A look into waste to fuels supply chains: from feedstocks to final products

Concawe Symposium

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About E4tech

We help businesses, policy makers and technology developers with strategic thinking in sustainable energy and chemicals

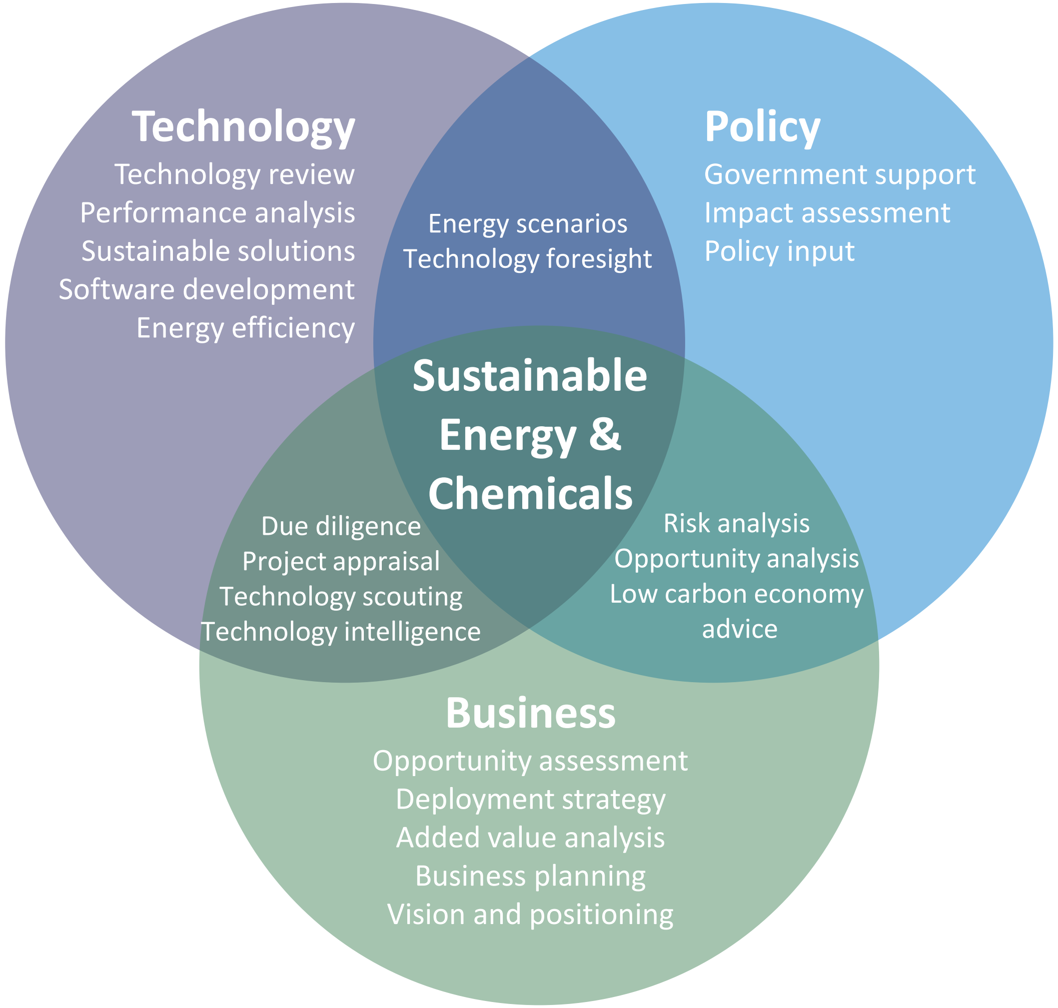
Successful sustainable energy and chemicals solutions consider:

- Competing **technologies**
- Evolving **policy** environments
- **Business** and finance imperatives

E4tech's objective analysis and expertise provides:

