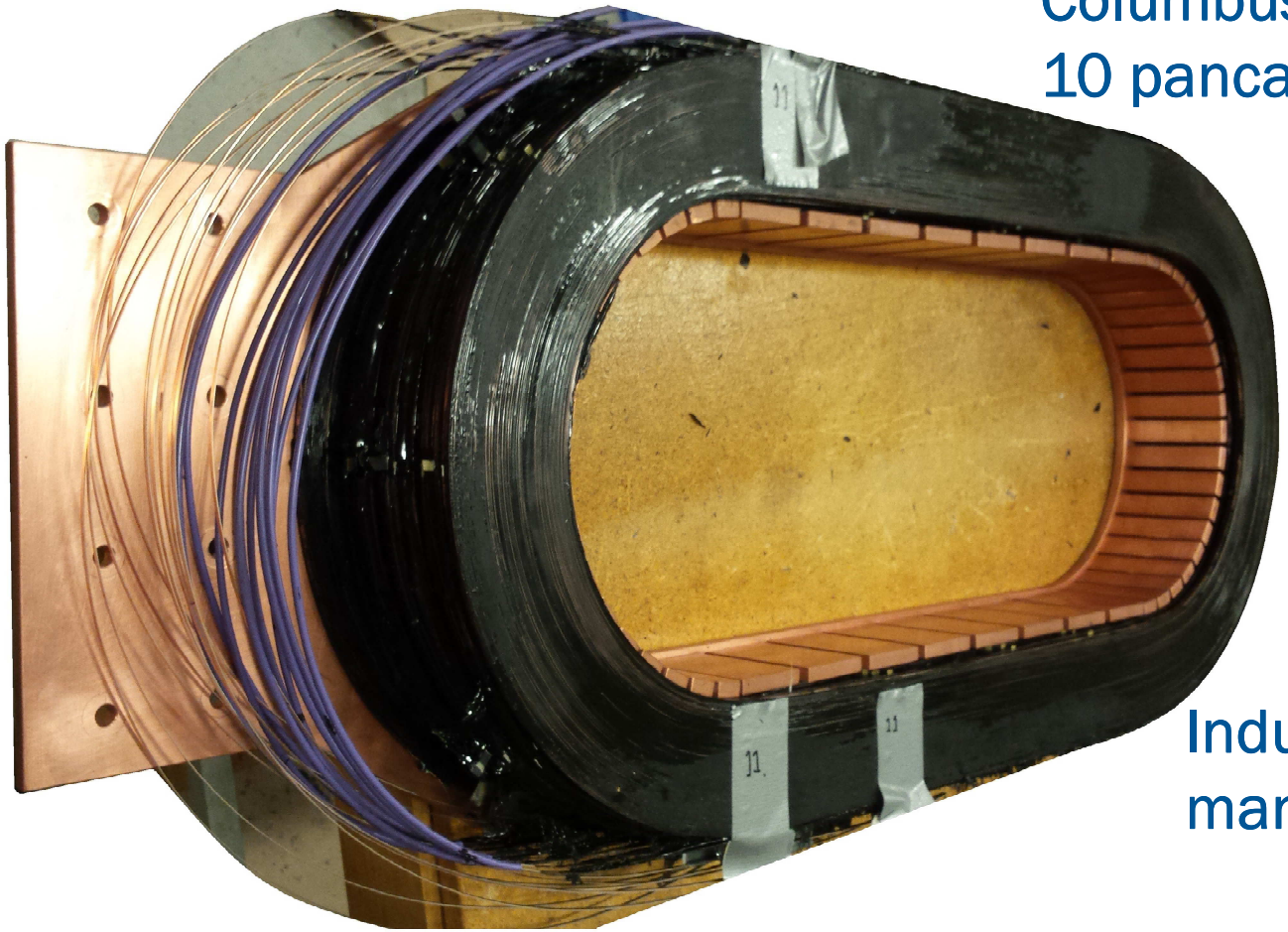
MgB_2 coil demo SINTEF



"Cheap but not too heavy"
Columbus Superconductors
10 pancake coils stacked

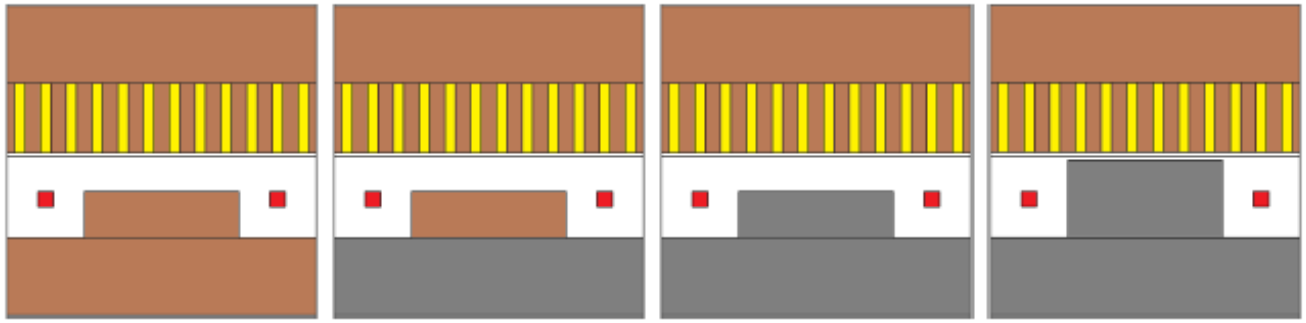
L ~	0.8 m
W ~	0.4 m
Turns:	2080
L_{MgB2}:	4.5 km
Height:	81 mm
Width:	87 mm

