# SR Unlocking Value in End of Life Assets Seminar

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# Nick Sharpe

Director of Communications

Scottish Renewables

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**Kirsty MacArthur**
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MacArthur Green

**Dr Liu Yang**
Senior Lecturer
University of Strathclyde

# Recycling End-of-Life Wind Blade

## *Towards a New Generation of Glass Fibre Products Based on Regenerated Fibres*

**Liu Yang, Kyle Pender**

***Advanced Composites Group***
***Department of Mechanical & Aerospace Engineering***

***University of Strathclyde***
***Glasgow, UK***

# UK Composites – Market Opportunities

UK composites supply chain has the opportunity to grow its current £2.3bn composite product market to £12.bn by 2030. [UK Composites Market Study]

University of Strathclyde Engineering

| | AEROSPACE | DEFENCE | AUTOMOTIVE | RAIL | CONSTRUCTION | MARINE | OIL & GAS | RENEWABLES |
|---|---|---|---|---|---|---|---|---|
| 2030 OPPORTUNITY | UPPER £3,590m 19% LOWER £1,250m | UPPER £1,150m 8% LOWER £910m | UPPER £3,490m 16% LOWER £1,430m | UPPER £160m 7% LOWER £130m | UPPER £1520m 10% LOWER £1240m | UPPER £370m 4% LOWER £320m | UPPER £1,100m 33% LOWER £320m | UPPER £1,100m 4% LOWER £880m |
| 2020 FORECAST | UPPER £1,160m 33% LOWER £1,040m | UPPER £950m 20% LOWER £920m | UPPER £530m 7% LOWER £480m | UPPER £100m 12% LOWER £80m | UPPER £640m 12% LOWER £510m | UPPER £270m 4% LOWER £240m | UPPER £340m 86% LOWER £80m | UPPER £690m 3% LOWER £650m |
| |  |  |  |  |  |  |  |  |
| 2015 BASELINE | £270m | £380m | £380m | £60m | £360m | £220m | £20m | £600m |

# The Composites Conundrum

There is a lost (LCA-impact) opportunity…and a lost (circular economy) opportunity when recycled content and recyclability are missing

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ELV directive 2000/53/EC

EU Landfill Directive 99/31/EC

FRP circular economy study – Stella Job

# Waste Management Hierarchy

## DIRECTIVE 2008/98/EC OF THE EU PARLIAMENT AND THE COUNCIL

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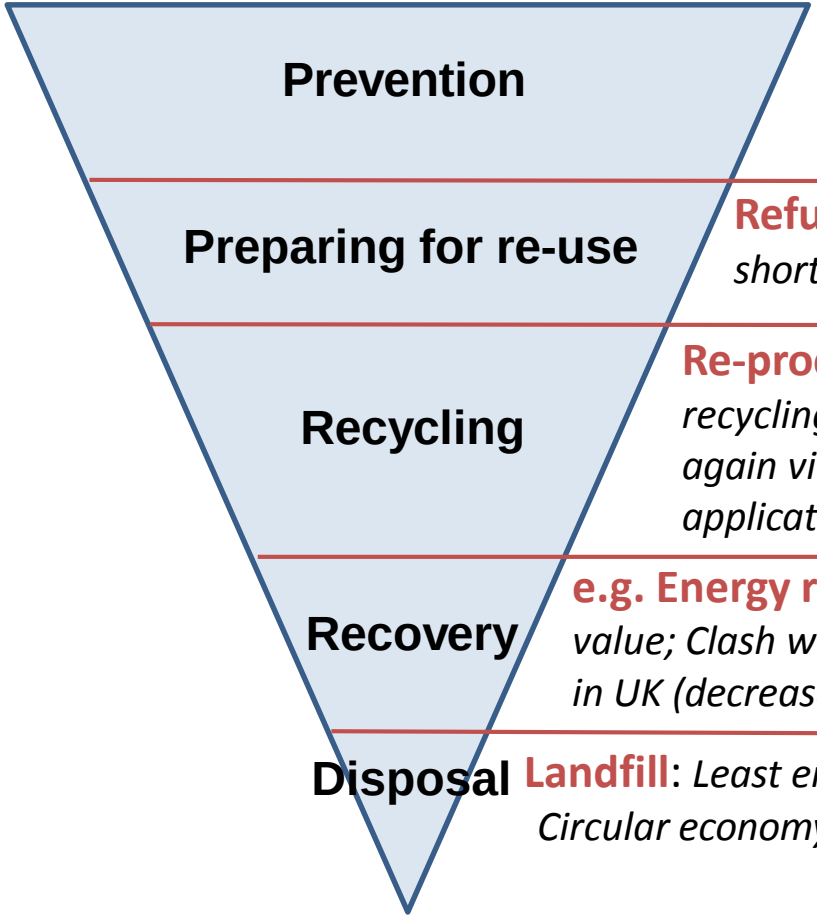



**Life extension**: *Increase return on investments; OEMs share O&M strategies; Operational safety; Opportunity for merging service market*

**Refurbishment**: *Second hand turbines; Technically possible; short lead time and low cost; challenging with large blades*

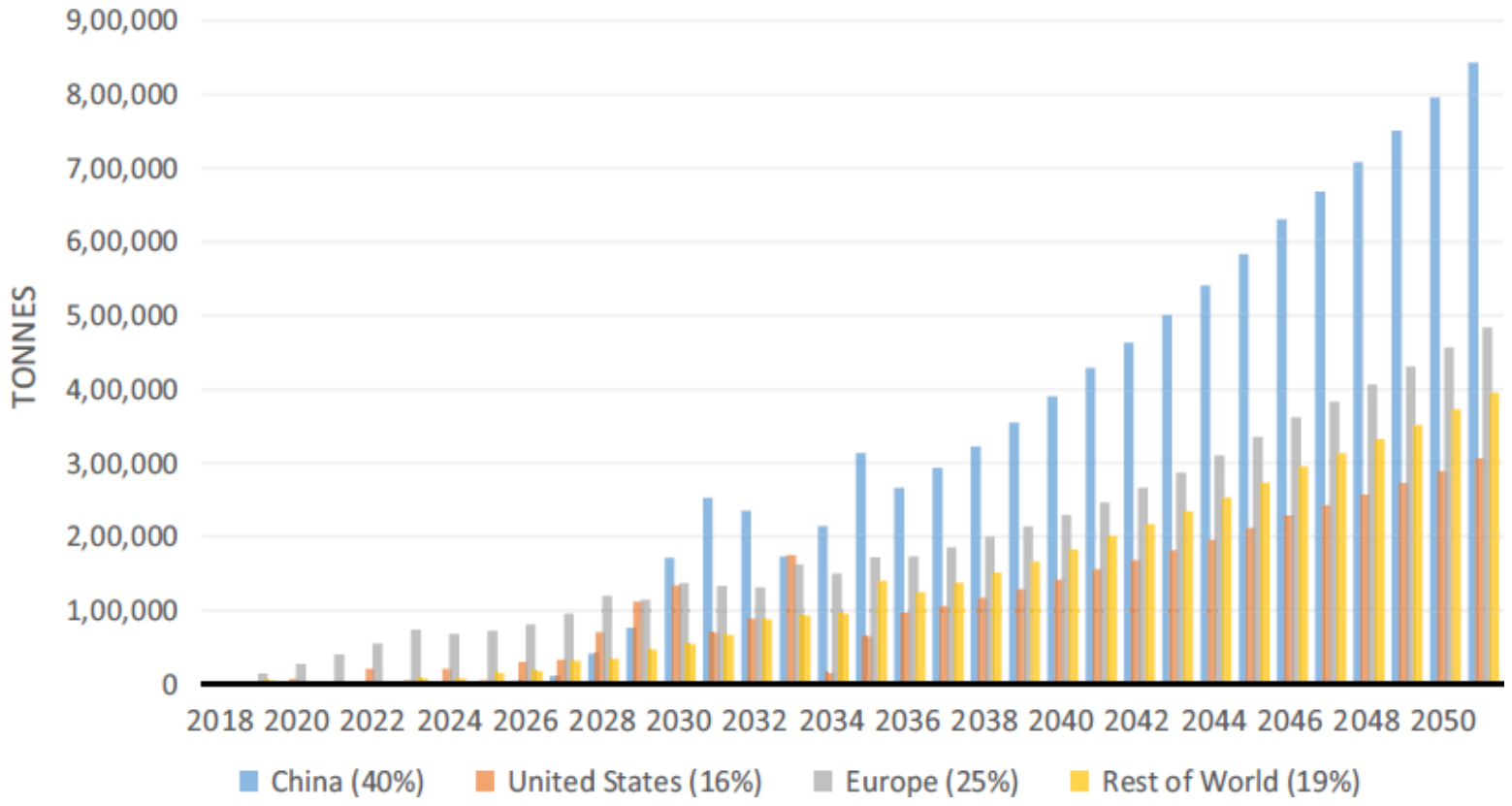
**Re-processing**: *Sustainability of composites industry; Follow recycling hierarchy; Much focused on CRP than GRP; Compete again virgin materials; Supply chain issue; Secondary applications development; Standards and regulations*

**e.g. Energy recovery**: *Incineration (EfW); Potential landfill; Less value; Clash with domestic waste management; EfW capacity grows in UK (decreased waste exports ahead)*