- Evaluation of opportunities and risks in these disparate areas
- Guidance under uncertainty
- Support in taking the next steps

We are part of the ERM Group, the world's largest pure play sustainability consultancy, with over 5,800 employees providing services in over 50 countries



Introduction to E4tech

Study objectives and background

- The Environmental Management (EMG) and Soil Wastes & Groundwater group (SWG) of the Energy Institute (EI) and Concawe commissioned E4tech to undertake this study
- Technical analysis (based on literature) of Waste-To-Fuels (WTF) technologies that could be integrated within the European refining system
- This study builds upon the findings of the Concawe 2050 study but considers a different set of feedstocks, namely wastes. It explores specific types of wastes and looks at what could be the most attractive use of them considering pathways within the refining sector

Which Waste to Fuel pathways did we pick

Which feedstocks did we initially consider?

	EU Volumes per year*	Current End of Life fate
Mixed residual waste	~222	Landfill (37%), EfW (40%), Incineration (4%), Recycling and backfilling (19%)
Non-recyclable mixed plastic waste (MRF and mechanical recycling residues)	~10	Landfill (37%), EfW (63%)
Municipal biowaste (incl. food and garden waste)	~48	Composting (64%), AD (26%), Combined composting and AD (10%)
Landscape care biomass	Currently unknown	Unused, composting, EfW, landfill
Sewage sludge	~11	Landfill (8%), Land treatment/release into water (6%), EfW (17%), Incineration (11%), Land application for agriculture or ecological improvement (58%)
Used tyres	~3	Material recovery (~62%), Cement kilns (~32%), EfW (~6%)
Automotive shredder residue (ASR)	~3	Landfill (mostly), EfW

Which primary conversion technologies did we consider?

Based on R&D and current level of interest, four primary conversion technologies were proposed to be part of this study

Primary Conversion(s)	Primary Products
Pyrolysis	Pyrolysis oil
Hydrothermal liquefaction (HTL)	HTL bio crude
Gasification + Fischer Tropsch (FT)	FT syncrude
Anaerobic digestion to biogas, upgrade to bioCH4 and reforming to syngas, + Fischer Tropsch (FT)	FT syncrude

Which feedstocks and primary conversion technologies did we select?

Mixed Residual Waste:
Large Volumes
Currently used for purposes lower down WH than fuels

Mixed Plastic Waste:
Currently used for purposes lower down WH than fuels

Sewage Sludge:
Currently used for purposes lower down WH than fuels
Concerns over its use in land application

Municipal biowaste (incl food + garden waste):
Large volumes
Existing supply chains

Gasification:
Less sensitive to contaminants than other techs

Pyrolysis:
Demonstration plants in development

HTL:
Can handle moisture
Studies underway on SS+HTL

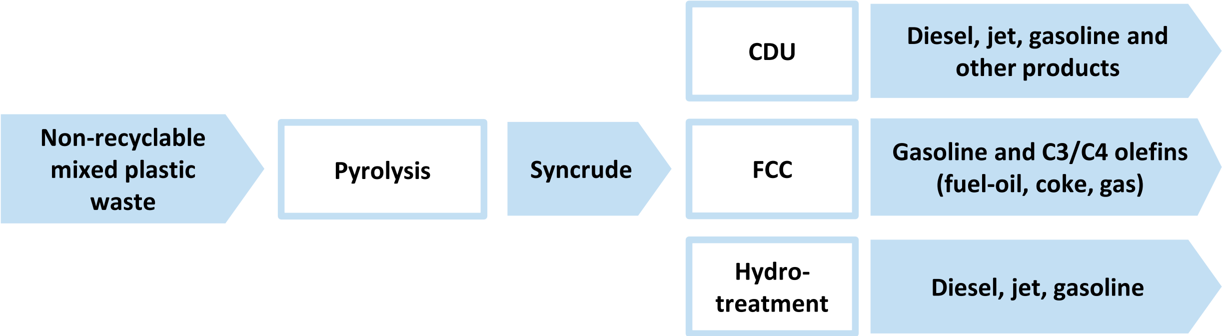
AD:
Can handle moisture
Proven technology