Industrialization of coil manufacturing needed

INNWIND:EU D3.13

Combine SC + Cu + Si steel + G10

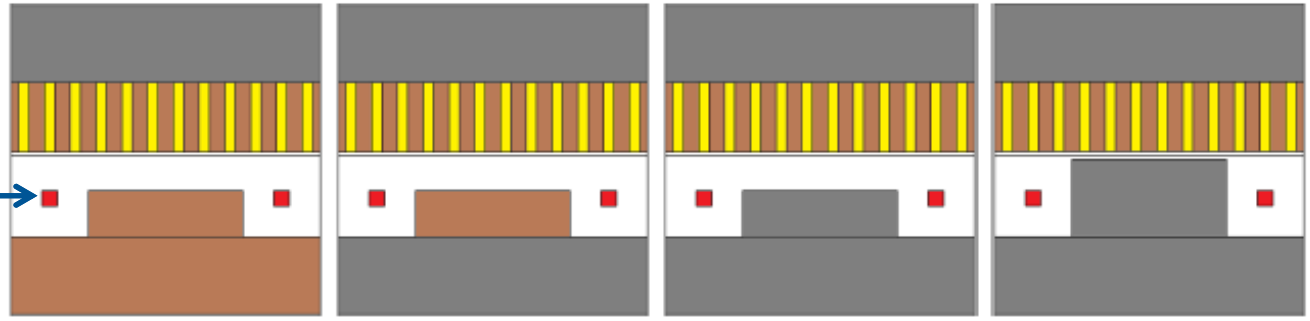
G10
15€/kg



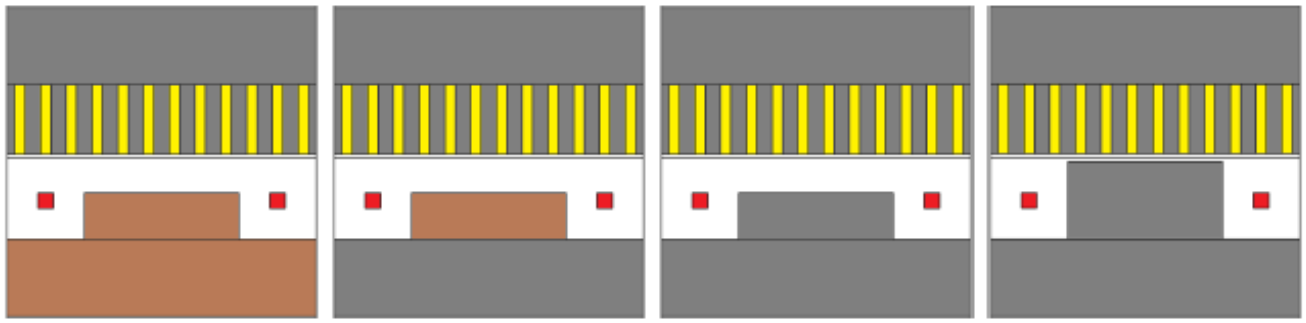
(a) T1 (b) T2 (c) T3 (d) T4

Cop-Per
15€/kg