**Landfill**: *Least environmentally friendly; Increasing landfill tax; Circular economy thinking; Future legislative ban in UK*

# Global End-of-Life Blade Materials

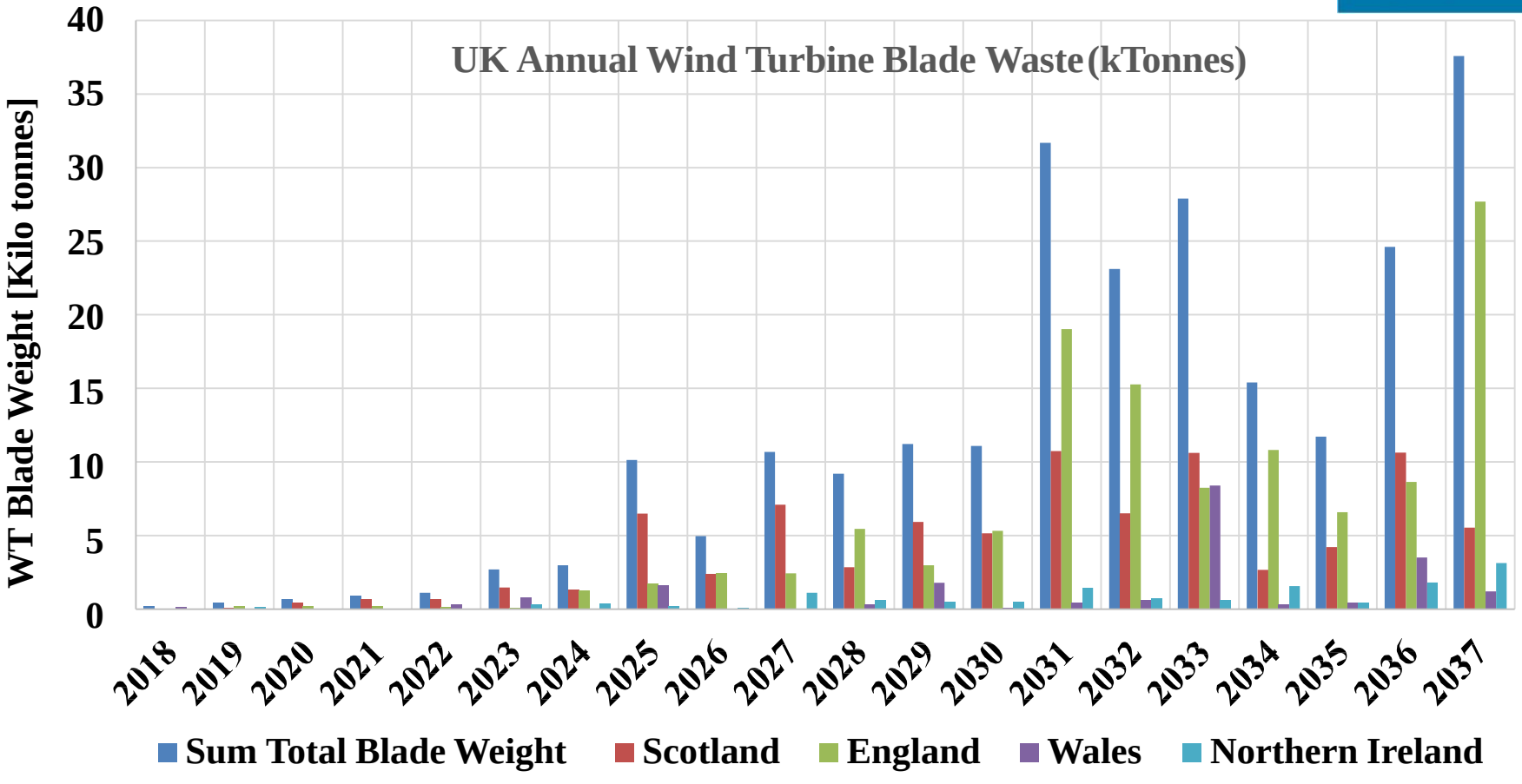
## Europe will face the problem first and ultimately China will have the largest waste inventory




*P Liu, C Barlow Waste Management, 62, 2017*

# UK End-of-Life Blade Materials

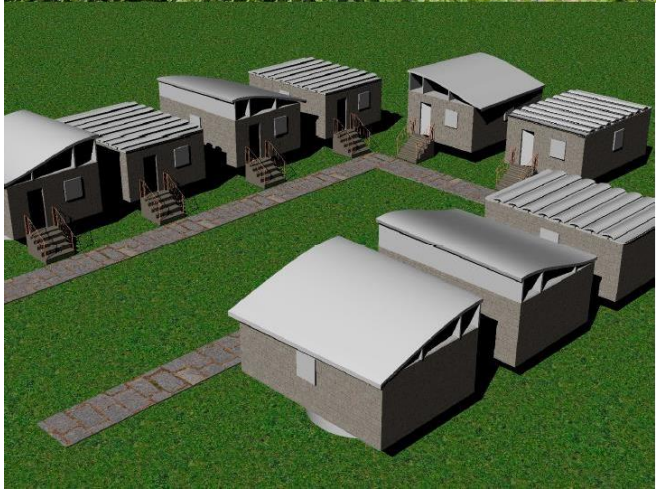
We need to develop towards economically viable EoL solutions now!!




*Plot Curtesy of ZWS*

# EoL Solutions – Reuse structure

| Advantages | Disadvantages |
|---|---|
| Extended material life | Applications limited by structure complexity |
| Potentially little re-processing required | Reliable material source with known dimensions required |
| Costs competitive with proper logistic management | Heavier reprocessing for construction elements |
| | Issue with codes and standards |



**Active companies/projects:**

- SuperUse Studio (Netherland)
- Re-use of decommissioned wind turbine blades (Queen's University Belfast - UK)

# EoL Solutions – Mechanical recycling

| Advantages | Disadvantages |
|---|---|
| Industrially trialled | Low value filler |
| Low energy/cost (0.1-4.8 MJ/kg) | Fibres not clean |
| In-house recycling | Poor bonding as “reinforcement” |
| Fine filler and fibrous fractions | Economically difficult |
| Downsizing equipment available | Hazardous working environment |

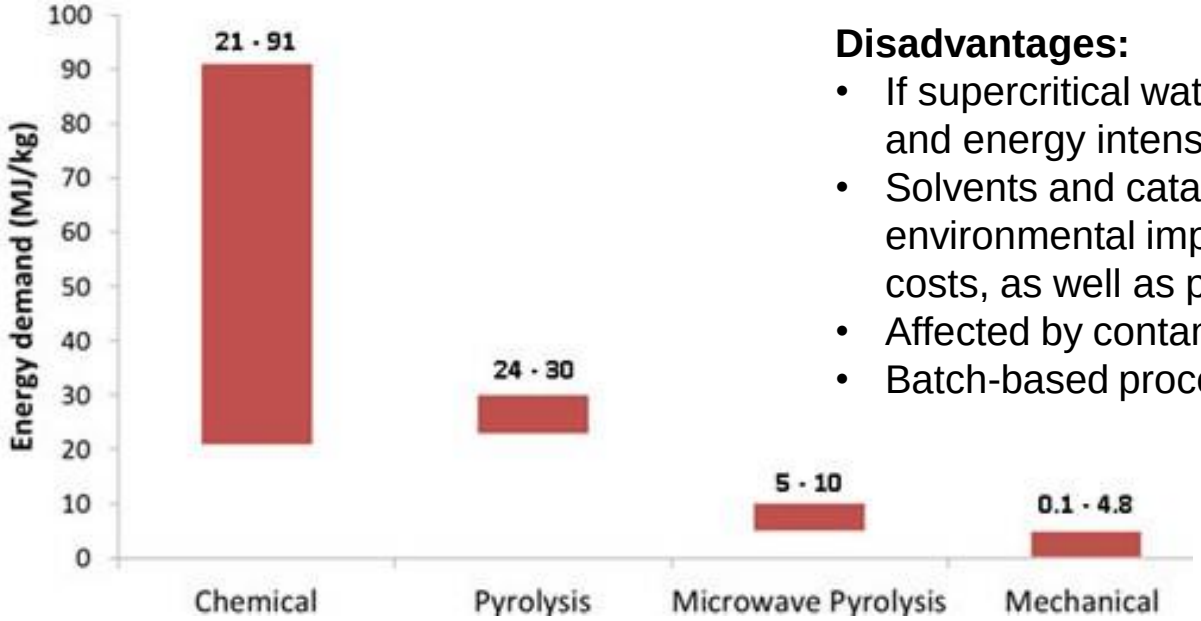
**Active companies/projects:**

- Eco-Wolf (Florida, USA)
- ADM Isobloc (Germany)
- Conenor (Finland)
- Reciclalia (Spain) – a truck-mounted solution for cleanly downsizing large composite structures (e.g. wind blades)

# EoL Solutions – Chemical

**Active companies:**

- Exist for CRP recycling not for GRP




**Advantages:**

- Lower temperatures (<500°C, c.350°C)
- Reclaim resin for chemical feed stock
- cleaner fibres, with no char formation

**Disadvantages:**

- If supercritical water used, reactors are expensive and energy intensive (>374°C and >221 bar)
- Solvents and catalysts have negative environmental impact, with associated disposal costs, as well as potential health risks
- Affected by contamination
- Batch-based process