Selected Waste to Fuel pathways

WASTE RESOURCE	PRIMARY CONVERSION (1)	PRIMARY PRODUCT	REFINERY CONVERSION	MAIN FINISHED PRODUCTS (2)
Mixed Plastic Waste 	Pyrolysis (without fractionation)	Syncrude	to crude distillation unit (CDU)	Diesel; jet; gasoline; other products lightolefins. Hydrocracking – mainly die
			to Fluid Catalytic Cracking (FCC)	Gasoline; C3/C4 olefins (fuel-oil; coke; gas)
			to Hydrocracking (HCK)	Diesel; jet; gasoline
Sewage Sludge 	Hydrothermal Liquefaction (without upgrading)	Hydrothermal Liquefaction Oil	to hydrotreatment	Diesel (naphtha; fuel-oil)
			to Fluid Catalytic Cracking (FCC)	Gasoline (fuel-oil; coke; gas)
			to Hydrocracking (HCK)	Diesel; jet; gasoline
Mixed residual waste 	Gasification + Fischer-Tropsch Synthesis	Fischer-Tropsch Syncrude	to crude distillation unit (CDU)	Diesel; jet; gasoline; other products
			to Fluid Catalytic Cracking (FCC)	Gasoline; C3/C4 olefins (fuel-oil; coke; gas)
			to Hydrocracking (HCK)	Diesel; jet; gasoline
Municipal biowaste (incl. food and garden waste) 	Anaerobic Digestion + Steam Reforming + Fischer-Tropsch Synthesis	Fischer-Tropsch Syncrude	to crude distillation unit (CDU)	Diesel; jet; gasoline; other products
			to Fluid Catalytic Cracking (FCC)	Gasoline; C3/C4 olefins (fuel-oil; coke; gas)
			to Hydrocracking (HCK)	Diesel; jet; gasoline

What did we learn about the individual pathways?

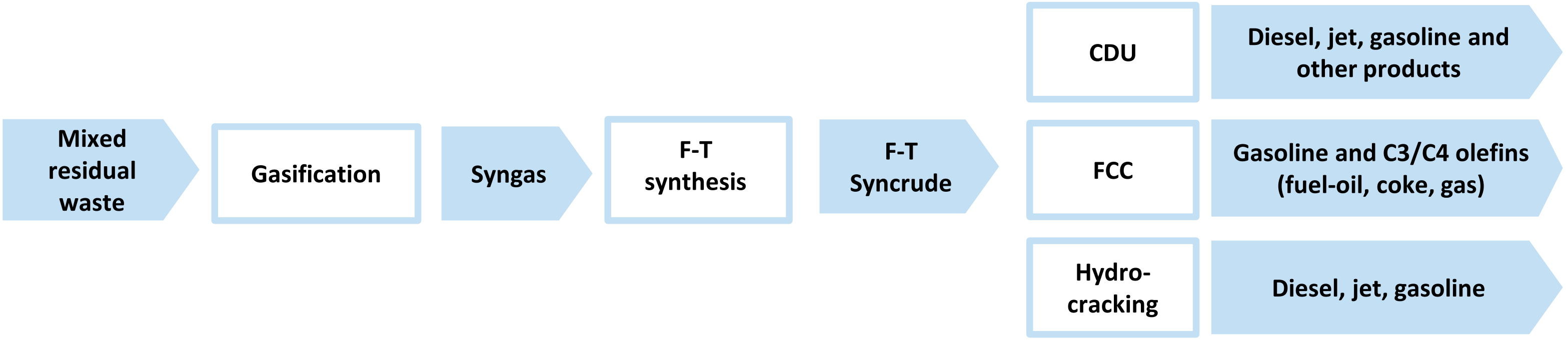
Mixed plastic waste > Pyrolysis to Pyrolysis Oil > Refining



