HBBA Study: Conclusions

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General remark

- Main output of HBBA study is to provide data base
  - Facilitates practical blending
  - Will also assist scientific research

- Data base has been created
  - Detailed data available in appendix to HBBA report
  - Made generally accessible via BioJetMap

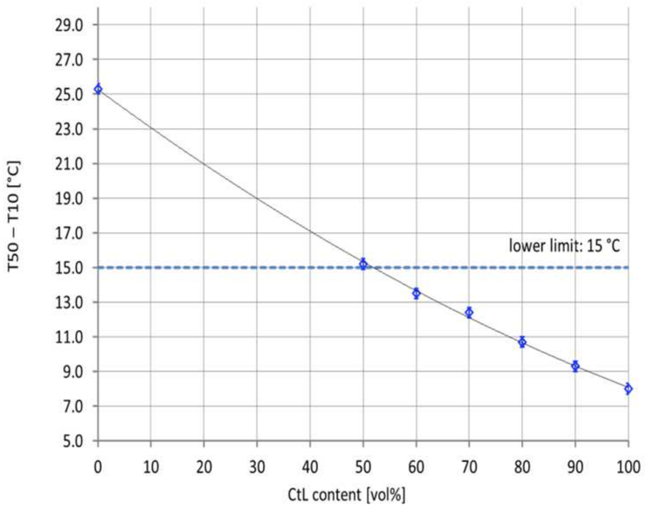
- In addition to data base, various insights gained

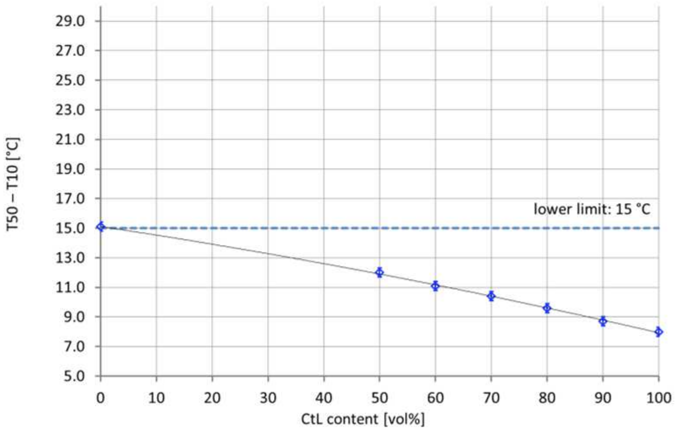
- Key conclusions outlined in this presentation

Constraining factors for FT and HEFA

- Constraining factors for FT SPK
  - Distillation curve gradients, particularly T50-T10
    - For three conventional kerosene, limited to some 50% blend ratio
    - For one conventional kerosene, limited to some 25% blend ratio
    - For one fuel with narrow distillation curve, blends off-spec at all ratios
  - Aromatics: Maximum blend ratio achievable 40% - 70%
  - Density: Maximum blend ratio achievable 50% - 75%

- Constraining factors for HEFA SPK
  - Aromatics: Maximum blend ratio achievable 40% - 70%
  - Density: Maximum blend ratio achievable 40% - 70%



