Investigating Industrial Hemp Biomass as an Alternative Fuel in Diesel Engines

A collaborative project between the Bioenergy Group and the Future Engines and Fuels Laboratory.

Michael Omatsola-Morgan

MEng Mechanical Engineering Student

mxo732@student.bham.ac.uk

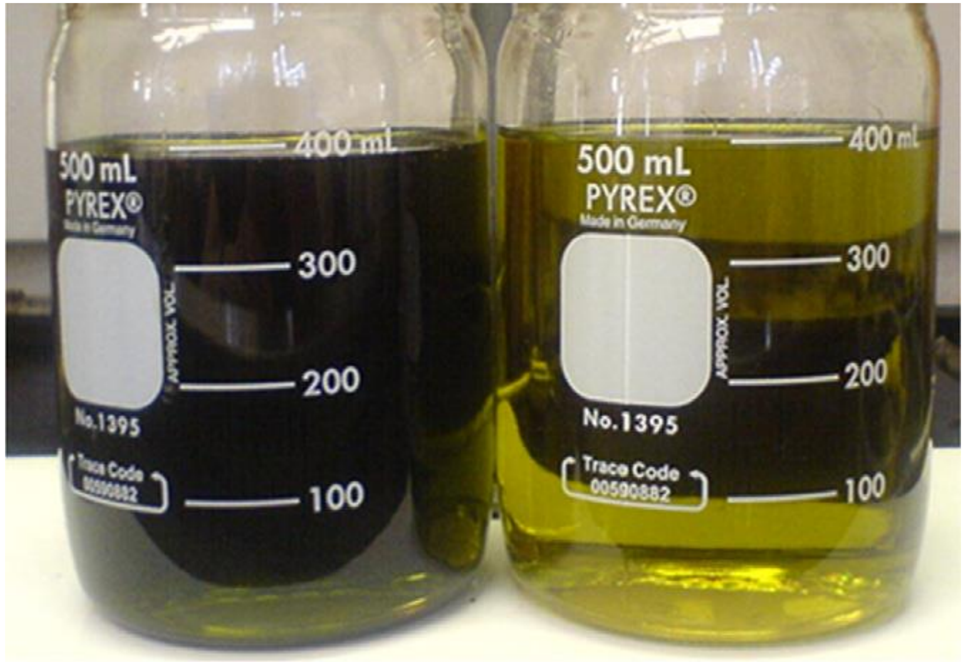

Figure 1: Hempseed oil (left) and hemp-derived fatty acid methyl ester (right) (Li, et al., 2010).

Overview

- Background and Context
- Literature Review
- Project Aims and Overview
- History of Cannabis
- Government Regulation
- Current Legal Cases
- Local Case Study
- Conclusion
- Questions

Background and Context: Environmental Impact and consequences

Last decade was Earth's hottest on record as climate crisis accelerates

- 2019 was second or third hottest year ever recorded
- Average global temperature up 0.39C in 10 years

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Climate crisis exerting increasing impact on UK, says Met Office

Extreme heat, less frost and snow, and trees coming into leaf earlier among signs in 2019

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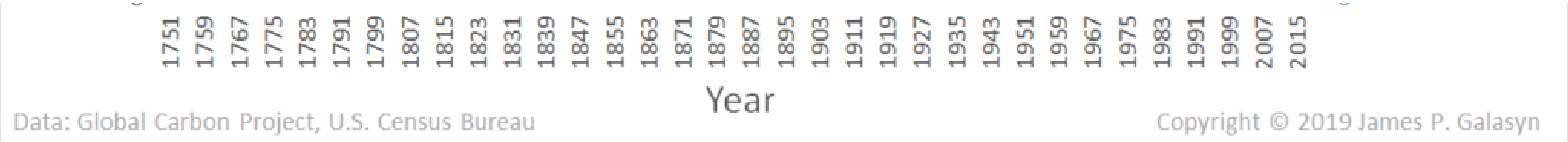

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Background and Context: Political Response

Claim | **Conclusion**

The UK has led the worlc committing to "net zero' greenhouse gas emissioi 2050.

The UK has made huge p in cutting greenhouse gc emissions.