Feedstocks	**Technical Readiness:**	**Product quality**
• Polyolefins are preferred for production of hydrocarbon liquids • Polymers containing heteroatoms (O, N, S and Cl) behave differently leading to process problems (eg tars) or product impurities deleterious to further upgrading (eg acids; S- and N-compounds) • Some polymers eg PET are more valuable if recycled separately.	• **TRL 8** for some polymer pyrolysis • **TRL 5/6** for low-level blending in gasoline or diesel • **TRL 4** or lower for refinery co-processing	• Raw liquid includes gasoline, diesel and heavier fractions depending on feed and process design. • The raw product is mainly paraffins, olefins and aromatics, so probably acceptable for direct fuel blending at low level. Hydrotreating may be required for higher levels in diesel.

Enablers	Challenges
• **Raw waste is hydrocarbon-like which allows simple primary conversion with high yield of gasoline & diesel-range material.** • **Primary conversion process has few steps and is technically viable at small scale; some commercial plants already in operation.** • **The hydrocarbons in the primary product are probably acceptable for direct blending in gasoline and diesel at low levels.**	• Relatively small volume (10 Mton/year) and wide resource distribution may limit it to low-level use at individual refineries. • Primary conversion, direct blending and refinery upgrading are all adversely affected by presence of oxygen-, chlorine- and nitrogen-containing polymers in waste feedstock.

Mixed Residual Waste > Gasification + FT to FT Syncrude > Refining



Feedstocks

- Mixed residual waste is very inhomogeneous including organics which cannot be recycled (eg due to size or combination with non-recyclables) , metals, inorganics and moisture.
- Pretreatment may include screening, electric/magnetic separation, density classification

Technical Readiness:

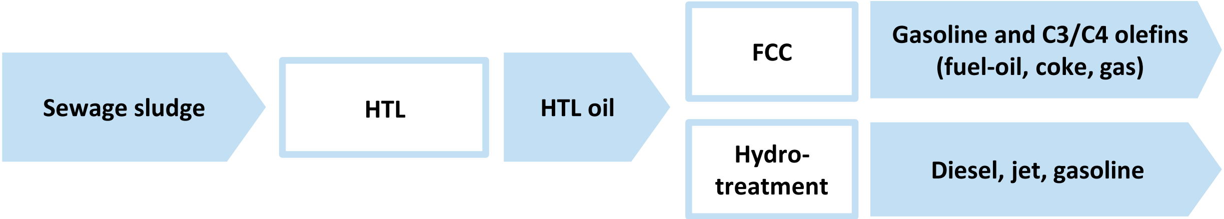
- **TRL 6/7** for some MRW-to-syncrude facilities
- **TRL 4/5** for refinery co-processing of FT syncrude
- *(**TRL 9** for CTL and GTL production of jet and diesel, and blending with refinery products)*

Product quality

- FT syncrude is usually a mix of paraffins with a wide-boiling range and a high melting point. Likely to have low impurity levels.
- Syncrude requires cracking, preferably hydrocracking/isomerisation to produce high-quality jet and diesel. In principle, FT syncrude might be co-fed to refinery crude units at low level (eg to avoid fouling.)

Enablers	Challenges
• Very large waste volume (>200 Mtons/year) might enable greater synergy with refineries than smaller volume wastes. • The economics of plants using mixed residual waste depends on receiving gate fees for waste treatment. Where available these can provide a significant positive impact to project economics. • High quality primary product with several options for refinery upgrading (e.g. HCK, FCC).	• Uncertain information about waste variability e.g. individual source volumes and waste quality. • Primary technologies are proven at different scales; challenge is integrating at common scale, and at smaller scale suited to resources. • Limited public information about refinery-based upgrading; likely hard to target a single product (especially jet).