*https://compositesuk.co.uk/system/files/documents/Recycling%20Report%202016.pdf*

# EoL Solutions – Cement co-processing

## Downstream material turned into new material

- Energy and Raw Material contribution
- Technically proven process with wind blades
- Favourable as to LCA aspects
- Compliant with the European Waste Framework Directive 2008/98/EC

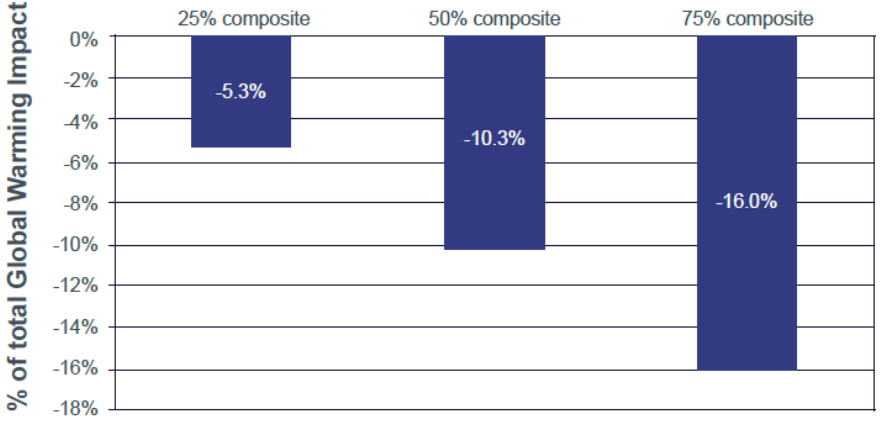



Fig.8 : Reduction of CO2 footprint for this specific clinker manufacturing plant with glass reinforced composite regrind, in comparison to a process without alternative fuels based on coal as fuel.
*Courtesy: Holcim*

**Active companies/projects:**

- Neocomp (Germany)

*Can be arranged by Agecko (UK)*
*Promoted by Composites UK*

# EoL Solutions – Thermal recycling

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**Thermal Processes**

## Pyrolysis

- High temperature (>500°C)
- Energy recovery
- Can't handle foreign parts (e.g. metal inserts)
- Char residual on reclaimed fibres
- Commercial process available for CRP recycling in UK, Germany, USA, and Italy
- Not economically viable for GRP

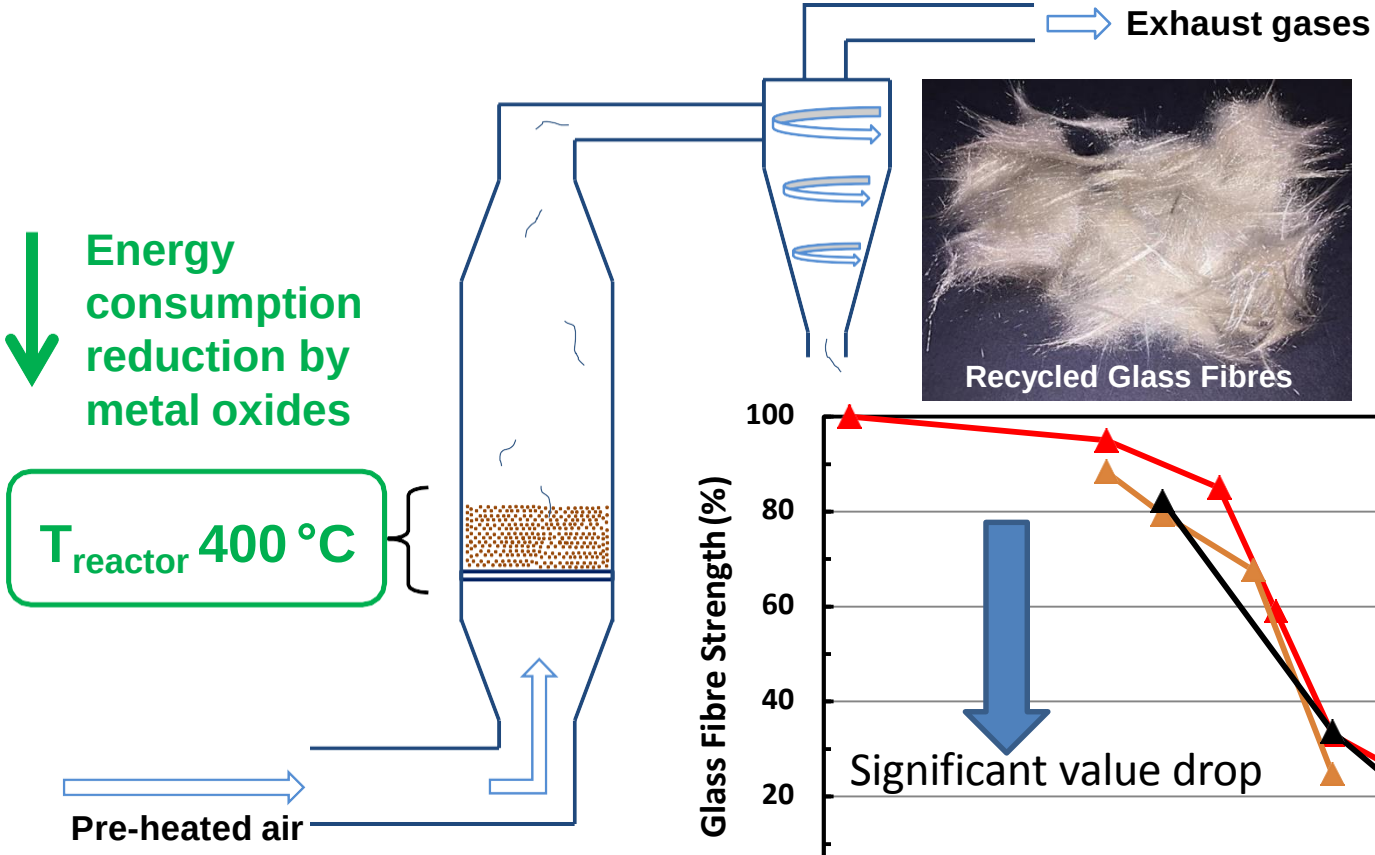
## Fluidised bed (Recycling & Recovery)

University of Strathclyde Glasgow

The University of Nottingham

- Clean fibers no residual
- Energy recovery from resin combustion
- **Contamination tolerant**
- Continuous process
- Not commercialized
- LCA proven with CRP
- **Challenging with GRP due to strength loss**

# EoL Solutions - Fluidised bed process









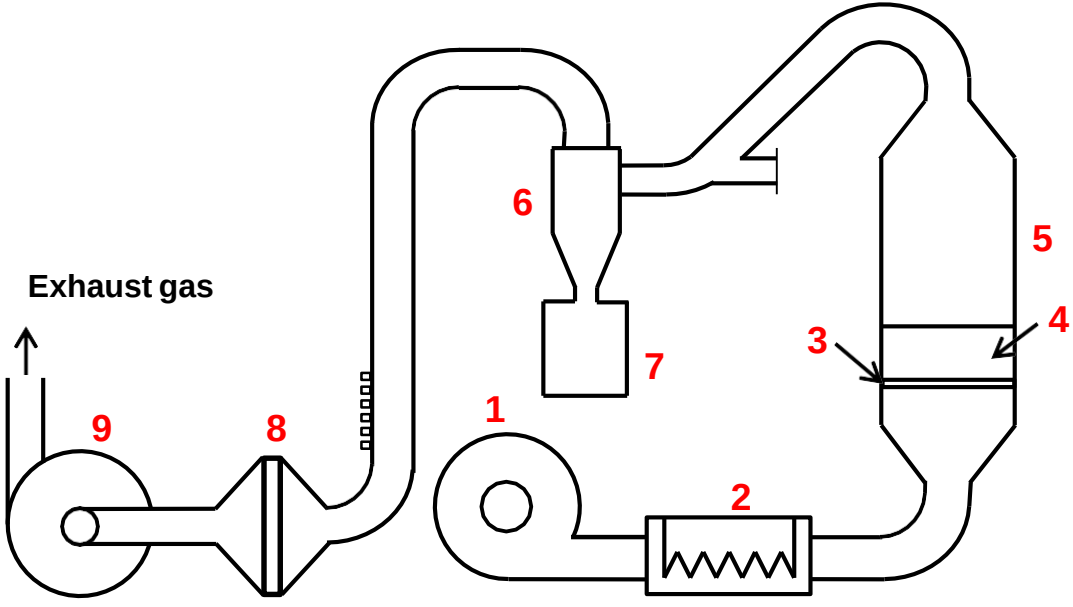

*K Pender, L Yang Composites Part A vol 100, 2017*

# ACG Fluidised Bed Recycling Process

University of Strathclyde Engineering

**The ACG has developed a lab scale catalysed fluidised bed rig which can be used to recycle glass or carbon fibre from waste composite scraps**