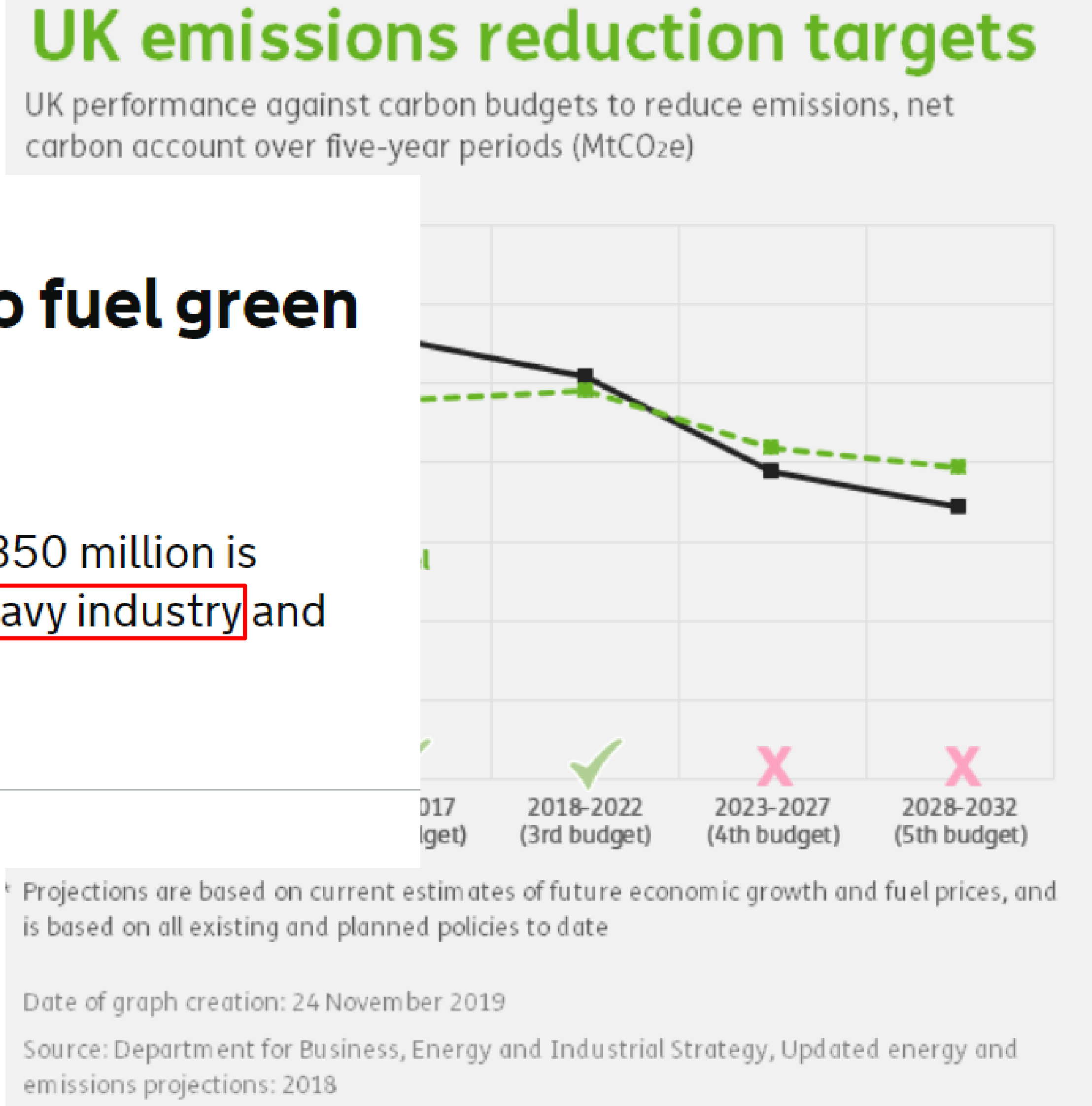
to be enough to meet future targets.

Press release

PM commits £350 million to fuel green recovery

Prime Minister Boris Johnson announces £350 million is being made available to cut emissions in heavy industry and drive economic recovery from coronavirus.

Published 22 July 2020



Background and Context: Transport Sector Statistics

- Transport accounted for 24% of emissions in 2019 (The Committee on Climate Change, 2020)
- Road transport accounts $> 50\%$ of oil demand (GOV.UK, 2019)
- Increasing dependence of diesel
  - Diesel-fuelled vehicles nearly trebled
  - UK is net importer of diesel
- Ultra-low emissions vehicles (ULEVs)
  - Emit $< 75\ g/km$ of CO_2 from tailpipe
  - 2.7% of new registrations in 2019
- Biodiesel
  - Sustainable fuel (≈net-zero emissions)
  - 5.3% of diesel fuel consumed in 2019

