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Landfilling. The Never-Ending Story of Change Management

Robert G Gregory



Scope of the Presentation

- We have had waste management activities since the dawn of humanity
- It took a long time to formalise “Landfilling” of waste
- In 1986 the UK published ***Waste Management Paper 26. Landfilling Wastes***
  - It was intended to improve landfill operations by encouraging new landfills to have engineered basal liners and clay caps to reduce leachate generation
  - Also in 1986 a house was blown up by landfill gas migration from a recently capped unlined landfill
- This keynote address looks at the way we have adapted our operations over the past 40 years, and how we have knee-jerk responded to the way we manage landfill through changing policies
- Like it or not, landfill will always be needed

HISTORIC PRACTICES AND THE EARLY CIRCULAR ECONOMY

Historic images: street sweepers and rubbish tips







- We've always been proud to keep our streets clean
- But we have not always been so careful with waste disposal – out of sight, out of mind
- Some UK landfills have been operational for over 100 years
- Waste management has changed significantly in that time

Historic Practices: first example of circular economy

- When we had open coal fires, much of our rubbish was ash dust – which of course went into the dustbin!
  - Ash was recycled as a soil additive
  - ‘Rag and Bone’ men retrieved metal, rags and bones
- We used to set fire to our rubbish tips at the end of every day’s tipping
- This had two beneficial results
  - It reduced the impact of rodents and flies
  - It increased voidspace
- Burning of landfill waste was stopped with the Clean Air Act in 1956
- Into the 1960s we got more affluent, and made more degradable waste, which went to landfill…



England Pre-Landfill Directive

- In England there have been 21,453 known landfill sites in use since 1900
- Today there are there 1,841 landfills which have a permit. 360 are still accepting waste
- Older landfills were mostly small and unlined. They operated under “dilute and attenuate” rules
- Larger landfills were developed in the clay belt around London, to “natural containment” and “natural attenuation” rules
- Only a small handful of the 65 hazardous waste sites identified in the 1978 *Co-operative Programme of Research on the Behaviour of Hazardous Wastes in Landfill Sites* (the “Brown Book”) required significant remediation. The rest relied on “natural attenuation” to safely treat the wastes
- The “Brown Book” became the blueprint for early Waste Management Licenses
- Through the mid 1980s and 1990s we moved to the “Blue Book” series of Waste Management Papers” recommending “containment” landfills using natural or PE based barrier systems

1986: BETTER MANAGEMENT OF LANDFILLS

Better Management: WMP 26 (aka the Red Book)

- In 1986 the UK published ***Waste Management Paper 26. Landfilling Wastes***
- **The intention of the Guidance**
  - We were landfilling more degradable waste, which produced landfill gas and leachate
  - It was intended to improve landfill operations by encouraging new landfills to have engineered basal liners and leachate collection systems
  - It also required the retrofitting of clay caps to reduce leachate generation, which was causing groundwater pollution
- **The unexpected consequence**
  - At this time, landfill gas was known about, but unlike leachate, it was never considered necessary to collect or control its generation and emission (it always escaped the site)
  - But something else happened in 1986. A house was blown up by landfill gas migration triggered by the use of a clay cap intended to reduce leachate generation