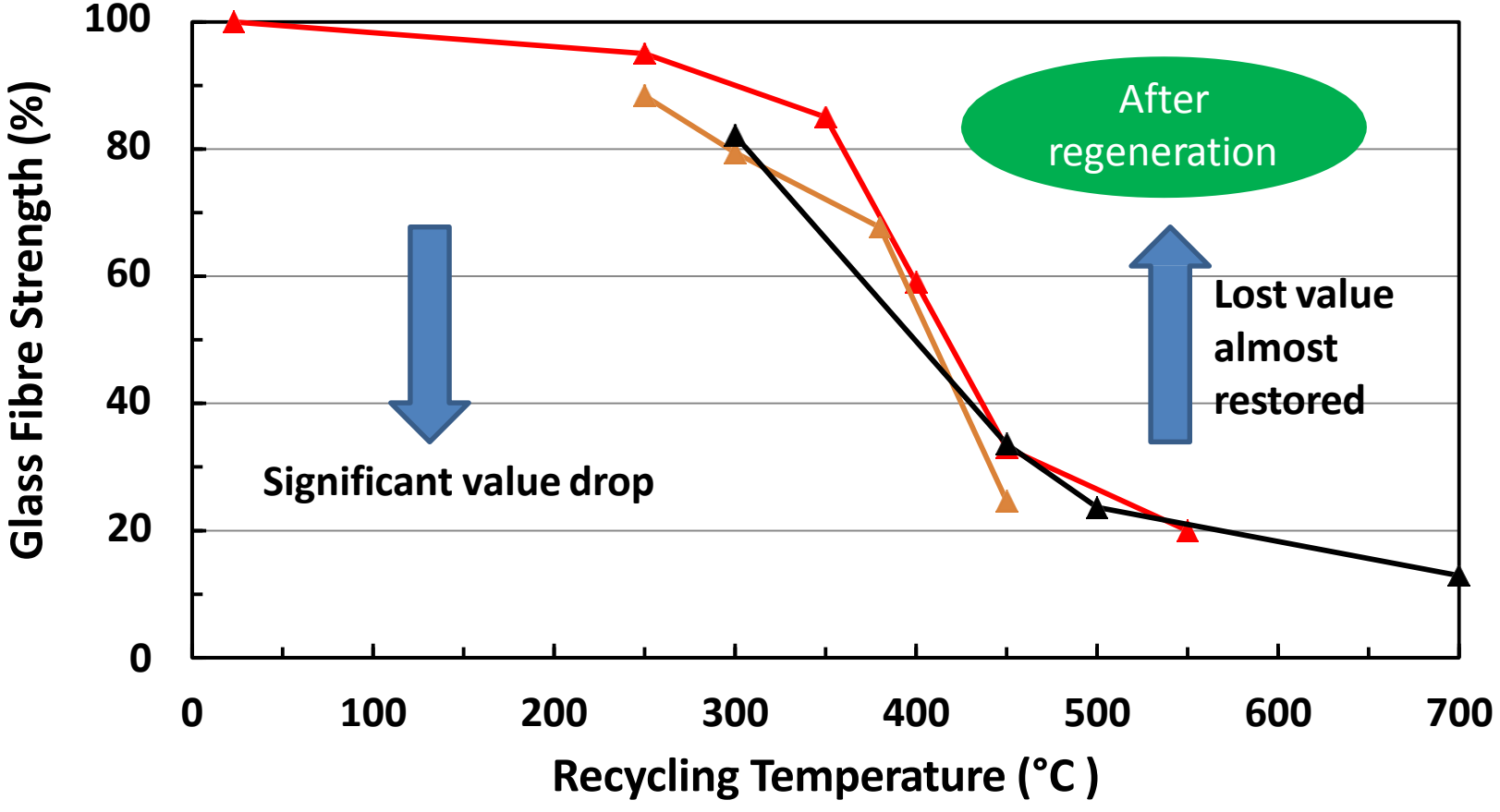
**Throughput estimate: 30t/year**




ACG Lab scale recycling process

# Glass Fibre Strength Regeneration

- We have successfully regenerated strength of recycled glass fibres
- ACG Patent – Glass Fibre Recovery



# Case Study - Recycling Wind Blade Scrap

University of Strathclyde Engineering

Wind blade Scrap - ORE

Downsizing

Downsized composite scrap

Recycling after fluidised bed

Recycled fibres

Post fibre treatments using ACG patented technology

"Regenerated" fibres

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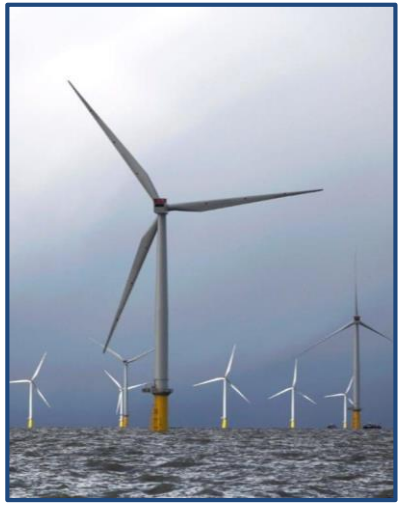
Route to Impact Scheme

# GRP Wind Blade Recycling & Reuse

Small scale wind turbine blade selected as composite component to manufacture with glass fibres recycled from ORE wind blade scrap



**“Large scale”/high performance end of life turbine blade**

**“Regenerated” fibres**

**Fluidised bed recycled glass fibres**

**Reuse fibres in “small scale”/less demanding turbine applications**

# GRP Wind Blade Recycling & Reuse

University of Strathclyde Engineering

**Component based on a Kingspan KW3, 3kW wind turbine blade**



**Pattern used to prepare mould –part supplied by Kingspan Wind in Scotland**

# GRP Wind Blade Recycling & Reuse

**Our initial bending test showed recycled blade is stiffer than the control blade without adding any more weight**

University of Strathclyde Engineering

Blade based on fibres recycled from wind blade scape

Original blade supplied by Kingspan Wind

Original wind blade
Weight = 1.93 kg

Wind blade prototype based on $R^2$ glass fibres
Weight = 1.82 kg

# Summary & Outlook

- Composites industry is pushing composites recycling
- Much focused on CRP recycling and little success in GRP recycling
- Commercial GRP (EoL wind blades) recycling only exists in Germany
- The ACG is developing **cost-effective** solutions to recycling GRP
- Recent case study of recycling EoL wind blades showed very promising results
- The ACG is seeking out industrial partners/HEIs to further develop GRP recycling

Formation and funding of **consortium of vested interests**

Defined input material stream, **EoL GRP (e.g. wind)**

Defined recycling process for fibre input to **Regeneration Technology**

Defined target **end-use applications** (e.g. automotive, construction, wind, marine…)

University of Strathclyde Engineering

# Thank You…

ACG
Advanced Composites Group

University of
Strathclyde
Glasgow

**James Barry**

Chief Executive

Renewable Parts

# Scottish Renewables circular economy conference

## 13th November 2018

Renewable Parts Ltd
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*Developing a greener Aftermarket*

# Today's talking points …

1. Observations from an adjacent industry
2. Demands of the life cycle
3. Three areas where we must innovate
4. Benefits from on-shoring capability
5. A look to the future

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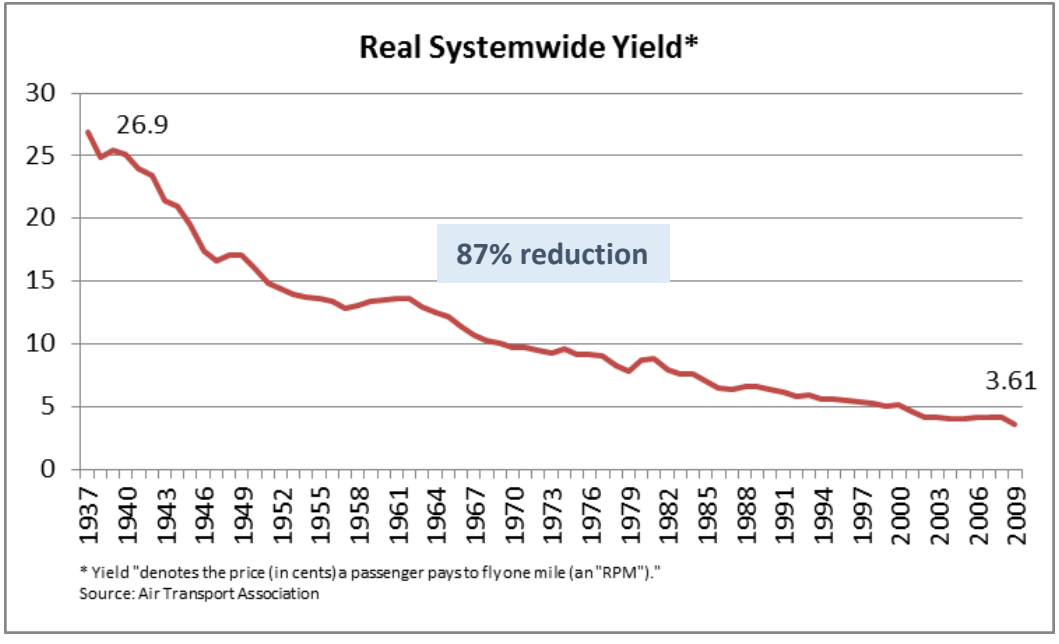
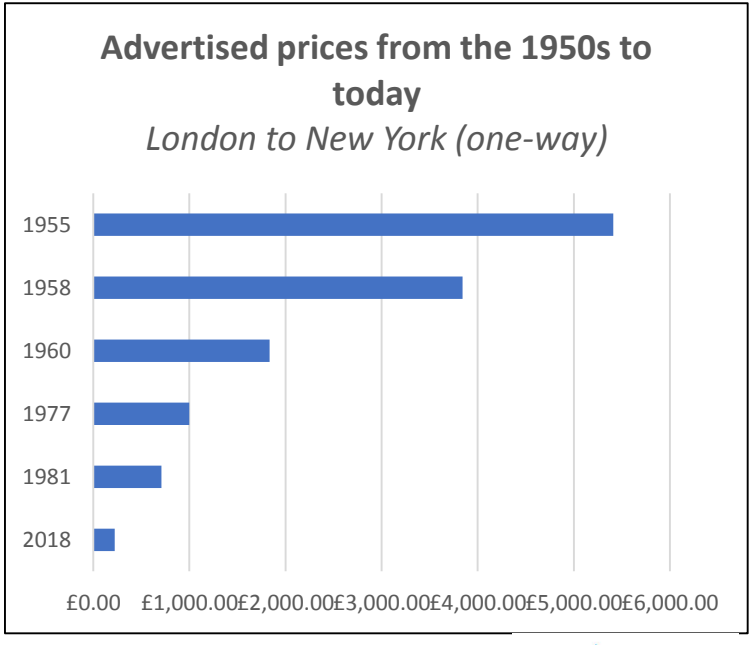
# The realities of a mature sector