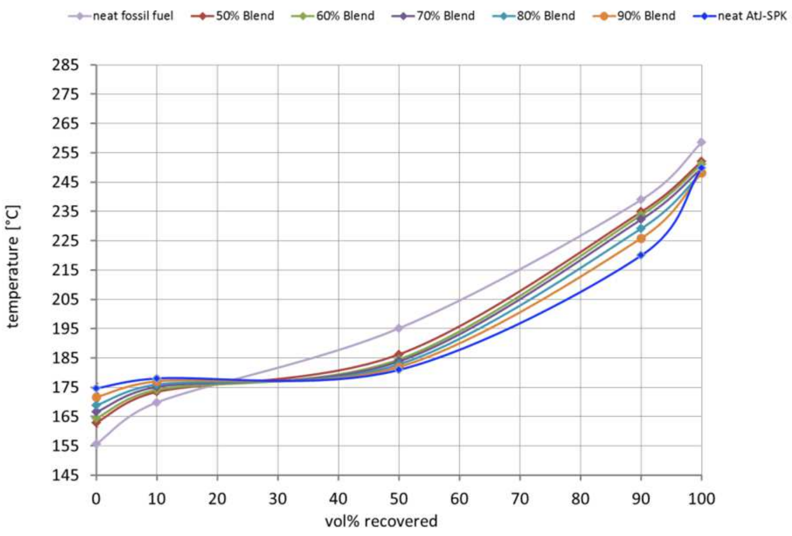


Two examples of T50-T10 for blends with CTL

Constraining factors for SIP and ATJ-SPK

- Constraining factors for SIP fuel
  - Viscosity at -40°C: Maximum in spec blend ratio achievable ca. 30%
  - Aromatics: Maximum blend ratio achievable 40% - 70%
  - Density only constraining factor at blend ratios well above 80%

- Constraining factors for ATJ- SPK
  - T50-T10
    - Only low blend ratios achievable, max. 30%
    - For kerosene with narrow distillation curve, blends off-spec at all ratios
  - Aromatics: Maximum blend ratio achievable 40% - 70%
  - Density: Maximum blend ratio achievable 40% - 70%

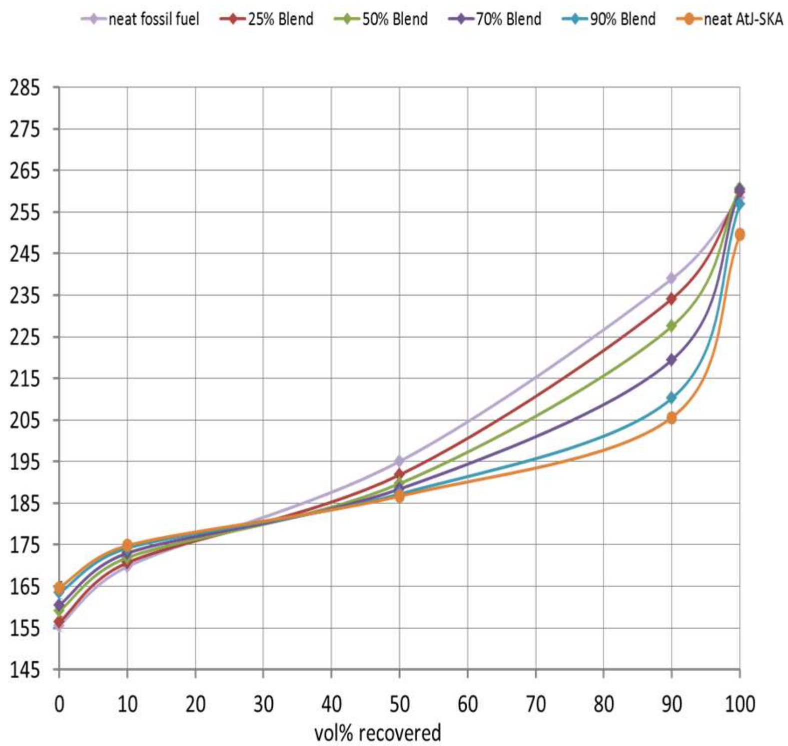


Distillation curve of ATJ-SPK and of blends

Constraining factors for ATJ-SKA and CH kerosene

- Constraining factors for ATJ-SKA
  - Distillation curve only constraint
    - Both T50-T10 and T90-T10
    - Maximum blend ratio between zero and 70%
  - For all other parameters, ASTM D7566 already met by neat fuel

- Constraining factors for CH kerosene
  - None
  - All ASTM D7566 parameters already met by neat fuel



Distillation curve of ATJ-SKA and of blends

Observations on destillation curve gradient

- For fuel samples analysed, importance of distillation curve gradient considerable, with major impact on CTL and ATJ blending ratios

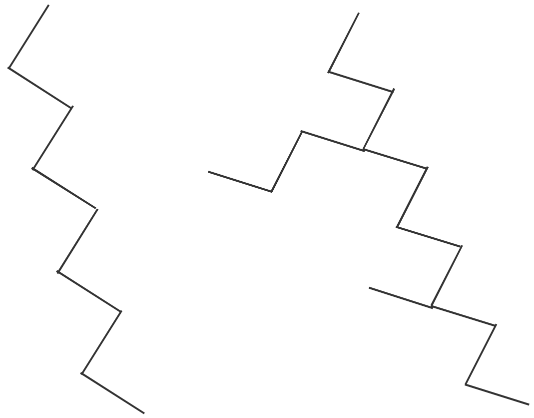
- Shallow distillation curve not necessarily inherent to CTL and ATJ-SKA production pathway
  - CTL with steep distillation curves used for ASTM certification
  - For ATJ-SKA producer states that pathway can also produce fuel meeting T50-T10 and T90-T10 requirements as neat fuel
  - May be an issue of extent of isomerisation, and hence cost of production