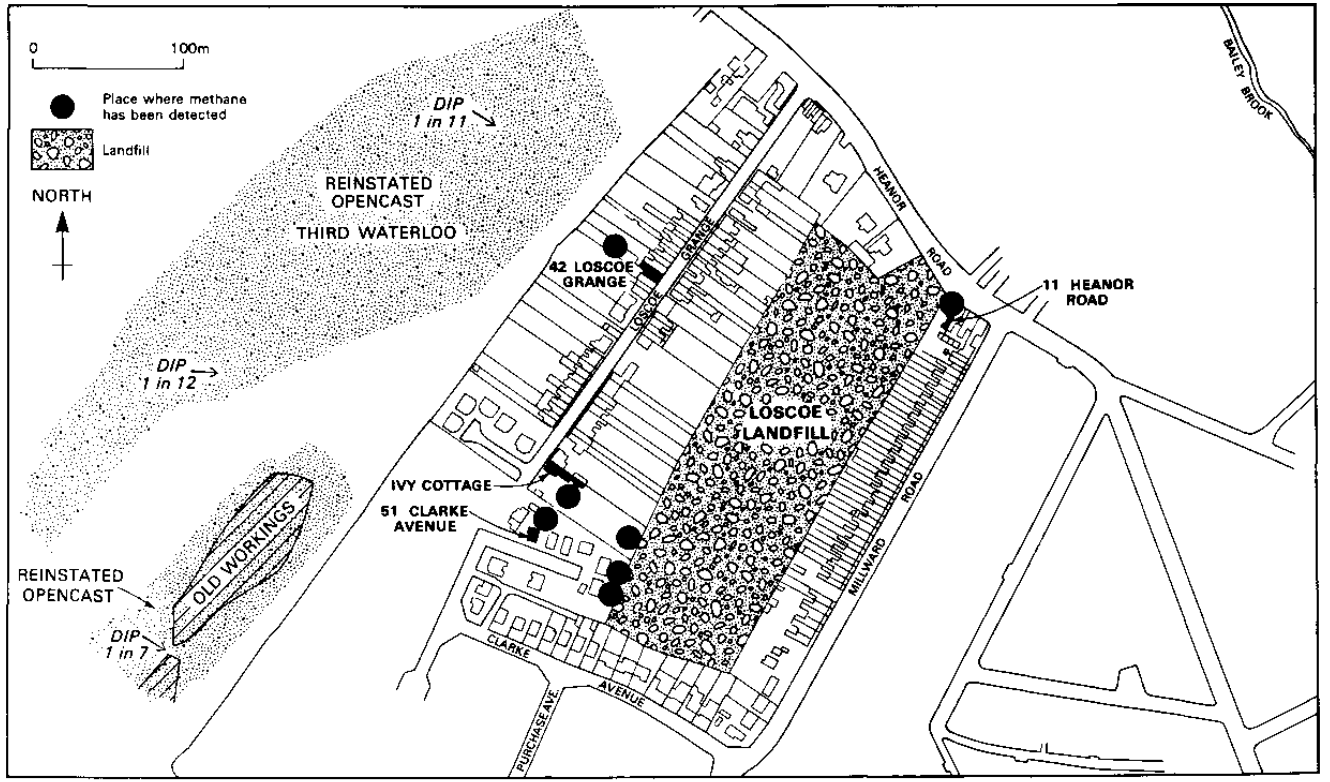
51 Clarke Avenue, Loscoe. 24 March 1986. 6.30 am





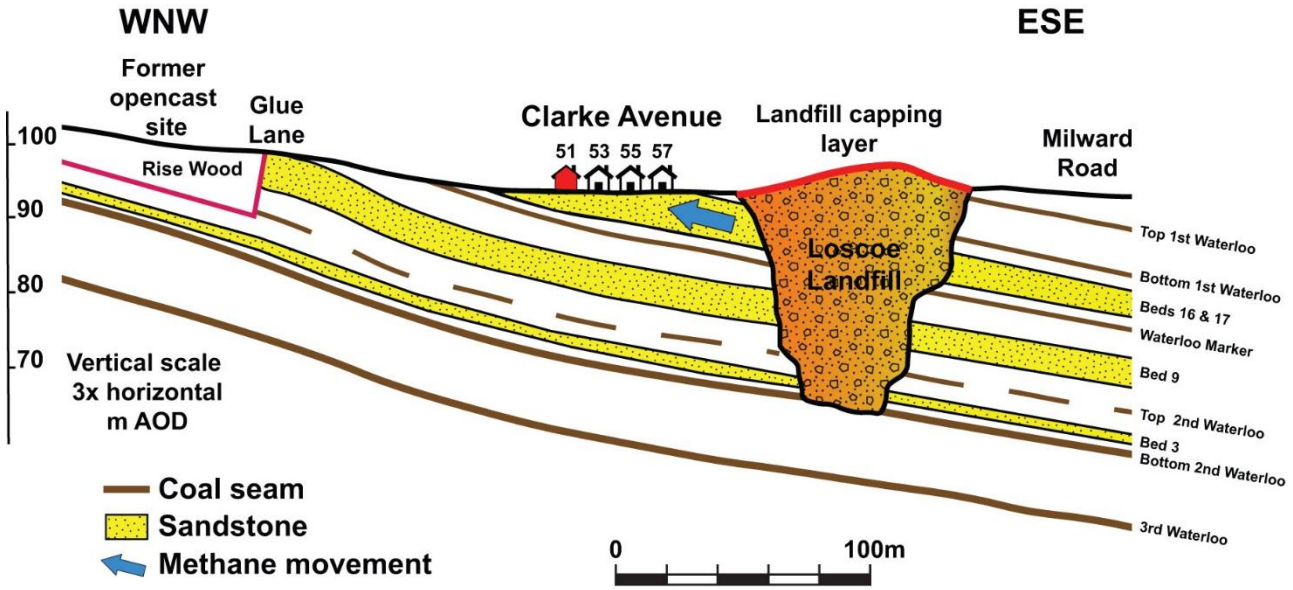
Loscoe: a former open cast coal mine site