- Aerospace, more than any other sector, has used innovation to reduce cost




***Greater innovation meeting customer expectation***

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# A glimpse at Aerospace

- The Wind sector must utilise the UK's extensive expertise in Refurbishment Engineering, Life Cycle Cost modelling and Condition Monitoring

- The similarities between the Wind and Aerospace sectors are striking, we do not need to re-invent the wheel

**Refurbishment Engineering**

**Inventory Management - JiT**

**Condition Monitoring**

***Learning from others will accelerate our progress***

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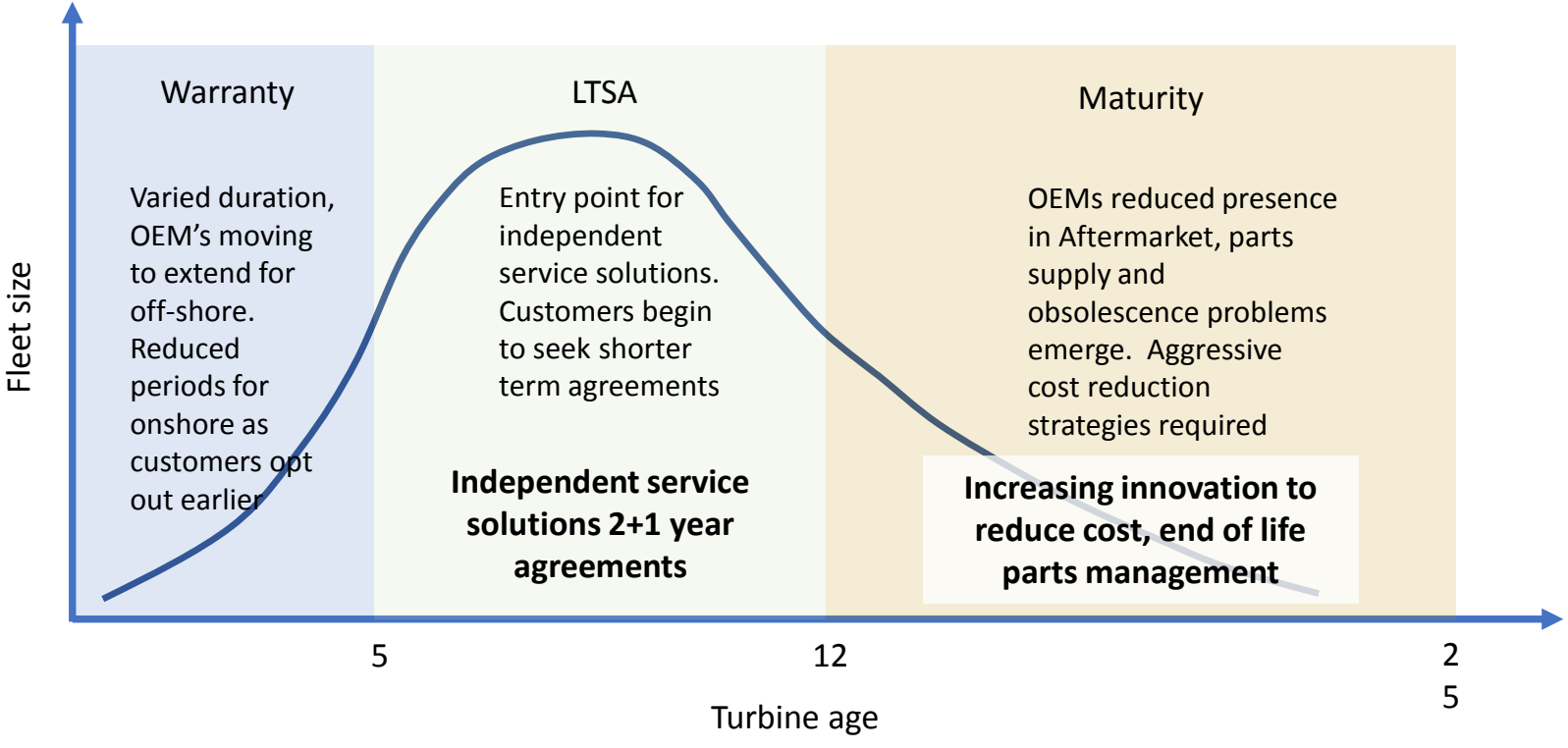
# Challenges through the lifecycle

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# Targets for innovation

- Our industry must become bolder and more innovative to realise system efficiencies. Renewable Parts' priorities are:

1. Refurbishment Engineering
2. Data analytics to optimise inventory holding
3. Parts wear out prognostics Condition Monitoring

**Cost of manufacture versus cost of refurbishment**

**Data fidelity and analysis remains elementary**

**Aerospace has proven 100% predictability on parts failure**

***Success through collaboration***

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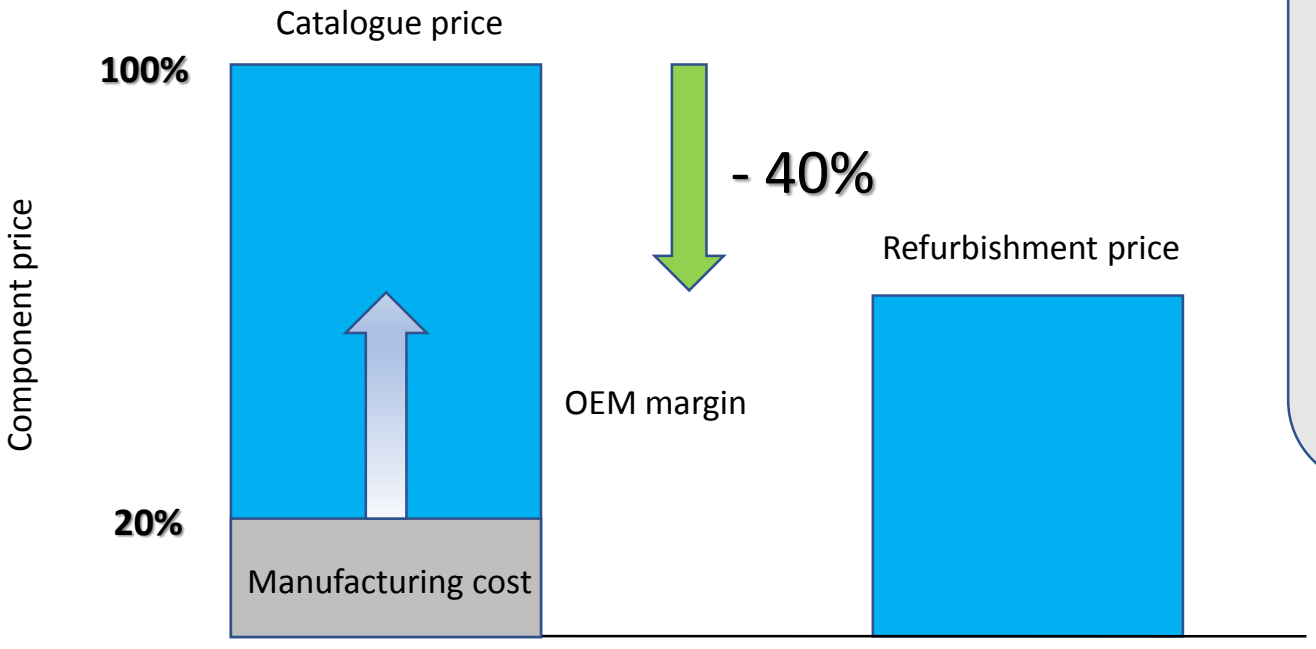
# The economics of refurbishment




**OEM considerations:**

1. Unit costs rise as OE production ends
2. Low volume management becomes problematic
3. Cost of ownership pressures mount
4. Obsolescence risks increase
5. OEM need to employ Make/Buy decisions

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# Refurbishment Engineering

- Refurbishment offers enormous potential to strengthen the supply chain, reduce waste and improve cost and lead-time
- Developing local skills and capabilities is key – we have the resource, expertise but do we have the ambition and are we willing to change?
- We are a Green energy source but are we following a Green Aftermarket agenda?