SC
4€/m



(e) T5 (f) T6 (g) T7 (h) T8

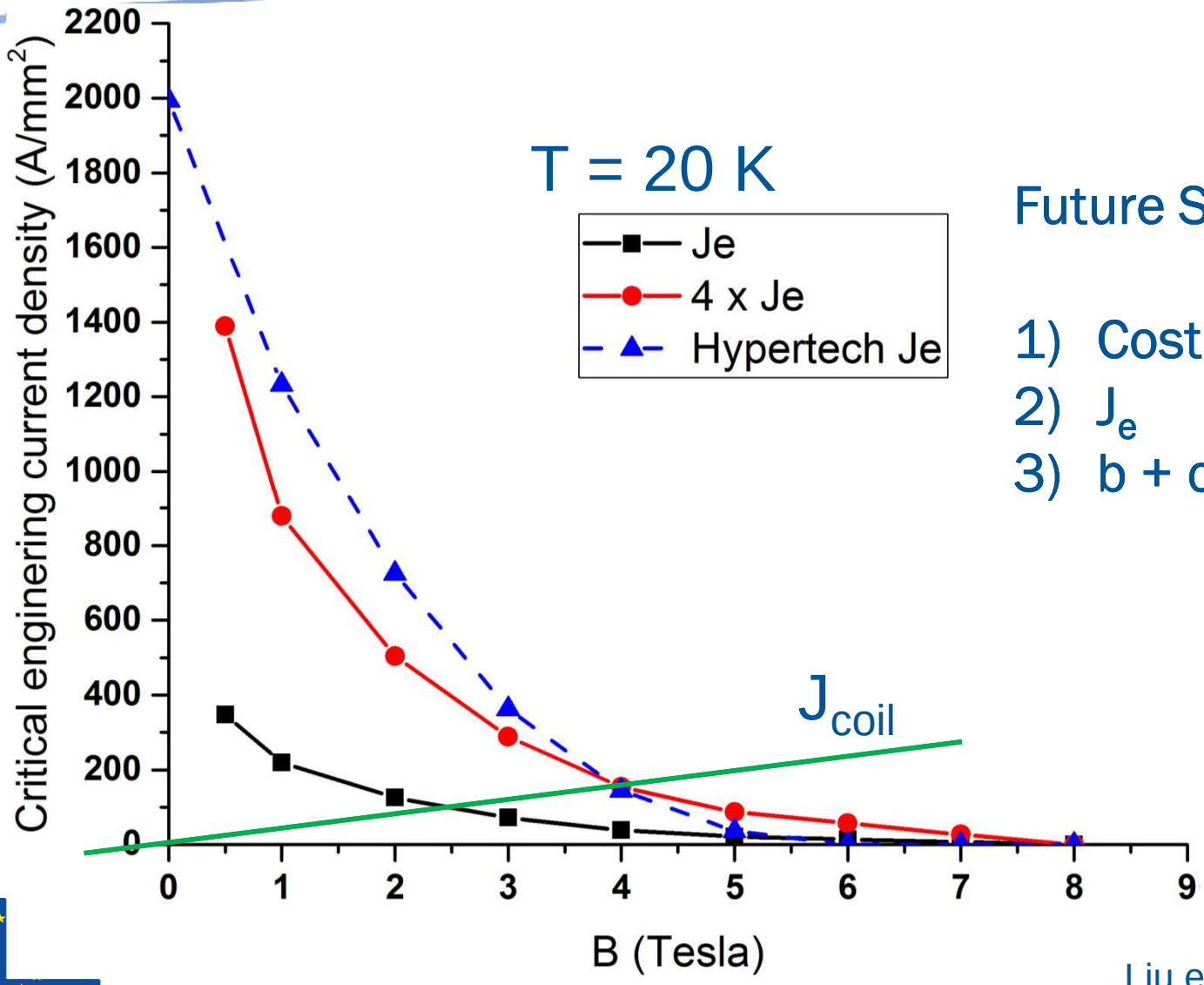


(i) T9 (j) T10 (k) T11 (l) T12

Iron
3€/kg

Liu et al.
IEEE TAS
2017

MgB_2 superconductor operation $J < J_E$



Future Scenarios

1) Cost → ¼
2) J_e → 4 x Je