- It all started innocuously
- In 1983 a pear tree in the garden of 51 Clarke Avenue died. The soil was found to be warm and dry
- Later, at 42 Loscoe Grange a 0.5m pit began to smell of sewage. At 3m depth there was 58% CH_4. **British Coal** installed a gas vent
- At Ivy Cottage there was 33% CH_4 at 2.27m depth
- Other locations also detected CH_4 at depth. **British Gas** investigated



Loscoe: the conceptual site model
(Developed by the Geological Survey for the 1989 Public Enquiry)

- A former open cast coal mine had been filled first with inert waste and then, without any licence, with municipal waste from 1977 - 1982
- The Town Council who operated the unlicensed landfill capped it with a clay cap in 1985 to prevent leachate generation
- The landfill was unlined, and the gas migration pathway was through a porous sandstone
- A very deep atmospheric depression passed over the area and the barometric pressure dropped by 40 mbar (4 kPa) in 3 hours



Loscoe: the result of capping the landfill

- Landfill gas moved quickly into the basement of properties built above the sandstone stratum
- There was a void below the floorboards into which the landfill gas had been drawn by the sudden drop in air pressure
- The ignition of the gas boiler ignited the gas beneath the bungalow.
- The occupants survived the explosion!
- Then followed the blame game. Was it a gas leak or mines gas?



Loscoe: Trevor Middleton's story
(a LinkedIn conversation I had with a Loscoe survivor in 2023)

- *I opted not to give evidence at the (1989) enquiry, which I must admit I now regret. I always felt it was my parents' story to tell, as they'd lost all they'd worked towards their whole life together. I was, however, awake just before the explosion, as my alarm was set to go off at 0630.*
- *Oh yes - the Ford Escort on the drive? My dad had paid off the mortgage on the bungalow the previous year, at the age of 54, and he'd treated himself (with the agreement, indeed encouragement, of my mum) to his very first brand new car: C738 OVO. The insurers wouldn't write it off, so it stood on the drive until the replacement body shell reached the local Ford dealership. It had fabric seats that were still full of brick dust when he sold it on to me seven years later.*
- *Must admit I was more gutted about the vehicle you can't see, further down the drive, our 1966 Commer campervan (LNU 944D), which was awaiting a bit of welding to get it through an MOT.*
- *My dad always used to get angry when people used to say how 'lucky' he was. So, for the record, I should say that he had to wear a surgical collar for weeks due to impacted vertebrae (like me, he was thrown horizontally out of bed into a wall, like a torpedo).*

Loscoe: Trevor Middleton's story
(a LinkedIn conversation I had with a Loscoe survivor in 2023)

- *My mum came off worst, as the roof fell in on her. She was pinned to the bed, sustaining a double break to her pelvis and a crushed left arm. She was in surgery for around six hours having her arm repaired. Had microsurgery techniques not been available at the Derbyshire Royal Infirmary, there was a realistic chance her left forearm would have had to be amputated.*
- *I came to, having been propelled head-first through a breezeblock dividing wall, into the bathroom, with the remnants of the toilet bowl visible to the left of me, and a roof timber with a large nail protruding from it next to my right eye.*
- *Our neighbours all pitched in and pulled us out. I still remember hearing one of them say*

***'Bloody hell - there's someone alive in there'**, when I shouted to let them know where I was.*

- There is a reason why I have included this transcript. This is a **human story** first and foremost. Whatever you do after this Conference, do it to protect **human health** and **the environment**
- In order to do that we need to understand the **physical** and **biochemical** processes we are regulating and how to manage them correctly