- Shallow curve likely inherent for ATJ-SPK, but ASTM gradient restriction perhaps not necessary
  - Distillation curve gradient restriction deliberately introduced in connection with CTL certification, to prevent combinations not covered in certification process
  - Applicability for ATJ pathway subject to debate
    - Fuel used in ATJ certification had low gradient from the onset
    - All the same, no issues observed

Assessment of blend ratio potential

- High biofuel blends in possible for most fuels analysed in HWWA study

- SIP limited by viscosity at -40°C
  - Achivable blend ratios 20 to 30%
  - SIP never designed for high blend ratios



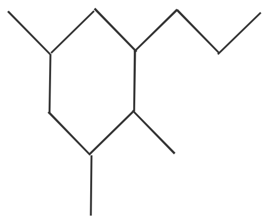
- N- and iso-paraffinic fuels requiring limited addition of aromatics and cycloparaffins for blend ratios much in excess of 50%
  - Suitable components being developed by Virent / Shell
  - HDO-SK provides cycloparaffins, HDO-SAK aromatics

- ATJ-SKA and CH kerosene designed as drop-in fuels, hence in principle no blend restrictions

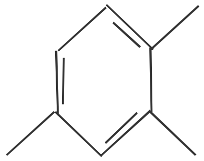
Observations on fuels not included in lab analyses

- Three fuels not included in Lab analysis since no samples were available

- Market position for HDO-SK and HDO-SAK clear
  - Intended to complement blends fuels composed of n- and iso-paraffins
  - HDO-SK provides cycloparaffins
  - HDO-SAK provides aromatics



- Market position of HDCJ / Pyrolysis less clear
  - Certification oriented towards certifcation for binary blends with conventional fuel
  - However, aromatics content of some 50% will severely restrict blend ratios
  - Also, resulting blends will have unneccessarily high aromatics content
  - Might be besser positioned to complement blends



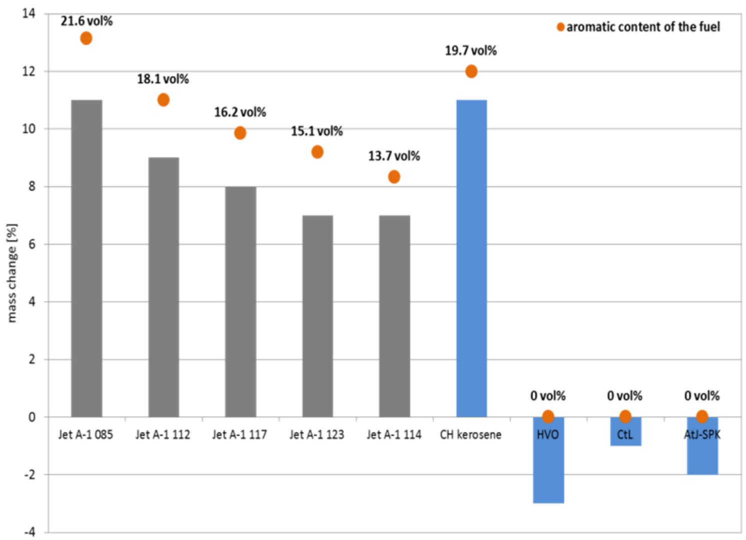
The two-faced role of aromatic compounds

- Presence of aromatic compounds required to preserve tightness of materials made from nitrile-butadiene rubber
  - Aromatics-free material not harmful in itself, but aromatics required for seal swell
  - No significant difference between HEFA, CTL and ATJ-SPK