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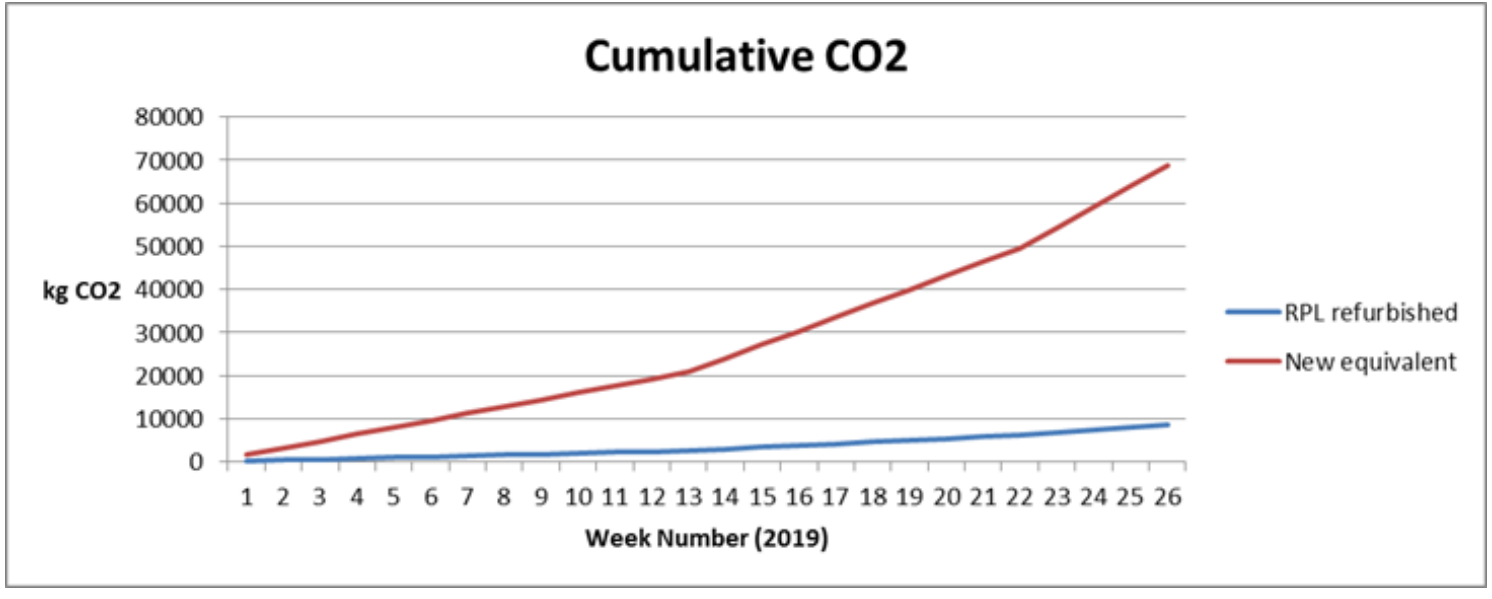
# Reducing our environmental impact

Assumptions:

**50kg $CO_2$ / to refurbish**
**400kg $CO_2$ to fabricate new**

- Forecast for carbon footprint for 2019H2 based on planned yaw gear refurbished programme




## 85% reduction in carbon footprint

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# Reducing our cost and carbon footprint

Assumptions:
1000 miles trip to OEM
9 mile/ gallon
2.62kg $CO_2$ / litre

**10kg $CO_2$ / yaw gear**
**400kg $CO_2$ to fabricate new**

- For illustration we take a Siemens 2.3MW yaw system:
  - Turbine has 8 yaw gears with an average life of 5 years
  - Each yaw gear weights ~250kg and costs ~£3,000 new

- Yaw gear refurbishment is seldom utilised despite offering cost and environmental benefits


**Carbon equivalent to a flying a 747 for 1 minute**

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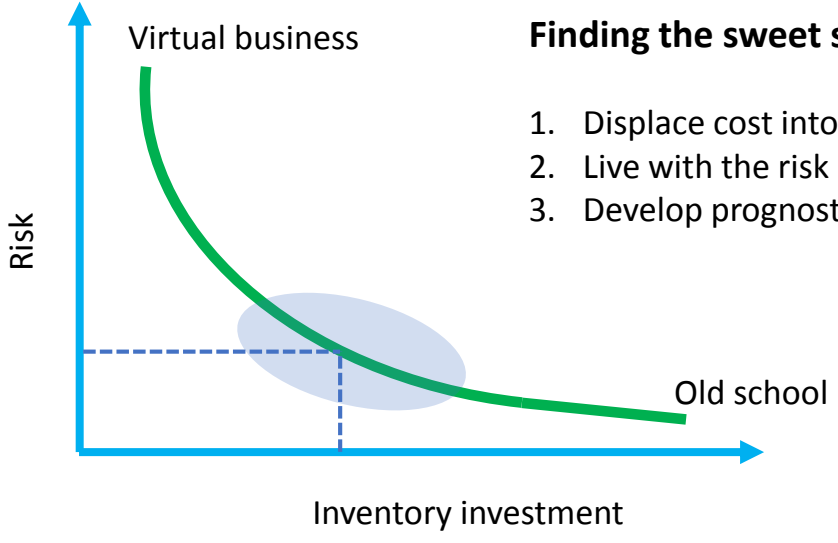
# Inventory – striking the right balance

- The depth and understanding of demand data is key to optimising inventory strategies

- Turbine availability levels come at a price, but how are businesses striking the optimum balance?




**Finding the sweet spot is tricky**

1. Displace cost into supply chain
2. Live with the risk and pay elevated pricing
3. Develop prognostic capability

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# Inventory optimisation, insights from a multi MW site

- Optimising inventory is a complex, dynamic challenge. It is a data hungry and requires advanced analytical techniques
- Our experience from data mining a large MW site demonstrates significant opportunities for cost reduction

**25,** the fleet size

**250,** the number of critical line items

**£200k,** the inventory holding

**10,** the number of parts related lost days p.a.

**0.1%** availability lost due to parts

**£3,500,** Inventory cost per MW

**40%,** the potential reduction in inventory holding

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# Condition monitoring

- CM in the Wind industry has advanced dramatically in recent years in both cost and its effectiveness, however we remain significantly behind adjacent sectors
- The next generation of CM will provide full prognostic parts wear out capability that can be integrated into procurement systems

| | |
|---|---|
| **Early CM systems** | **Expensive, limited effectiveness, failure to identify problems and some spurious non-existent problems** |
| **Current best CM systems** | **Inexpensive lease per month, >90% detection effectiveness and accuracy, user notification on action requirements** |
| **Advanced CM systems H1 2019** | **Detection and high probability of parts required integrated into procurement / sourcing systems** |

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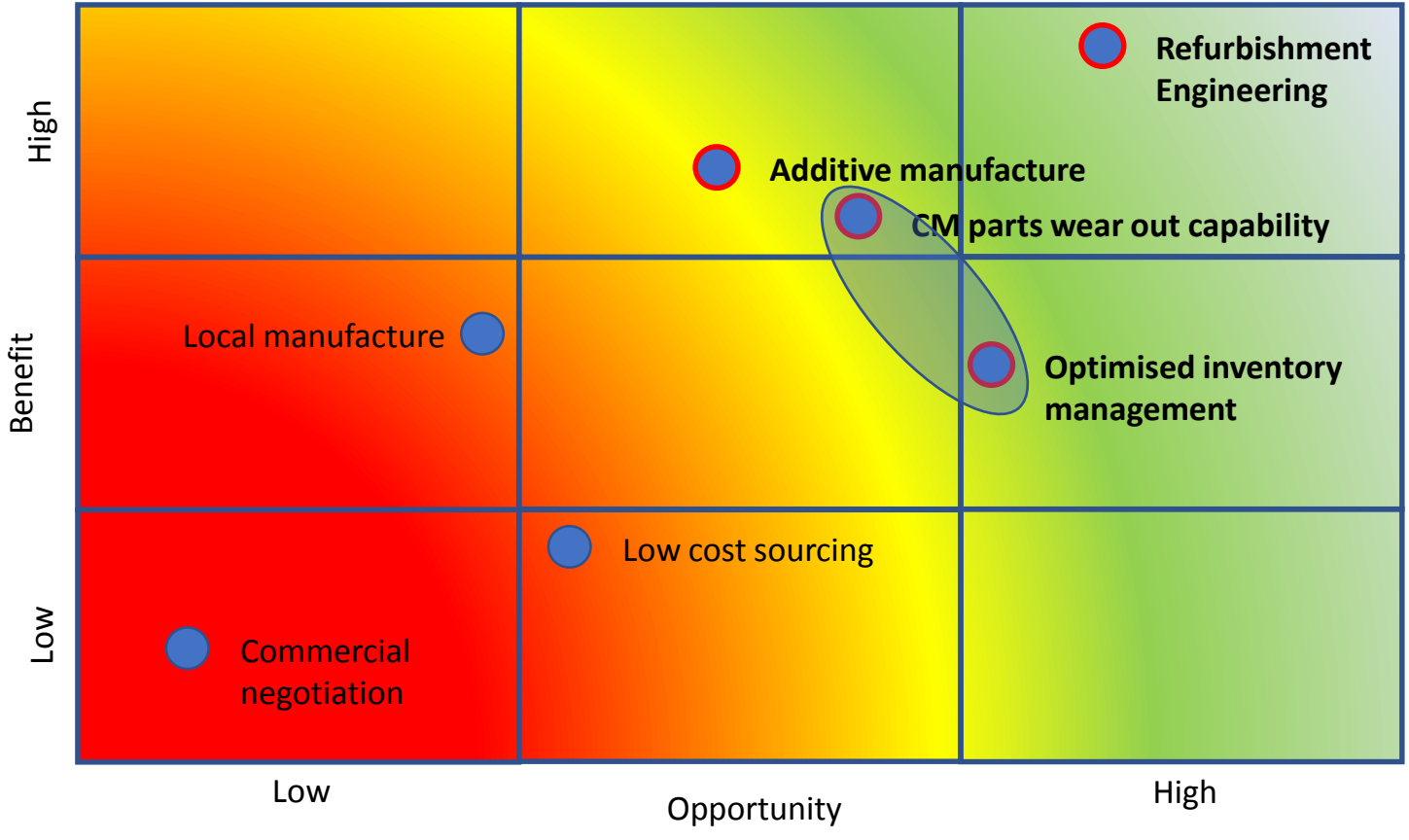
# Where might our best interests lie?