1999: THE EU LANDFILL DIRECTIVE AND WASTE DIVERSION

Waste Diversion improved Recycling Rates

- The EU Landfill Directive sought to reduce Biological Municipal Waste (BMW) (and similar commercial wastes) going to landfill.
- Countries like the UK that landfilled more than 80% of their municipal waste in 1995 received a 4-year derogation
  - Reduce BMW to 75% of its 1995 level by 2006 (2010 for UK)
  - Reduce BMW to 50% of its 1996 level by 2009 (2013 for UK)
  - Reduce BMW to 35% of its 1996 level by 2016 (2020 for UK)
  - failure to meet these dates would result in fines being paid by Governments to the EU
- The UK met these targets using mechanisms like
  - The **Landfill Allowance Trading Scheme** (a complete success) and
  - The **Landfill Tax** escalator (currently a disaster)
- Generally, these was very effective at achieving the required levels of waste diversion

What was diverted from landfill first?

- Waste diversion has been very effective
- The easiest materials to divert from landfill were recovered and recycled first
- **Not all the early diverted materials contributed to reducing BMW to landfill**
  - Glass, ferrous metals, non ferrous metals and hard plastics don't reduce BMW
  - Cardboard and paper, and cotton-based textiles do reduce BMW
  - Green waste reduces BMW and was easily separated for composting
  - Food waste still remains a problem. Many of our AD plants just consume energy crops
  - Waste pretreatment and separation is key to AD digestate quality and useability
- Waste diversion also affects Energy from Waste (EfW) plants in terms of both the volume and the chemical composition (calorific value) of the fuel they burn
- EfW plants usually experience two distinct phases of impact: an initial boom followed by long-term capacity and composition challenges

Impact on AD – increase in CHP and digestate fertiliser









Rejected Digestate from Ball Mill pre-processing vs Clean Digestate from source separated food waste





Impacts on EfW plant

1. The Initial Boom

- Early waste diversion targets drove growth in the EfW sector, by landfill avoidance

2. Changes to Fuel Quality (Calorific Value)

- Waste diversion alters the Calorific Value (CV)
  - Diverting Food Waste (Positive for EfW): Diverting food waste to Anaerobic Digestion (AD) improves the calorific value of the waste burned at the EfW plant.
  - Diverting Plastics and Paper (Negative for EfW): Recycling these materials lowers the calorific value of the residual waste, meaning the plant has to burn *more* physical tonnes of waste to generate the same amount of electricity.

3. The Long-Term "Capacity Crunch"

- As we move toward a circular economy, EfW plants face supply issues
  - The Overcapacity Risk: If government initiatives—such as packaging reform, Extended Producer Responsibility (EPR), and Deposit Return Schemes—succeed in drastically scaling back waste creation, the total volume of residual waste will drop
  - Lock-in Effect: EfW plants are expensive to build, so operators require Councils to sign long-term contracts (often 25+ years) to supply a minimum tonnage of waste. Successful waste diversion may lead to mothballing of plant

Impact on landfill: Hydrogen Sulphide in Landfill Gas

- From ~2005 to 2010 we saw increasing concentrations of H_2S in landfill gas.
- This was eventually found to be related to changing waste compositions upsetting the natural processes in landfills which we had thought we understood – based on experience from the previous 20 years

Hydrogen Sulphide: what we understood up to 2005

- H_2S generation is most likely due to the co-disposal of biodegradable wastes with:
  - Construction wastes (plasterboard) or fine residues from waste processing
  - Calcium sulphate rich waste sludge and cake from effluent treatment plants
- Ongoing production of H_2S at low levels is a normal part of waste degradation
- The emission rate of H_2S relies on the fine balance between sulphate reduction and sulphate removal, and presence of elemental iron and other zero valent metal cations in the waste
- Waste diversion has removed most of the iron and other zero valent metals