Sewage sludge > HTL to syncrude > Refining



Feedstocks	Technical Readiness:	Product quality
• Sludge comprises proteins, lipids/fats and carbohydrates mixed with variable amounts of water (70-80%) and inorganics (10-40%). May need pretreatment eg to remove solids and metals. • High water content likely limits transportability leading to on-site HTL processing but centralised upgrading.	• **TRL 6/7** for wood-based HTL; lower for sludge • **TRL 4/5** for hydrotreatment of HTL oils	• Raw HTL liquid has a boiling range similar to heavy diesel, but contains % levels of oxygen; it may be acidic. • Hydrotreated product is mainly diesel-range, but the gasoline yield can be increased by hydrocracking.

Enablers	Challenges
• **The primary conversion process has few steps and is technically viable at small scale.** • **HTL plants have the potential to be more scalable than pyrolysis plants, but are at an earlier TRL.** • **HTL oils contain oxygenates but these are much lower than biomass derived pyrolysis oils.** • **Sewage sludge can be sourced zero, low cost or sometimes with a gate fee either providing a low cost feedstock or a revenue driver.**	• Relatively small volume (10 Mton/year) and wide resource distribution may limit it to low-level use at individual refineries. • Uncertain information about waste variability e.g. source volumes and waste quality eg ash; impurities from industrial waste waters. • Limited public information about refinery-based upgrading; likely hard to target a single product (especially jet).

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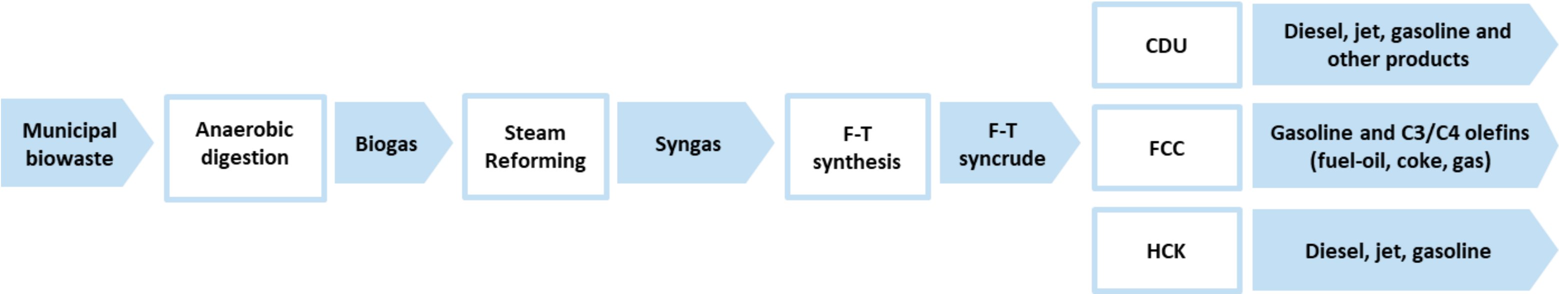
Municipal biowaste > AD + Reforming + FT to FT syncrude > Refining



Feedstocks	**Technical Readiness:**	**Product quality**
• Municipal biowaste is a variable mixture of food waste, "digestible" biomass and other biomass.	• **TRL 4/5** for micro-scale FT syncrude production. • **TRL 4/5** for refinery co-processing of FT syncrude • *(**TRL 9** for CTL and GTL production of jet and diesel, and blending with refinery products)*	• FT syncrude is usually a mix of paraffins with a wide-boiling range and a high melting point. Likely to have low impurity levels. • Syncrude requires cracking, preferably hydrocracking/isomerisation to produce high-quality jet and diesel. In principle, FT syncrude might be co-fed to refinery crude units at low level (eg to avoid fouling.)