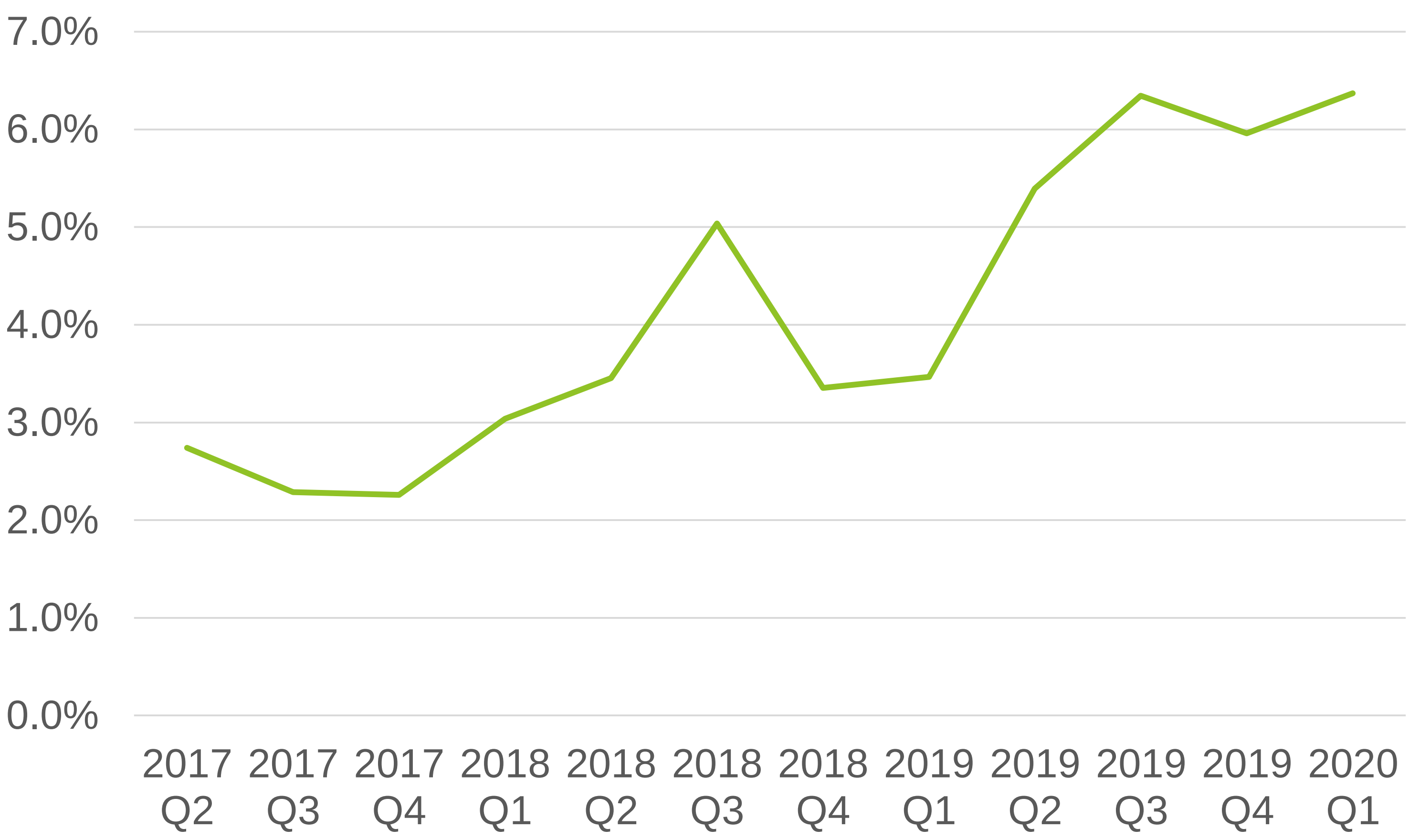


Figure [illegible] 2001 - 2020 Q1 p (GOV.UK, 2019).

Background and Context: Potential of Industrial Hemp

- *Cannabis sativa L.* with low tetrahydrocannabinol (THC) content
- Fast growing biomass
  - Take between 8 weeks - 4 months to grow (Wilhelm, 2017)
  - High biomass yield (Crini & Lichtfouse, 2020)
  - Grow in a range of climatic zones including the UK
- Great carbon sink
  - Sequester around $2.5 - 13.4\ t$ of CO_2 per hectare (Crini & Lichtfouse, 2020)(European Industrial Hemp Association, 2020)
- Grow on contaminated soil
  - Long root system
  - More susceptible to phytoremediation (Ahmad, et al., 2015)
- Needs fewer inputs compared to other crops:
  - Act as retardants suppressing weed growth.
  - Naturally repel insects and pests
  - Inhibit growth of nematodes (Crini & Lichtfouse, 2020)