Hydrogen Sulphide: a byproduct of recycling

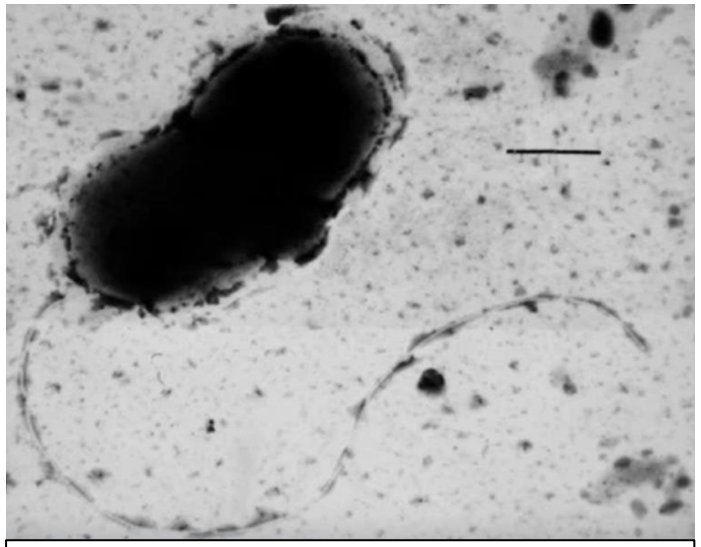
- Sulphate (SO_4^{2-}) can be reduced to sulphide ion (S^{2-}) as sulphate reducing bacteria (SRBs) are more resilient than methanogens

$CaSO_4.2H_2O + H^+ \rightarrow Ca^{2+} + H_2S$ (gas) + H_2O

- This process can be managed if there are sufficient metals in the waste to take up sulphide (typically forming FeS)

$CaSO_4.2H_2O + Fe + H^+ \rightarrow Ca^{2+} + FeS$ (solid) + H_2O

- From the mid 2000s we started recycling in earnest, removing the easiest substances to recycle first: **Metals**, paper and card, textiles
- From the mid 2000s, we saw H_2S concentrations increase in landfill gas
- **The H_2S problem has increased as recycling levels have increased**



SRBs are some of the oldest microbes on the planet, 'breathing' sulphate rather than oxygen

2005: EU LANDFILL DIRECTIVE BAN ON CO-DISPOSAL

What was co-disposal?

- Landfill operators deliberately mixed liquid or solid hazardous industrial wastes (like acids, alkalis, and chemical sludges) with ordinary household waste
- The household waste acts as a chemical buffer, regulating pH and Eh
- Natural biological processes absorb, dilute, neutralise and potentially degrade the hazardous components over time
- Banned in July 2005, this part of the Landfill Directive permanently ended the mixing of hazardous and non-hazardous waste in the same landfill site
- The number of sites legally permitted to accept hazardous waste instantly dropped from ~200 down to less than 15



How good is the buffering effect of a landfill?

- In 2002, this hazardous waste landfill had a balancing lagoon for holding leachate prior to aerobic treatment at the leachate treatment plant
- The lagoon had gone anoxic and stank
- The operator dosed the lagoon with many tanker loads of hydrogen peroxide, to alter the redox potential of the lagoon
- The landfill happily swallowed tanker loads of oxidant and no effect was seen on the lagoon or its odour
- Ultimately the lagoon had to be drained, backfilled, and the odour emissions stopped





2016: TROMMEL FINES: A CIRCULAR ECONOMY WASTE STREAM

Trommel Fines. A Waste Stream for the 21st Century

- Many operational UK landfills are relatively long-lived sites with more recent disposal of trommel fines, forming a large proportion of their current inventory
  - These trommel fines predominantly have LOI <10%
  - A good proportion of this LOI is fine grained very reactive carbohydrate
  - They also contain a low level of gypsum at between 1 – 2%, fine grained, very reactive and currently impossible to exclude from the waste stream
  - We banned monolithic gypsum from landfill in 2009. We cannot achieve segregation of this highly reactive form of gypsum and carbohydrate residues from other landfill wastes
  - Because of effective metals diversion, there is insufficient metal going to landfills currently to act as the sink for sulphide that was present even 15 to 20 years ago
- Most sites have seen a short-term increase in landfill gas generation and an increase in H_2S
- None of the internationally validated landfill gas models have waste streams calibrated on real sites and shown to be representative of these circular economy wastes

Trommel Fines

- The process is ubiquitous in the UK
- It has been driven by a policy for materials recovery
- A typical simple shredding and material recovery operation starts with this material…



Trommel Fines

- …and finishes with this type of material. Fine grained. Highly biochemically reactive in a landfill



The problem with these “New” waste streams

- The fine-grained composition of Trommel Fines means that gas generation, and overall reactivity generally, is enhanced compared to the traditional bulky nature of unsorted wastes
- These waste streams are not as well understood as the traditional wastes which were evaluated in depth in the 1980s and 1990s, and this knowledge is needed to produce reliable risk assessments and to be able to demonstrate best landfill gas management practice
- The landfill gas generated from these waste types is not a slow release
  - High surface area residual waste materials have fast gas production rates and the gas can be gone just as quickly. What would take 6 months historically for gas generation to start is now taking weeks
  - Operators need to construct gas control and extraction systems earlier in the process of waste placement to recover the landfill gas more efficiently than before