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# Conclusions

- Our industry is advancing rapidly but we can learn much from adjacent sectors
- There are significant opportunities to increase efficiency and reduce cost – realising them will require us to think and behave differently
- We may be a green energy source but cannot extend that claim to our Aftermarket – we all have a responsibility to do more!
- Developing more UK based capability lies in all our interests but will require investment and a long term perspective

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**Kirsty MacArthur**

Director, MacArthur Green

**Dr Liu Yang**

Senior Lecturer, University of Strathclyde

**James Barry**

Chief Executive, Renewable Parts

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**Scott Bryant**
Sector Manager, Energy
Infrastructure – Circular Economy
Zero Waste Scotland

# Circular Economy Opportunities in the Scottish Renewables Sector

Scott Bryant
Sector Manager, Energy Infrastructure (Circular Economy)

zerowastescotland.org.uk
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# Why Zero Waste Scotland?

## Aim

Our goal is to help Scotland realise the economic, environmental and social benefits of making best use of the world's limited natural resources.

We're funded to support delivery of the Scottish Government's circular economy strategy, *Making Things Last*. We receive additional funding to support the EU's 2020 growth strategy.

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# From This

Source: Save Your Energy UK, 2018

Source: ThinkAboutNow, 2018

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# To This

Source: InstallerOnline, 2018

Source: Futuristic News, 2018

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# Or More Likely This

Source: Bonfiglioli, 2018

Source: Reneweconomy, 2018


Source: Unique Heating Supplies UK, 2018

Source: Civil Engineers Forum, 2018

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# Relevance to the Energy Sector?

**Share of renewable energy in Scotland**

| | Today | 2030? |
|---|---|---|
| **All Energy** | **15.2%** | **50%** |
| Electricity | 53.8% | 100% |
| Heat | 5.3% | 50% |
| Transport | 3.1% | 50% |

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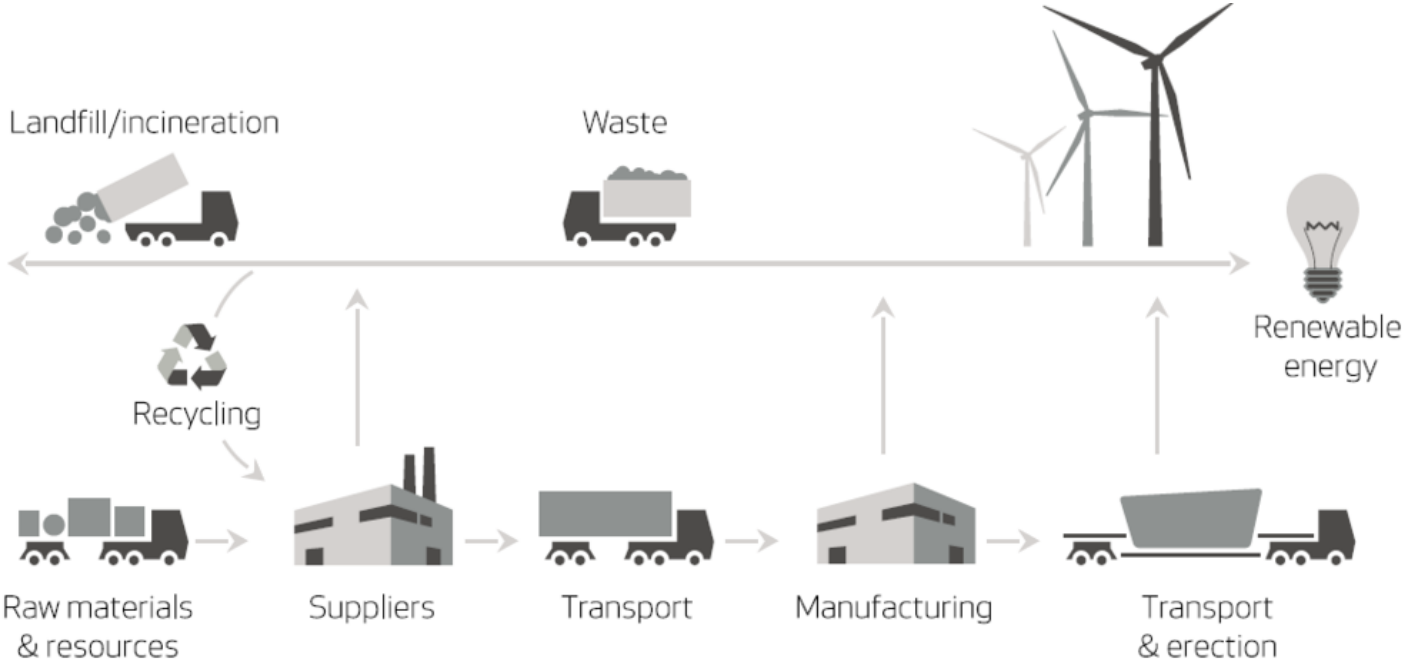
# So where does CE come in?




**Source:** Saskwind, 2016

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# So where does CE come in?

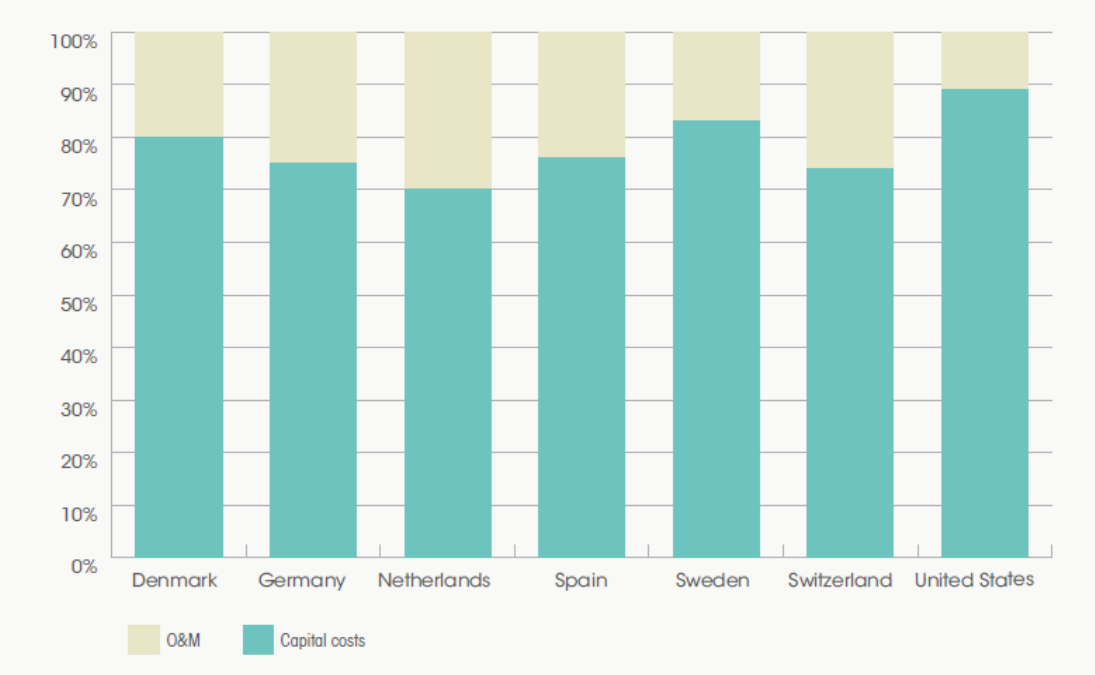


FIGURE 6.3: SHARE OF O&M IN THE TOTAL LCOE OF WIND POWER IN SEVEN COUNTRIES

Source: IRENA, 2017

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# So where does CE come in?

## General energy examples

- Reuse (with remanufacturing) for same purpose
- Repurposing of assets or material streams
- Better design, usage, monitoring, maintenance and component remanufacture (w/ retained ownership, “servitisation”)

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# So where does CE come in?