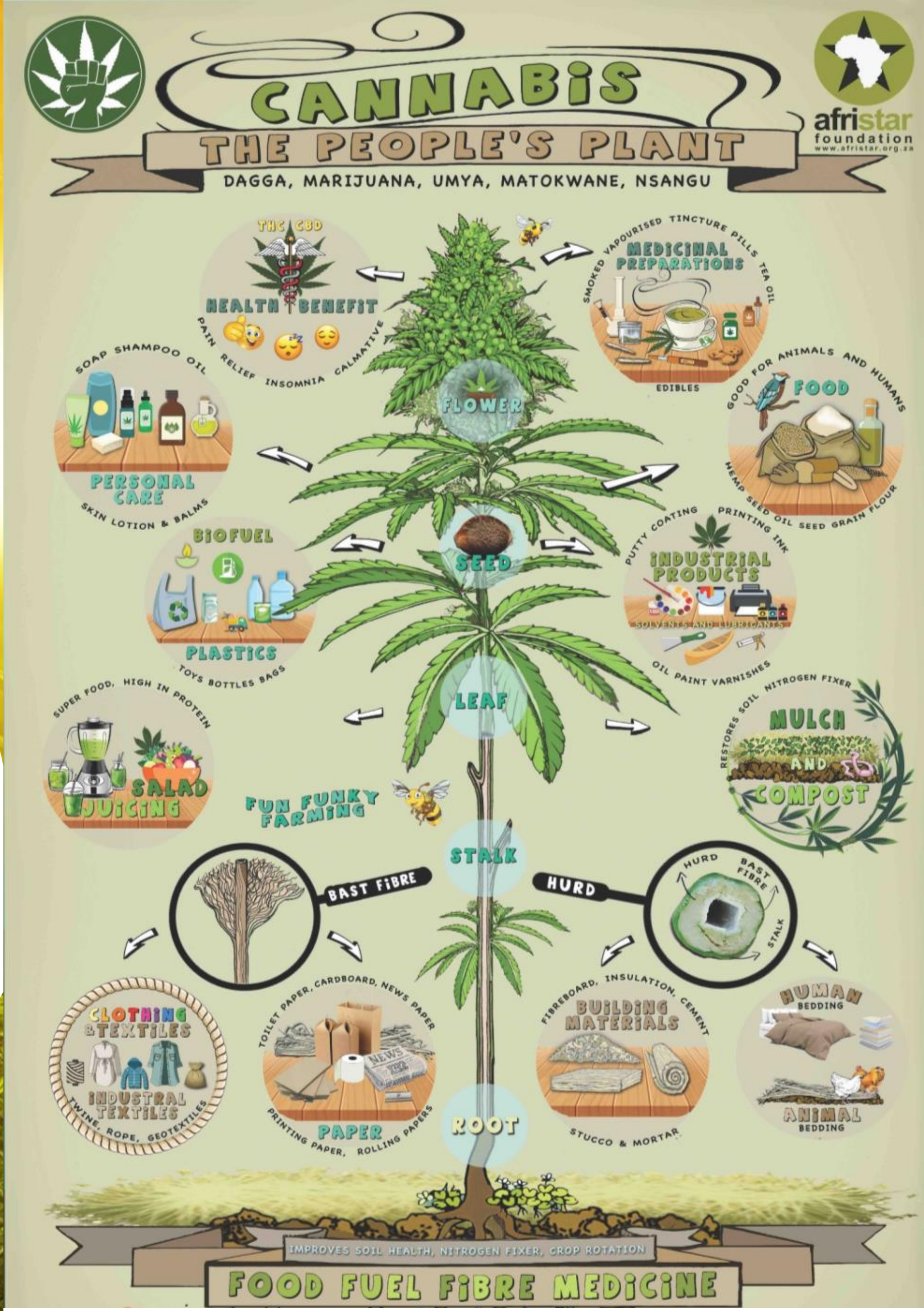


Figure 6: Applications of hemp (Crini, et al., 2020) (Afristar Foundation, 2020)

Literature Review: Transesterification

- Conventional method
  - Vegetable oil (mixture of triglycerides) to biodiesel (fatty acid methyl esters)
- Cheap and easy to set up
- Cleaner combustion and lower emissions (Mofijur, et al., 2017)
- Lower energy content
- More susceptible to oxidation
- Selective hydrogenation (further treatment)
  - Requires high poly-unsaturated fatty acid content
  - Higher oxidation stability (Zaccheria, et al., 2009)
  - Produces hydrogenated fatty acid methyl ester (HFAME)
- Conform to **EN 14214: Automotive fuels. Fatty acid methyl esters (FAME) for diesel engines. Requirements and test methods** after further treatment and additives added
- Blend with other biodiesels and fossil diesel

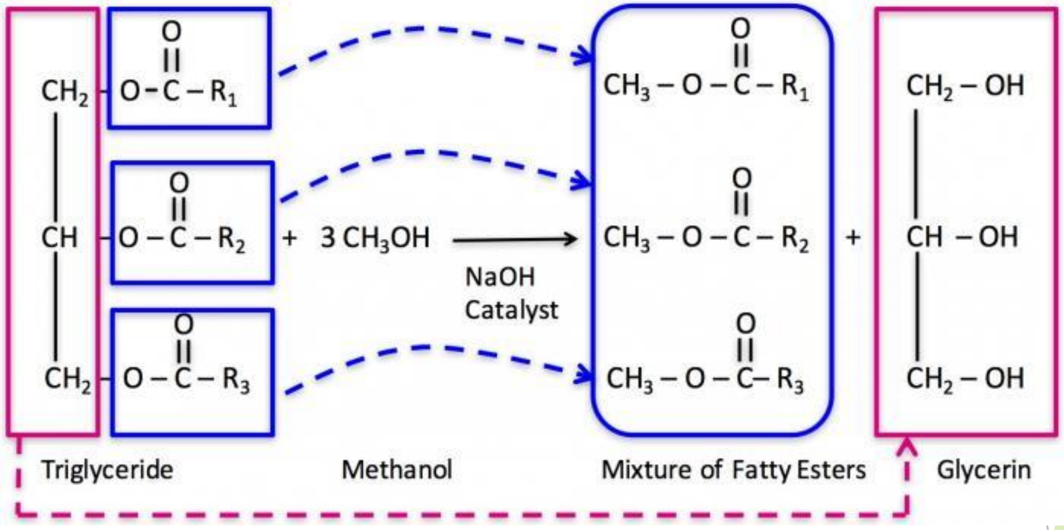


Figure 7: Transesterification chemical process.