The problem with these “New” waste streams

- Circular economy heroes highlight all the benefits of clean, recycled material
- But matter can neither be created or destroyed
- They don’t mention the post-processing concentrated solid material residues which might be hazardous waste and are definitely highly reactive
- Think of Trommel Fines in the Circular Economy as the equivalent of the products of Reverse Osmosis
- In Reverse Osmosis we produce a clean permeate by also producing a concentrate which then has to be disposed of
- It’s exactly the same with trommel fines

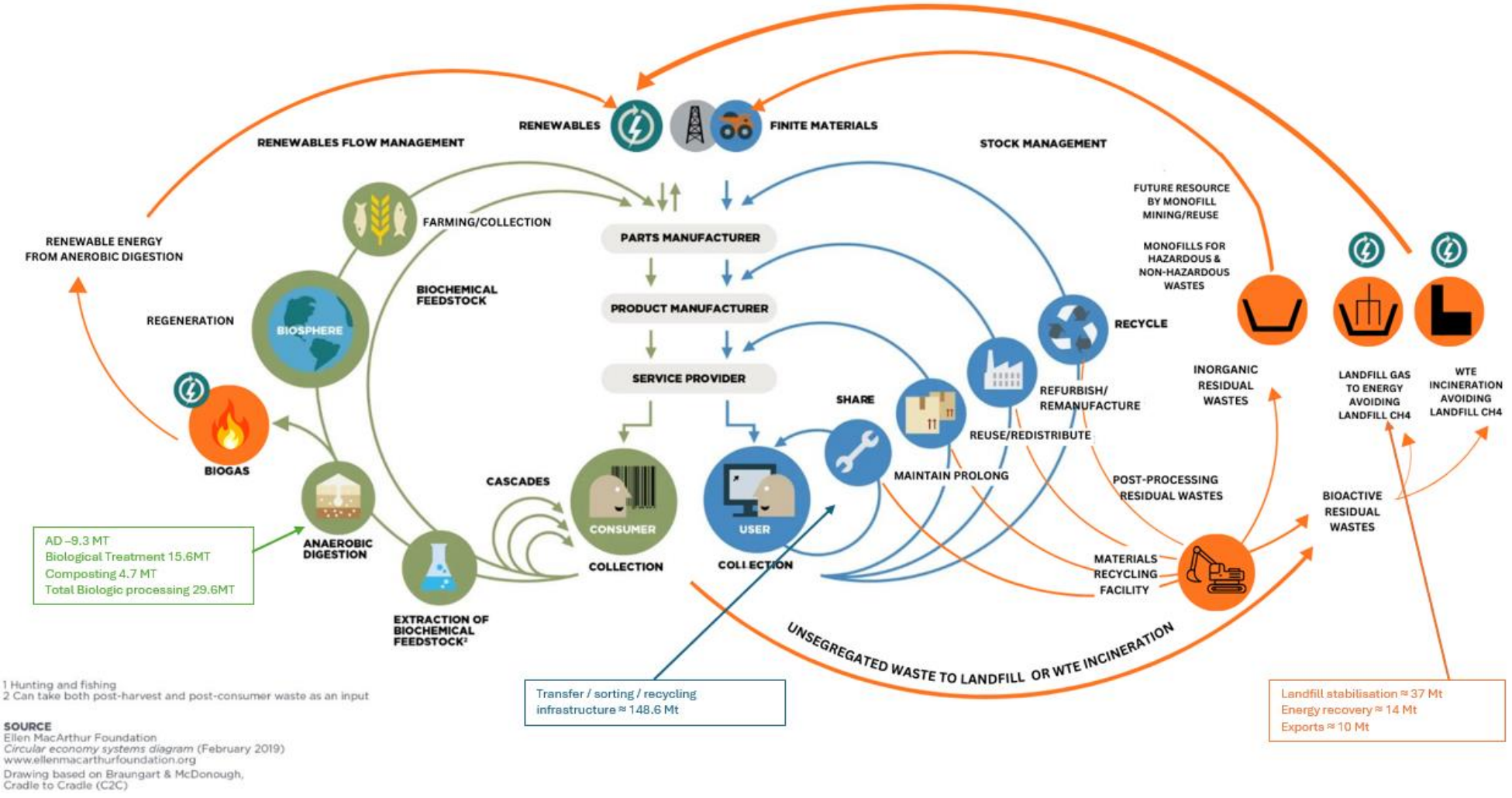
2026: THE CIRCULAR ECONOMY IS INCOMPLETE IF IT IGNORES THE MANAGEMENT OF THE RESIDUAL WASTES FROM CIRCULAR ECONOMY PROCESSES