3) b + c

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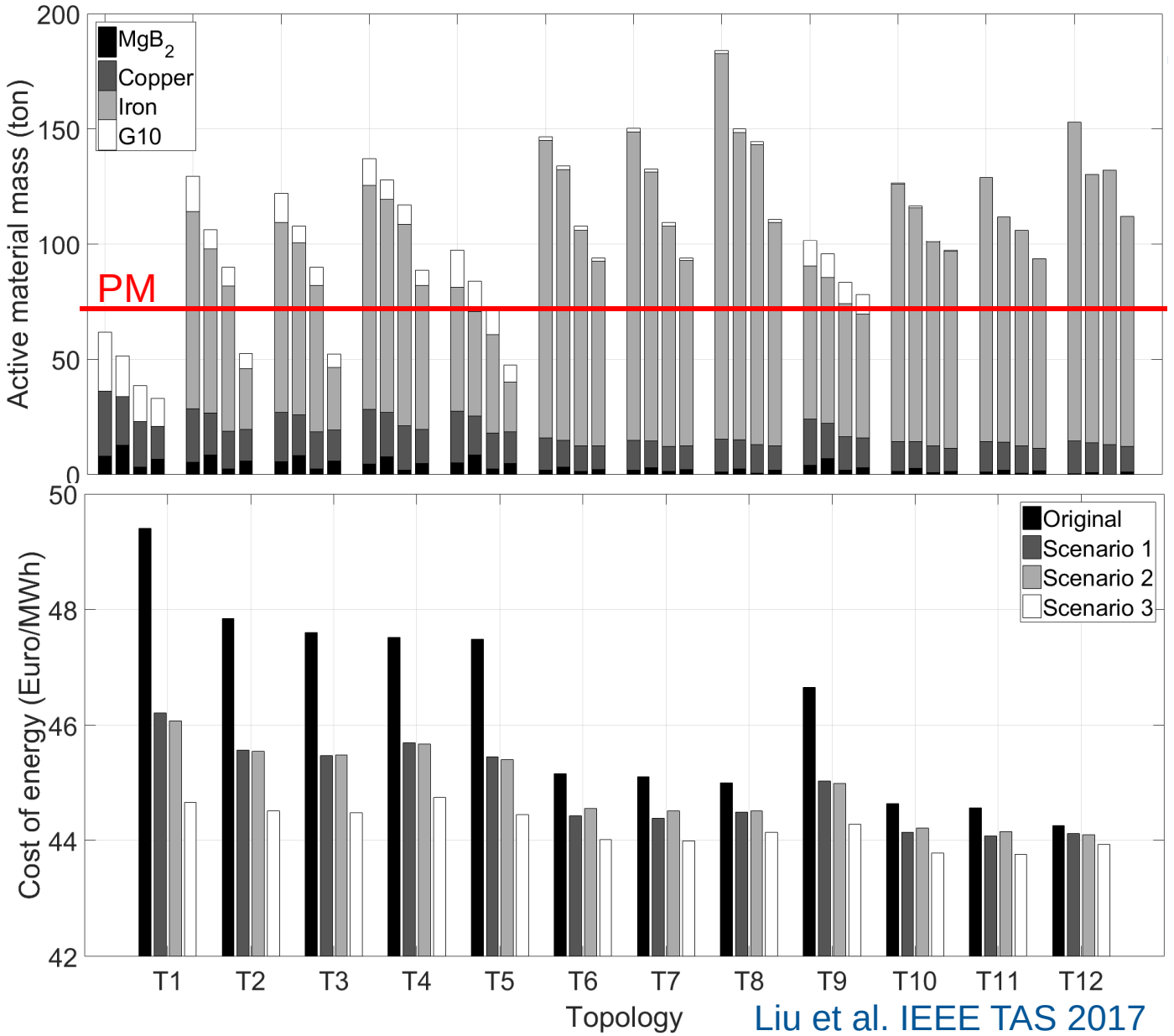
Optimized designs

- With iron: cheap but heavy
- Without iron: light but expensive
- Scenario 4 and 1/4: small differences between