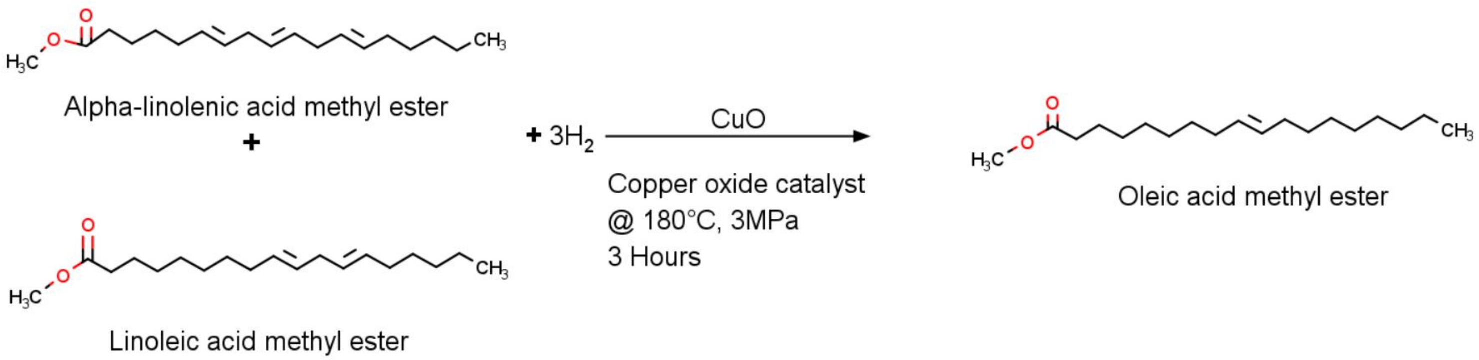


Figure 8: Selective hydrogenation chemical process.

Literature Review: Thermo-Catalytic Reforming® (TCR®)

Literature Review: Thermo-Catalytic Reforming® (TCR®)

- Cutting-edge method
  - Biomass and waste to sustainable fuels
- High quality by-products:
  - Biochar
  - H_2-rich synthesis gas
  - **Crude liquid bio-oil (aromatic hydrocarbons)**
- Aromatics can be further treated:
  - Hydrotreatment to replace sulfur, nitrogen, oxygen atoms with hydrogen atoms
  - Fractionated into bio-gasoline, **biodiesel**, and bio-kerosene
- Conforms to **EN 590: Automotive fuels. Diesel. Requirements and test methods** after further treatment
- Blends with other biodiesel and fossil diesel (Schmitt, et al., 2019)

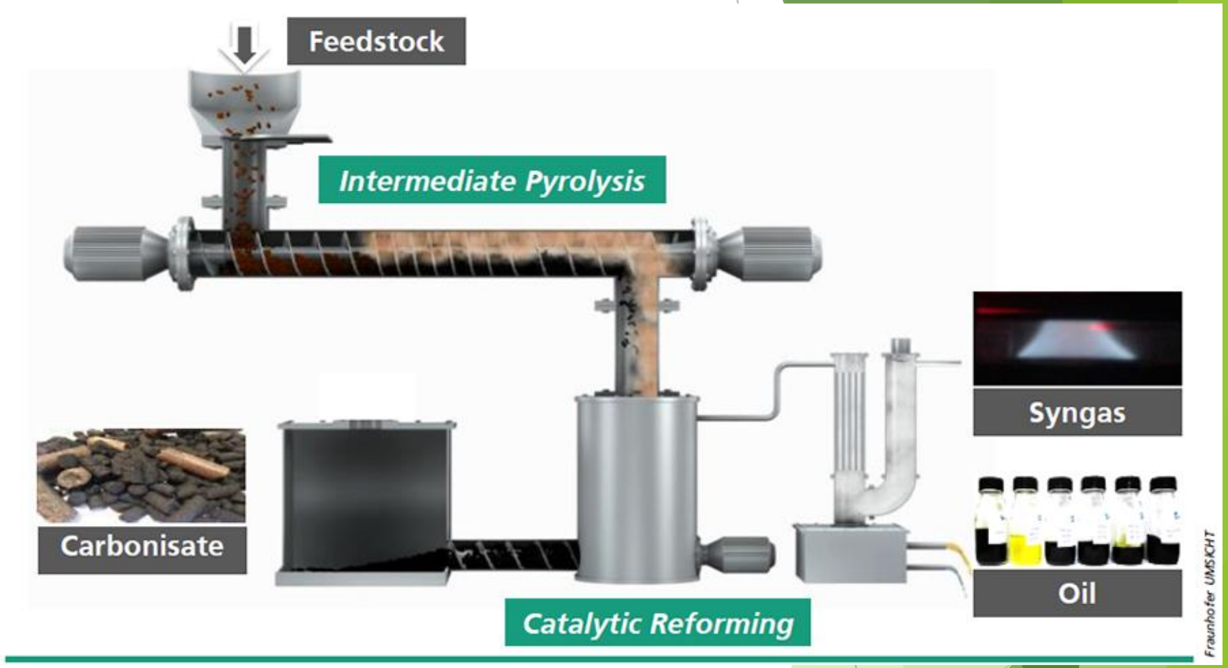


Figure 9: Thermo-Catalytic Reforming® schematic (University of Birmingham, 2020).