Circular Economy Residues: The Forgotten Fractions

- The circular economy is presented as a pathway to "zero waste"
- In practice, circular processes generate significant by-products that still require disposal. Landfill remains the destination of last resort for many of these secondary wastes:
  - Digestate rejects: Oversize, plastic-contaminated, or non-sterile material from AD plants
  - Compost oversize: Screenings from IVC and open windrow sites that are too coarse or contaminated
  - Residuals from WEEE, textiles, and furniture dismantling: Mixed polymers, shredded foams, or mineral wool
  - Rejected recyclate: Bales of paper, card, or plastic returned from export or MRFs due to contamination
  - Residual waste from MRFs and MBT: Moisture-laden, biologically active materials with high variability. Chemically reactive, producing landfill gas and H_2S very quickly. Difficult to stabilise, and can also contain heavy metals and organics. It is a perfect example of how circular success creates new landfill challenges
- Landfill is also required for emergency disposal routes – Foot and mouth, BSE, Bird Flu outbreaks
- Landfill is also the preferred route for waste disposal when WtE incineration plants are out of action

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The Circular Economy concept is incomplete without consideration of the residual wastes



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input

SOURCE
Ellen MacArthur Foundation
Circular economy systems diagram (February 2019)
www.ellenmacarthurfoundation.org
Drawing based on Braungart & McDonough, Cradle to Cradle (C2C)

There are three elements to the Spherical Economy

- **Renewables Flow Management** (biological resources)
  - Biochemical Feedstocks, Anaerobic Digestion (and Composting)
  - Energy plants for AD and recycled food waste for AD (**NOT on the original Diagram**)
  - Renewable energy from AD (electricity, CHP or gas to grid) (**NOT on the original Diagram**)
- **Finite Stock Management** (geological resources) (in blue)
  - Maintain, re-use and recycle of materials
- **Residual Waste Management** (residual biological and geological resources) (in orange)
  - Materials Recovery Facilities (MRFs) (**NOT on the original Diagram**)
  - Sorting of residual wastes into inorganic future orebodies and organic renewable energy cells (landfill gas and WtE) (**NOT on the original Diagram**)