## Wind turbine component remanufacture

- Fraction of the cost of new components
- Lets older sites operate longer
- Partially avoids OEM lock-in

Source: Bonfiglioli, 2018

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# So where does CE come in?

## Retained ownership & “heat as a service”

- Allows better use of assets
- Saves end-customers money
- Allows entrance of higher-CAPEX low-carbon solutions

Source: NIBE, 2018

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# So where does CE come in?

## National Grid's Material Reuse

- 100% reuse/recycling by 2020
- T&D cabling re-processing
- Old cable material to new cables
- **An example for turbine blades?**

Source: Wall Street Journal, 2018

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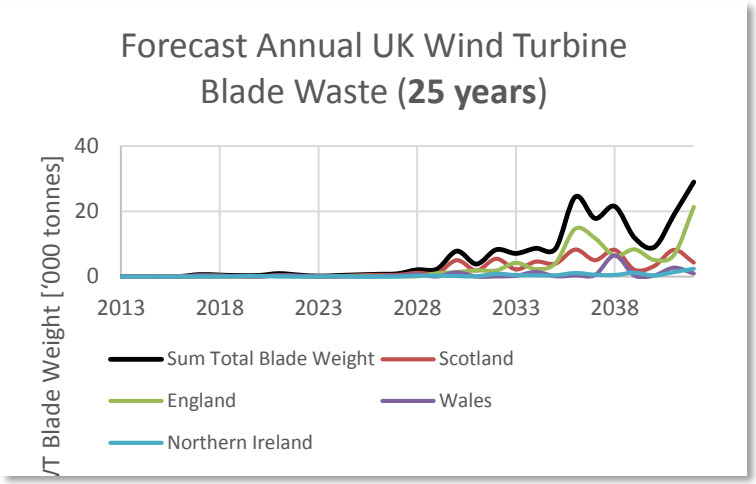
# So where does CE come in?

## End-of-life routes for blades

- Potentially major PR and CSR drivers for wind farm owners & utilities
- **Process need only compete with the cost of landfilling**
- Potential pressure for similar landfill ban as in Germany
- Solution for the renewables sector could drive down costs for a composite-industry-wide recycling solution




**Sources:** Variable Pitch, 2018; BEIS, 2018; RenewableUK, 2018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# Can we use CE opportunities to drive down the cost of renewables?

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# Support for new opportunities

## Circular Economy Investment Fund

- An **£18 million fund** for SMEs & SME-led consortia available until the end of 2019

- Per project, **£50,000 to £1,000,000** for transformational projects; commercialisation/trial CE projects

- Ultimately looking to **bridge the gap between feasibility and market entrance** via **commercial scale demonstrators and trial projects**

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# Support for new opportunities

## Circular Economy Business Support Service

- Up to **30 days free business development support** for SMEs & SME-led consortia for Circular Economy projects

- **Focusing on** technical & commercial viability, route-to-market, market analysis etc.

- Ultimate aim is to move **circular projects** further towards commercialisation

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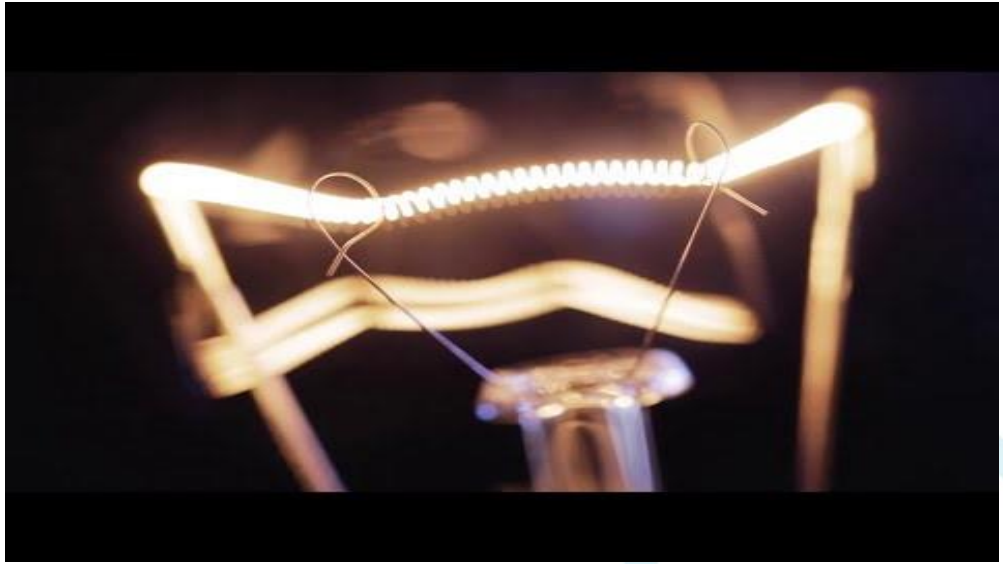
# Wider industry is already engaged with the circular economy, can renewables?



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# Furthering Circular Economy Opportunities in Scotland

November 2018

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*Where there's muck there's brass*

*dirt bodds luck*



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## Hot Topics:

1. Waste Heat
2. Second life batteries (transport to energy storage)
3. Waste heat
4. Reuse of materials
5. Waste heat
6. Waste $CO_2$ and waste $O_2$ as feedstocks
7. Waste heat
8. Reuse of components
9. Waste heat

# Two Groupings….

## Value from Current Waste Products

| Challenge | Opportunity |
|---|---|
| New business models | Job Opportunities |
| Co-location | Special Economic Zones |
| Current Business Practices | Market Flexibility |

Economics

## Material / Component Second Life

| Challenge | Opportunity |
|---|---|
| Manufacturer risk | supply chain strengthening |
| Product risk - “second hand” | Cheaper Access to Materials |
| Finance Risk | ? |
| Insurance Risk | New Marketing Offering |

Risk



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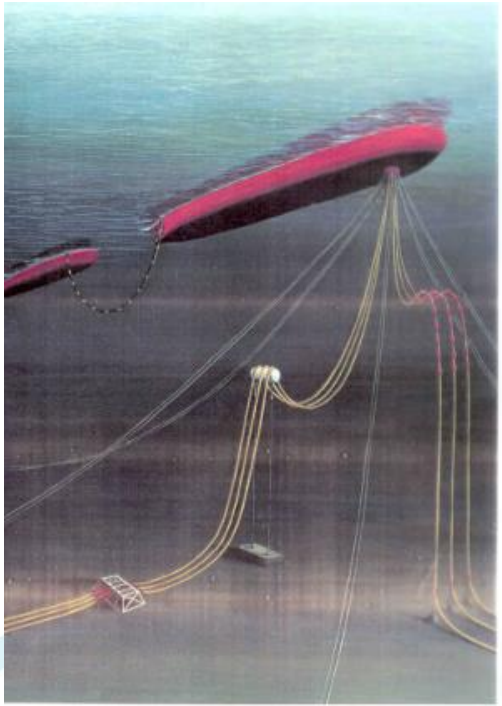
- **Business Support Plan**
  - » Initial stakeholder engagement
  - » Targeted operator survey
    - Survey monkey
    - 25-30 operators/service providers
    - 5 responses (approx. 20% response rate)
- **Why?**
  - » Oil Mac committed to driving reuse throughout the whole industry
  - » Focused on understanding reasons for operator decisions in decommissioning
  - » Oil Mac reuse business model is based on a targeted, selective, high-value equipment approach
- **Next steps**
  - » Follow up with operators who completed survey transparently
  - » Engage with their own operator networks to discuss survey results and behaviours around re-use
  - » Ongoing liaison with Zero Waste Scotland regarding further sector-wide engagement


- **Business Support Plan**
  - » Market analysis to identify available supply
  - » Business canvas
    - Identify key actions
    - Address proposition gaps
    - Sources for further funding

- **Why?**
  - » ReFlex encourage the reuse of subsea materials including flexible pipes, umbilicals and subsea furniture
  - » This reuse could significantly reduce the waste of raw materials and has a cost saving
  - » ReFlex offer repair and testing services to give buyers confidence in product's reliability and effectiveness

- **Next steps**
  - » Seek co-operation with key partners
  - » Meet with support bodies
  - » Develop industry engagement strategy



# And to Scotland…

- Innovation in heat storage and transfer
- Oil and gas sector
- Creating more resilient supply chains
- High tech – blockchain
- Finance sector
- Community innovation
- Agriculture

- Space industry!



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# Discussion Areas / Observations

- Lack of interaction/communication across the supply chain;
- Perceived liability and damage to reputation from use of second/third-hand equipment is too great a risk;
- Incomplete / inaccessible audit trails on usage, certification and warranty
- Disconnect between operator aspiration and observed behaviours
- Equipment degradation and high refurbishment costs
- Genuine appetite to explore innovation within the industry amongst majority of stakeholders:
  - SMEs
  - Oil and Gas Regulators (BEIS, OGA, SEPA)
  - Oil and Gas Industry and Innovation Bodies (OGUK, OGIC, OGTC, DNS)
  - Waste management contractors & Asset Re-sellers
- Opportunity (and need) for collaborative sector-wide communications around economic benefits of reuse
- Need for ‘top down’ push of reuse, to help drive ‘bottom up’ technology/innovation from the supply chain

# Talk to Us!

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November 14, 2018

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# SR Unlocking Value in End of Life Assets Seminar

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