Literature Review: Comparing the two Methods

Table 1: Comparison of biodiesel produced from transesterification and thermo-catalytic reforming®.

	Fatty Acid Methyl Ester (FAME) Biodiesel	Thermo-Catalytic Reformed® (TCR®) Biodiesel
Similarities	High heating value similar to fossil diesel	
	Low kinematic viscosity	
	Can be blended with another biodiesel or fossil diesel	
	B100 fuel can be used directly in diesel engines with no engine modifications	
	Can be hydrotreated to improve fuel quality	
Differences	Creates fatty acid methyl ester	Creates aromatic hydrocarbons
	Lower oxidation stability due to higher unsaturated fatty acid chains content	Higher oxidation stability
	Conforms to EN 14214 standard*	Conforms to EN 590 standard*
	Lower energy content due to higher oxygen content	Higher energy content due to higher carbon and hydrogen content
	Higher completed combustion	High thermal stability
	Conventional method	Cutting-edge method

** After hydrotreatment and/or with addition of additives*

Project Aims

- What limitations arise when using hemp biomass as a source for biodiesel?
- Do the fuel properties of hemp–derived hydrotreated thermo-catalytic reformed® (HTCR®) biodiesel adhere to the standards set by EN 590?
  - Are additives necessary to achieve these standards?
- How are engine performance parameters influenced by different blends of the HTCR® biodiesel and fossil diesel (B0, B7, B20, B50, and B100)?
  - How will this compare with a mixture of 80% volume hemp-derived HTCR® biodiesel blended with 20% volume hempseed hydrogenated fatty acid methyl ester (HFAME) biodiesel?
- How economically viable is it to produce the biodiesels at a commercial scale?

Stage 1: Computational Modelling of Engine Combustion (MEng Final Year Project)

- **Time frame: 6 Months**
- Characterise hemp biomass
  - Thermogravimetric analysis (TGA)
  - Determine ash content
- Produce test samples of TCR® crude bio-oil, HTCR® and HFAME biodiesel
  - Test critical biodiesel properties (density, viscosity, flash point, calorific value, Total Acid Number (TAN), and water content)
  - Determine composition of hydrocarbon molecules through Gas Chromatography-Mass Spectrometry (GC/MS)
  - Determine composition of elements through Ultimate Analysis
- Conduct engine simulations of proposed mixtures
  - Theoretical data will give indication of fuel quality within combustion

Stage 2: Production and Fuel Quality Analysis

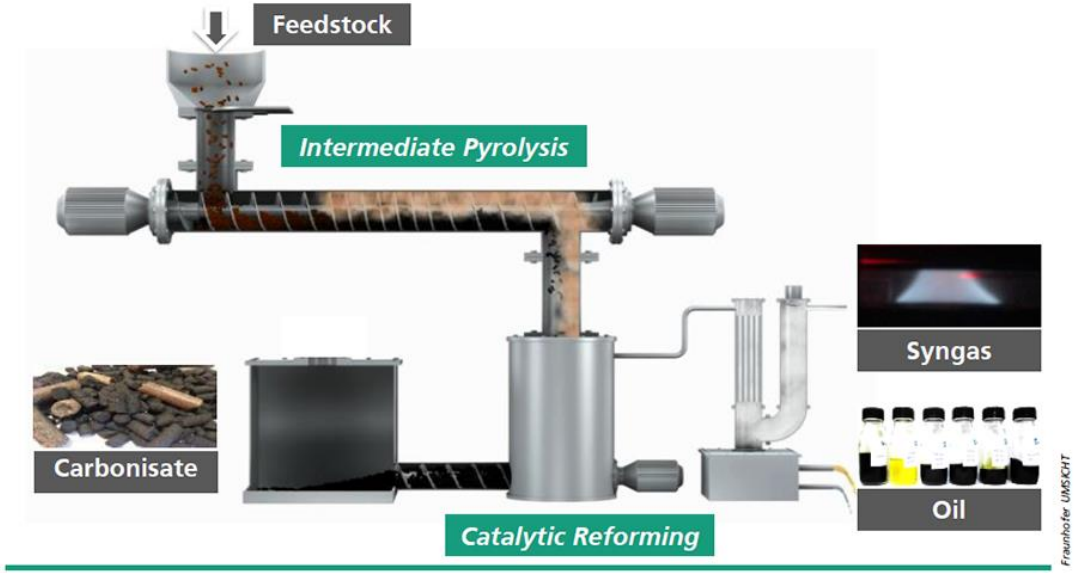


Figure 10: Thermo-Catalytic Reforming® schematic (University of Birmingham, 2020).