Residual Waste in the Spherical Economy

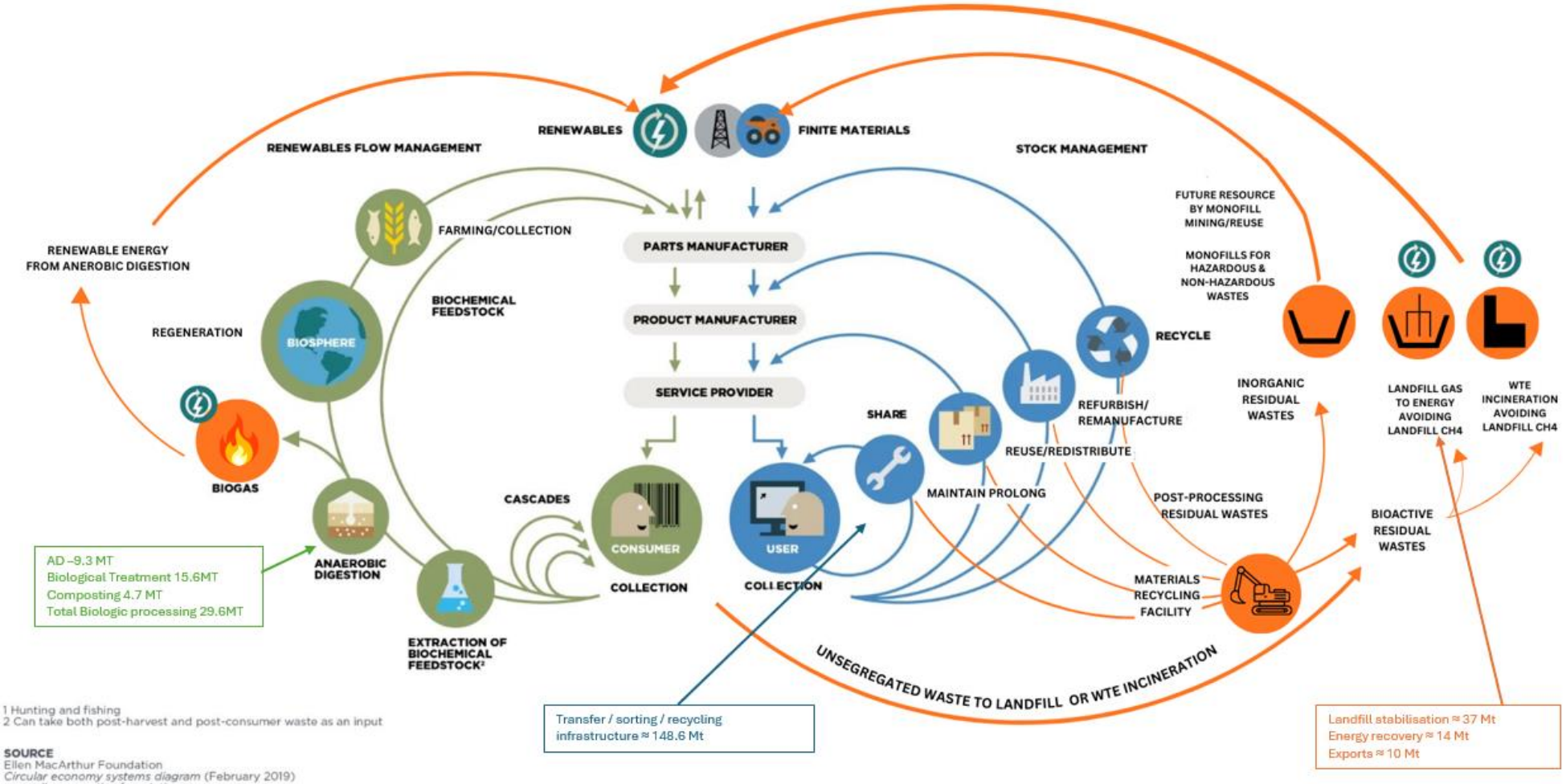
- By considering Residual Waste Management as part of the Spherical Economy:
  - It legitimises waste management as a necessary third part of the Spherical Economy

It doesn't sweep difficult parts of the Spherical Economy under the carpet

  - it faces up to the issue that we need landfill, even if that isn't a fashionable thing to say
- It creates a home in the Spherical Economy for
  - Energy plants and recycled food waste for renewable energy from AD (electricity, CHP or gas to grid)
  - Materials Recovery Facilities (MRFs) for processing and post-processing of residual wastes
  - A route to renewable energy for unsegregated biological municipal wastes and residual wastes
  - A route to more efficient recovery of residual waste materials from future monofill "ore bodies"

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The Circular Economy is really a Spherical Economy



My vision for the future of landfill

- There is no waste management process that does not result in residual wastes going to landfill
- Industry continues to innovate but within that there will be some technology failures
- There will also inevitably be policy decisions that can limit waste management treatment routes
- Landfill provides an option that no other waste management solution provides. It is a buffer to enable above ground technologies to function, and to absorb policy changes
- The remaining challenges are both technical and managerial:
  - Understanding the risk associated with a residual hazard (such as weak LFG or leachate) so that sensible long-term management strategies including permit surrender can be handled appropriately
  - Keeping the landfill skillset alive while we educate new landfill practitioners, policy makers and regulators

Progress and adaptation is the future for landfill





My vision for the future of landfill

- Does Landfill Mining have a future?
- Disaggregated materials are currently too costly to recover, but mono-filling of similar waste types could make future recovery more cost effective
- Landfill Mining could become an extractive industry Chemical Engineer's next challenge
- It could potentially make current environmental management challenges easier
- **This will inevitably come with an additional cost, but no more than the new technologies we are adopting**
- Instead of us pretending landfill does not exist in the circular economy, I would love to see landfill return as a responsible "grown up" solution to residual waste management

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Thank you!