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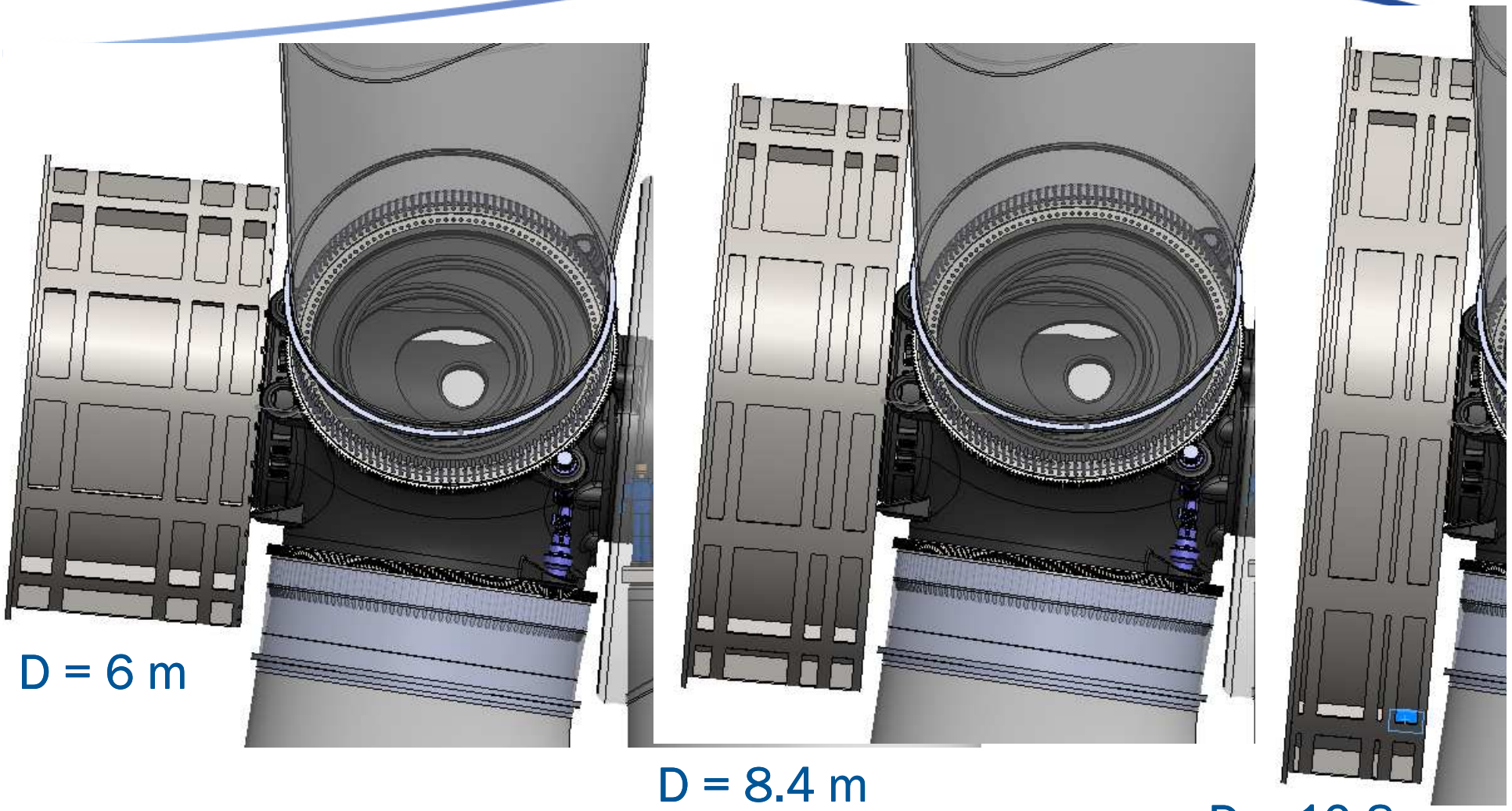
Different diameter length ratios



Different diameter length ratios

	6 m	8.4 m	10.8 m	cost	6 m	8.4 m	10.8 m
	[t]	[t]	[t]	[k€/t]	[k€]	[k€]	[k€]
Torque transm.	8	8	8	4	32	32	32
Kingpin	13	13	13	2.5	33	33	33
Rotor structure	82	98	112	2.5	205	245	280
Stator structure	49	49	58	2.5	123	123	145
Total structure	152	168	191		392	432	490
Active mass	153	118	96		706	579	509
Total	305	286	287		1098	1011	999