- **Time frame: 10-13 months**
- Convert hemp biomass into liquid bio-oil with thermo-catalytic reforming®
  - Screw reactor temperature $@400-450℃$ (Schmitt & Hornung, 2017)
  - Reforming temperature $@500℃$ (Santosa, et al., 2020)
  - Maximise oil production (Santosa, et al., 2020)
- Hydrotreat TCR® oil
  - Hydrogen, and NiMoS/Al_2O_3 catalyst $@280-380℃$, $15-17\ MPa$, $20\ Hours$ (Schmitt & Hornung, 2017)
- Fractionate HTCR® biodiesel
- Test with EN 590 test methods, GC/MS*, and ultimate analysis (UA)

* Gas Chromatography - Mass Spectrometry

- Convert hempseed oil into HFAME
  - High and unique content of poly-unsaturated fatty acids (Li, et al., 2010)
  - Clean combustion
- One-pot transesterification and selective hydrogenation process (Yang, et al., 2010)
  - Product yield of 96% (Yang, et al., 2010)
  - Methanol, Hydrogen, and CuO/SrO catalyst $@180℃$, $3\ MPa$, $3\ Hours$ (Yang, et al., 2010)
- Test with EN 14214 test methods, GC/MS*, and UA

Stage 3: Engine Combustion Tests

- **Time frame: 2-5 months**
- Combustion of the following mixtures:
  - B0, B20, B50, and B100 of hemp-derived HTCR® biodiesel and fossil diesel
  - 80% volume of hemp-derived HTCR® biodiesel and 20% volume of hempseed HFAME
- Analyse the following parameters:

Engine power output	Exhaust gas pressure
Thermal efficiency	Unburned hydrocarbons
Fuel consumption	Smoke opacity
Particulate matter deposits	
Engine exhaust emissions	
Exhaust gas temperature	

Why isn’t it used everywhere?

History of Cannabis

- 1533: King Henry VIII mandated landowners to grow at least ¼ acre of hemp for every 60 acres
- 1579: Queen Elizabeth I increased quota to 1 acre and imposed fine of £5 (Gibson, 2006)
- 16th – 18th century: British Royal Navy grew to be world's most powerful navy
  - Fought with hemp sails and ropes (Gibson, 2006)
- Mid-to-late 19th century: Decline of sailing navy and replaced with steam propelled ships
  - Hemp cultivation decreased (Crini & Lichtfouse, 2020)
- 1928: Dangerous Drugs Act adds cannabis (and other forms) to the act (The Health Foundation, 2020)
  - Cultivation became illegal
- 1941: Henry Ford produces car door and fender prototype made from hemp-based plastic
  - He envisioned the car to run on hemp-ethanol (Crini, et al., 2020)
- 1971: Misuse of Drugs Act classes cannabis as class B
- 1993: Home Office grants licenses to grow hemp for industrial applications (Gibson, 2006)
  - Imposed regulations surrounding cultivation

Government Regulation

- Cultivate for stalk and seeds (non-controlled parts of the plant)
- Apply for a licence from the Home Office required
  - Undergo a Disclosure and Baring Service (DBS) check to be eligible
  - New licences cost £580 for 3 years
  - £326 to renew each growing season
- Leaves and flowers **cannot** be harvested (controlled parts of the plant)
  - Can be licensed to cultivate high THC cannabis or controlled parts (£4700 cost)
- Subject to a compliance visit, and a fee of £1371 (GOV.UK, 2020)
- Flowers and leaves $< 0.2\%$ THC content (GOV.UK, 2020)
  - THC concentrations mostly determined by genotype.
  - Climatic conditions have an influence (Crini & Lichtfouse, 2020).

What can we do?

Current Legal Cases

We The Undersigned

- Challenging Home Office on cannabis prohibition
- Disinformation of cannabis
- Denied human rights
  - Freedom of consciousness
  - Peaceful beliefs and practices
  - Pursue best quality of life
  - Free from arbitrary interference from State
  - Misuse of Drugs Act conflicts with Human Rights Act
- Raising legal funds

Plan B

- Plan B & 11 Citizens vs UK 2050 Carbon Target
  - Unsuccessful claim
  - However, Government reviewed 2050 targets
- Plan B v Heathrow Expansion
  - Successful claim
  - Heathrow expansion unlawful
- Plan B v Government Bailout for Polluters
  - Government allocated £1.8 bn to airline companies and failed to consider climate obligations

Local Case Study

- The Tyseley Energy Park (TEP)
  - Phase 2 of Master Plan
  - UK's first low and zero emission refuelling station
    - £3.5 million project
    - Fuel could be utilised
- Birmingham Clean Air Zone (BCAZ)
  - Planned launch in 2020
    - Postponed until 2021
  - Charges incurred on most polluting vehicles
  - Scheme should incentivise switch to 100% biodiesel
    - Minimal environmental impact
    - Closed loop carbon cycle