Enablers	Challenges
• Large waste volume (ca. 50 Mtons/year) might enable greater synergy with refineries than smaller volume wastes. **• The primary conversion process is built of technologies which are already commercial in other applications (e.g. AD is widely deployed).** **• The AD producer receives a gate fee. This can become an important influence on the AD producer's economics.**	• Uncertain information about waste variability eg individual source volumes, waste quality, methane yield. • Primary technologies are proven at different scales; challenge is integrating at common scale, and at smaller scale suited to resources. • Limited public information about refinery-based upgrading; likely hard to target a single product (especially jet).

Policy, Regulatory and Sustainability Enablers and Challenges

	Enablers	Challenges
Mixed plastic waste	• Utilising non-recyclable mixed plastic waste may complement rather than compete with recycling initiatives, as mechanical recycling technologies currently are not able to process such waste.	• Unclear policy positions on the use of recycled carbon fuels; there is a risk that some countries may not support fuels based on recycled carbon with no biogenic content. • EoL fates higher up the waste hierarchy (e.g. chemical recycling) may be prioritized over recovery options which includes the WTF pathway.
Mixed residual waste	• Landfill reduction targets will promote diversion of this waste feedstock to alternative fates including WTF. • The biogenic portion of mixed residual waste is supported by RED II for fuel production. • Biogenic materials degrade in landfill releasing methane emissions so avoiding this EoL fate and diverting waste to this WTF pathway may result in potential GHG savings.	• Initiatives encouraging waste reduction limit the potential feedstock for this WTF pathway. • Unclear policy positions on the use of recycled carbon fuels. The fossil content in this waste stream may affect the level of support for this pathway.
Sewage sludge	• Sewage sludge is recognized as a feedstock for advanced biofuel in RED II and there may be more support for this WTF pathway from policies currently under review that encourage uptake of sustainable fuels.	• Recycling sewage sludge to land application is higher up the waste hierarchy, potentially prioritizing it over the WTF pathway. • If sewage sludge was diverted to the WTF pathway, alternative fertilizers would be required for land application, which may have greater environmental impacts.
Municipal biowaste	• Policy targets to reduce the amount of biowaste ending up in mixed residual waste promote more separate collection and therefore could increase feedstock availability for this WTF pathway.	• Recovery is further down the waste hierarchy compared to alternative EoL fates such as composting. • Initiatives to reduce food waste will limit the feedstock available for this WTF pathway.

Overall study findings

Key challenges of waste to fuels pathways

Technology: Key technical challenges relating to refinery upgrading of intermediates into finished fuels

Scale: Primary conversion steps much smaller than current refinery operation (only few % of current capacity)

Policy and regulation: Complex, some policies support, and others hinder. Some policies might divert feedstock away from fuels and towards recycling

Economics: CAPEX and OPEX are highly dependent on local conditions, hard to generalise. Gate fees are important consideration.

Pathway TRL: some individual steps proven, but overall pathways at lower TRLs. Some pathways less mature than others

Some views on the role of Waste to Fuels

- **Waste Hierarchy:**
  - The use of these feedstocks for fuels may not be seen as favourably as using these feedstocks for forms of recycling such as mechanical and chemical.
  - However, it should also be noted that not all wastes can be recycled, and that chemical recycling technologies have also not yet reached commercial scale.
- **GHG saving potential:**
  - Diverting certain non-recyclable waste feedstocks away from EfW plants and towards fuel production can result in GHG savings. This shows there is opportunity for the WTF pathways to deliver GHG reductions compared to their current EoL fates.
- **Refinery asset utilisation**
  - From a technology and supply chain perspective, these pathways may enable refinery assets to be utilized and enable the transition towards the use of lower carbon feedstocks.
  - However, given the relatively small volume of these wastes in comparison with the scale of refineries, whilst these pathways may enable some degree of GHG reduction, other complementary feedstocks (e.g. e-fuels) or technologies (e.g. CCS) may be needed for fuels to reach net zero emissions on a well-to-wheel basis.

Backup slides

Waste Hierarchy