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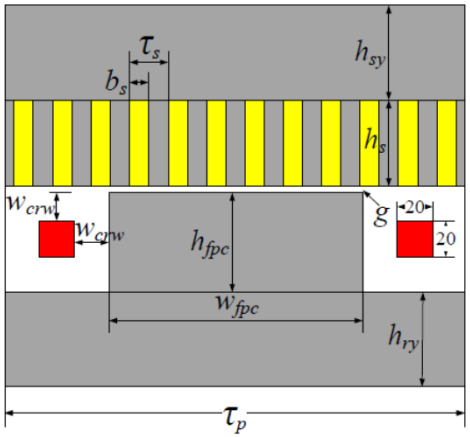
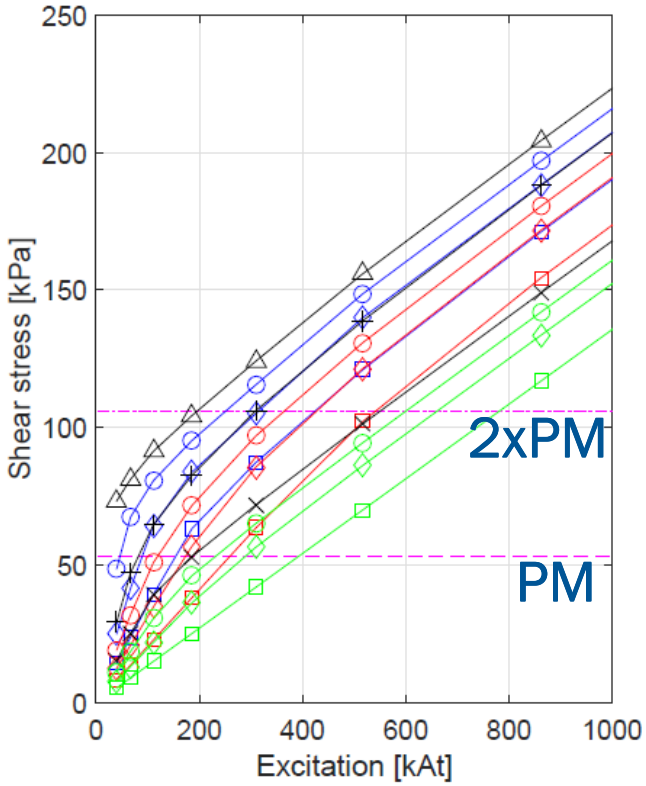
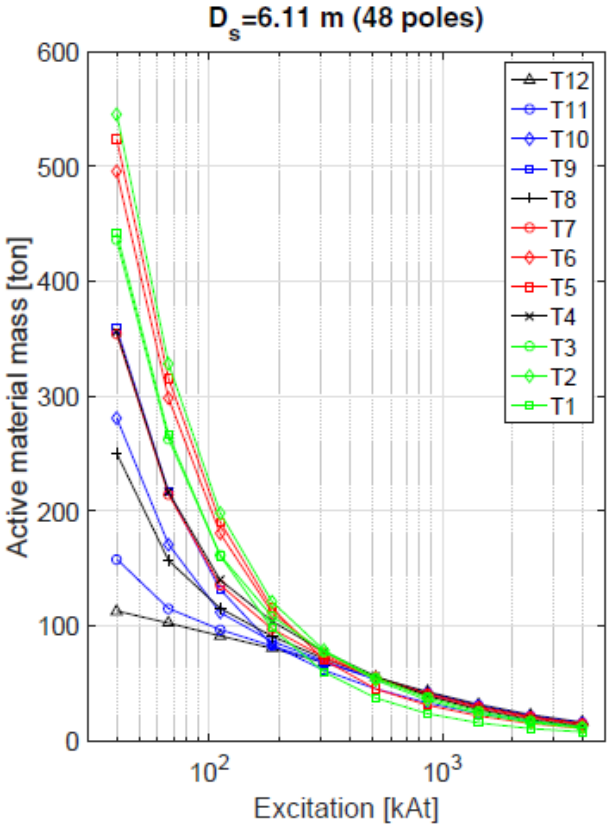
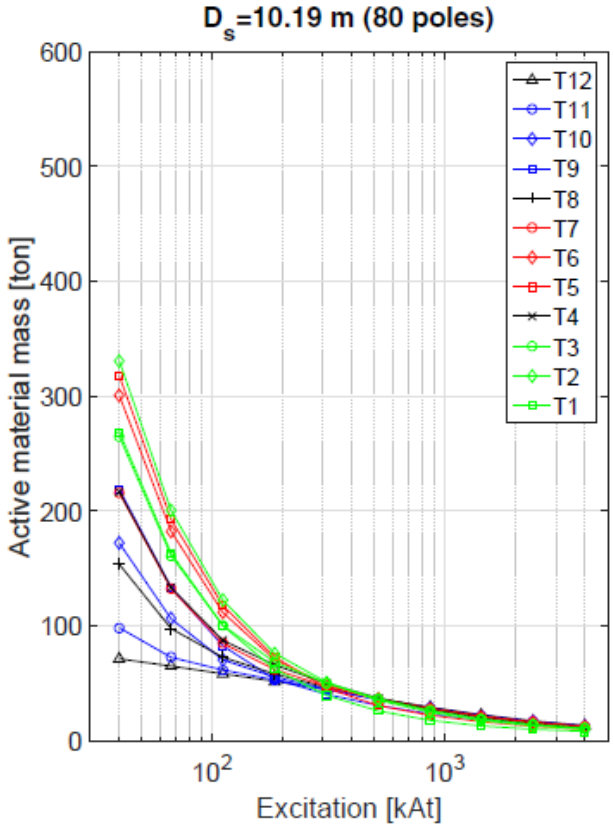
Potential study