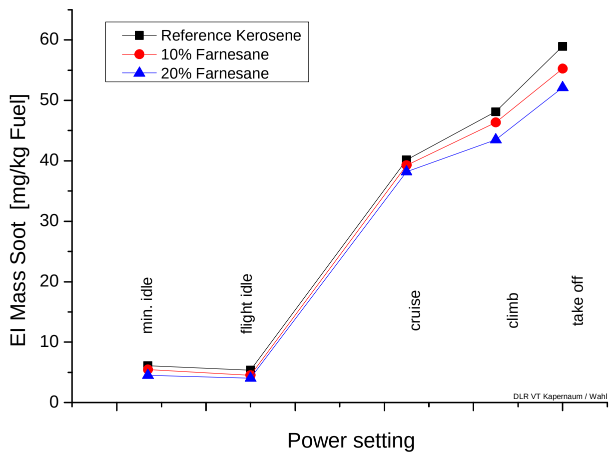
- However, adverse effect on emissions
  - Reduction in aromatics content gives better burning fuel
  - Primarily relevant for soot emissions

- Hence, aromatics content should be limited to the minimum necessary.

Effects on mass change of NBR seals

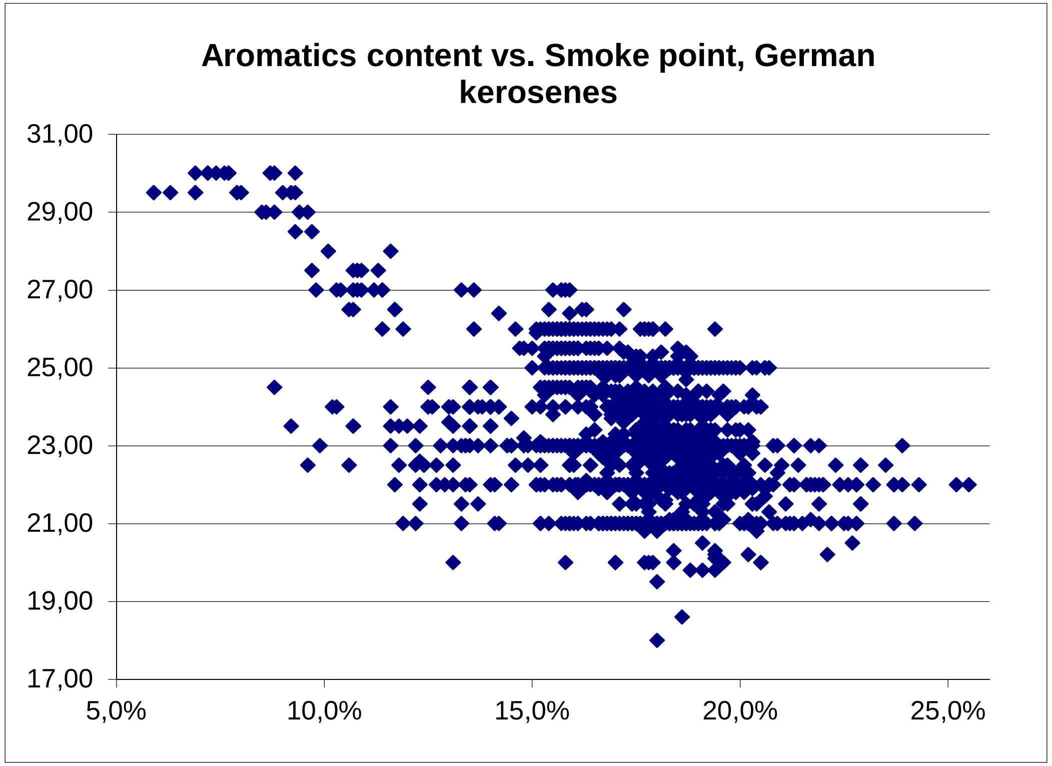


Soot Mass, in mg/kg fuel



Outlook: Further research required

- Not all aromatics are the same
  - «Aromatics» overall term for many different kinds of compounds
  - Not all aromatics have the same effect on emissions
  - Example: monoaromatics probably different from biaromatics
    Ideally some aromatics may be found that produce seal swell but have little adverse effect on emissions



- Reserch on effects of different kinds of aromatics desirable

- Also, empirical determination of size of soot - contrails - climate effects desirable
  - Current estimates ranging from «as bad as all CO2 accumulated emissions from aviation together» to «not very much»
  - Makes setting of priorities difficult