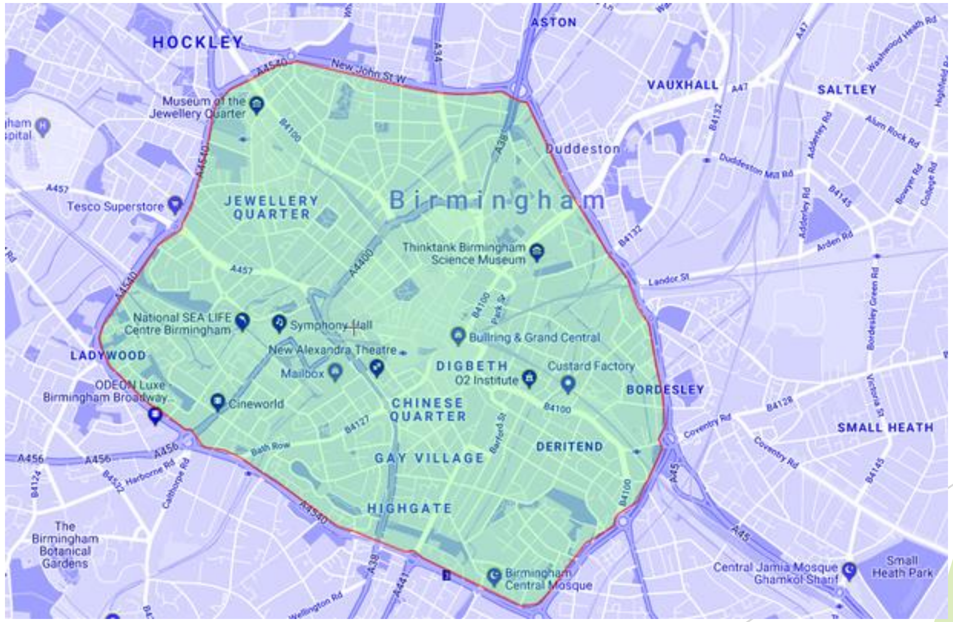
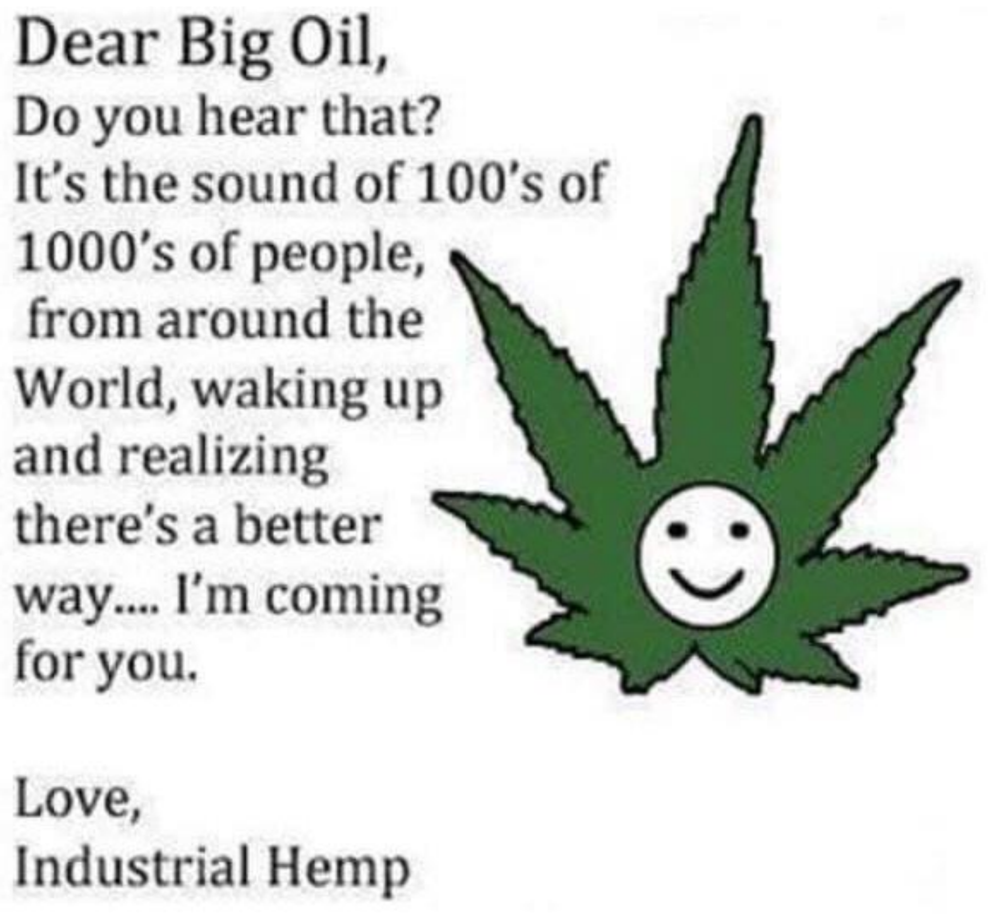


Figure 11: Birmingham Clean Air Zone.

Conclusions

- Essential for the UK Government to achieve net zero target **as soon as possible**
- Supply of diesel could be affected post-Brexit transition
- Industrial hemp shows promising qualities to **clean** the environment
- Industrial hemp could be a viable crop for a **domestic renewable energy source**
- Pressure should be put on the government to **remove the regulations** surrounding hemp cultivation to make it more viable
- More research is needed related to the combustion performance of HTCR® biodiesel (and its other fractionates) in automotive and aviation engines
- TCR® technology has promising benefits to car owners living in the greater Birmingham area, nationally, and internationally
- Expected project time frame is **12-18 months**
- Bench cost for the project is **£256,000**



Thank you!

Any questions?

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