- What is the potential if extremely strong superconductors become available?
- Minimum: double shear stress







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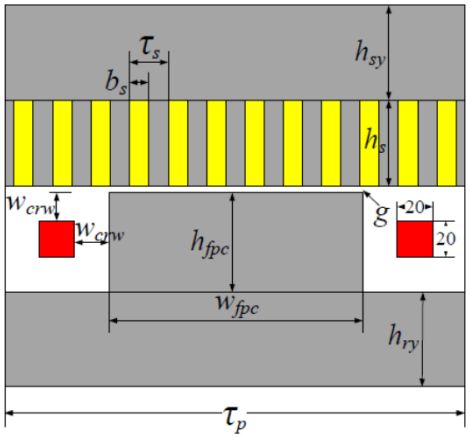
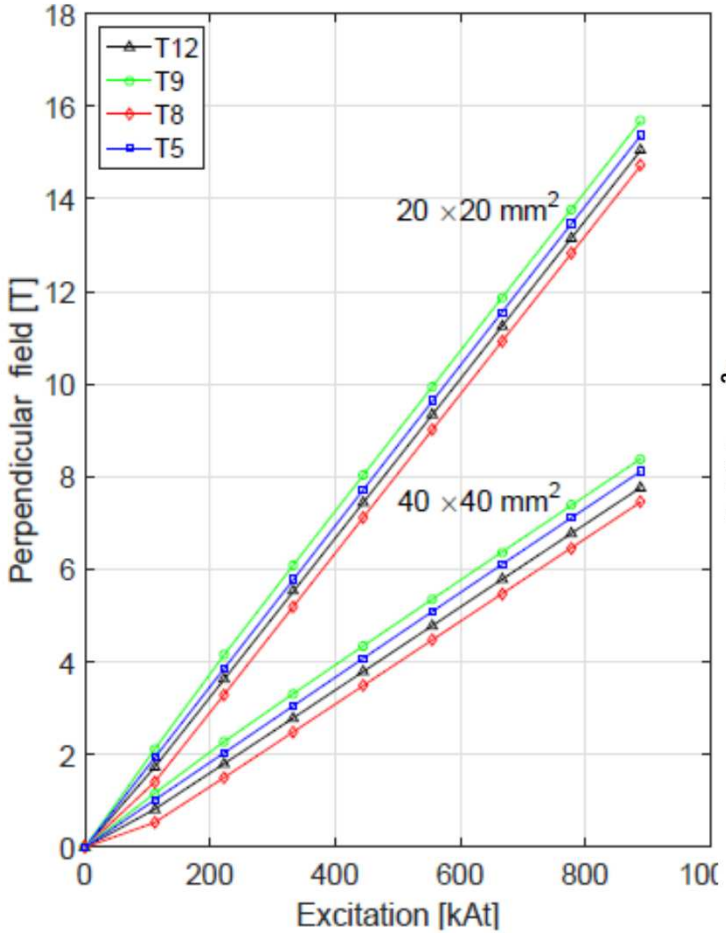
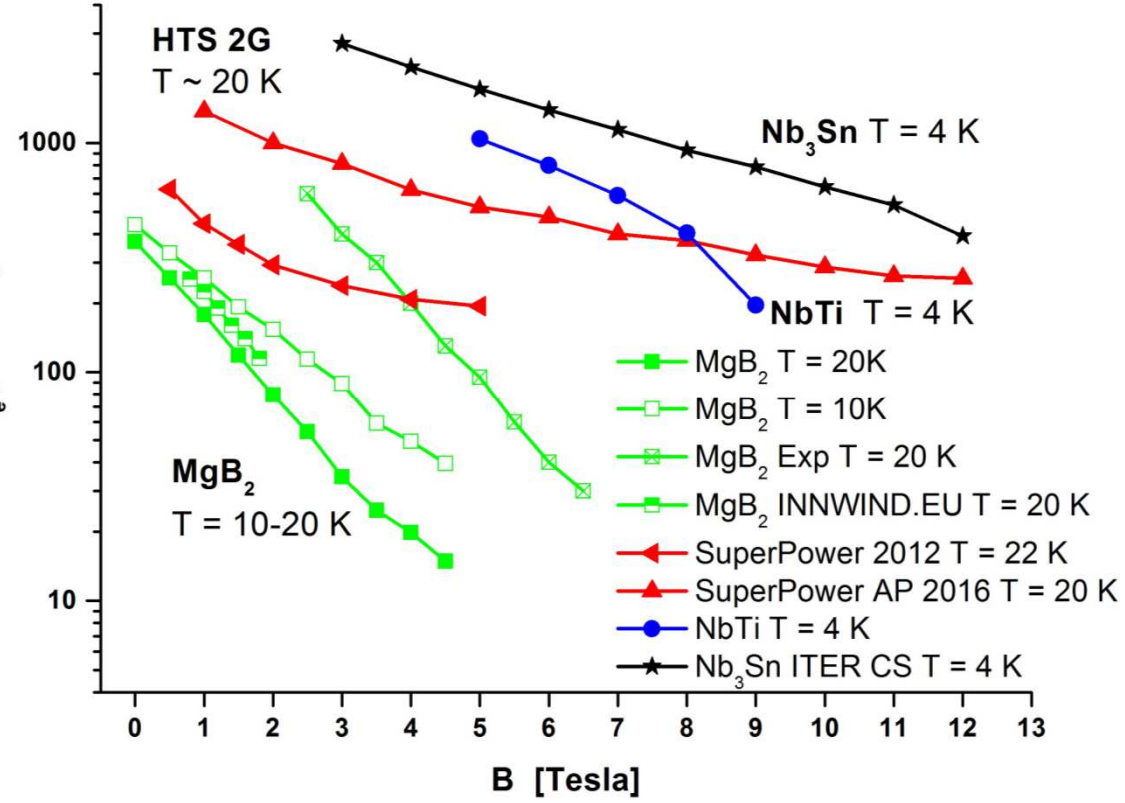
Potential mapped to SC wires







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Conclusions

- SC can be more compact and efficient than PMDD
- Minimum LCoE > iron cored topology
  - Heavier than PMDD and PDD
  - More expensive than PMDD and PDD
- Reasons to consider SC
  - Developments in superconductors (cost, performance)
  - Developments in other technologies (PM)

Contributions

- Henk Polinder, Dong Liu
  - Delft University of Technology (NL)
- Asger B. Abrahamsen (asab@dtu.dk)
  - DTU Wind Energy (DK)
- Niklas Magnuson
  - SINTEF (N)
- Arwyn Thomas, Ziad Azar
  - Siemens Wind Power (UK, DK)
- Gerrit-Jan van Zinderen, Ewoud Stehouwer
  - DNV GL (NL)

- Project website: www.innwind.eu

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