(FP7/2007-2013)
grant agreement n° 213266

http://www.alfa-bird.eu-vri.eu

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ALFA-BIRD:
Alternative Fuels and Biofuels for Aircraft Development

Overview of main results

prepared by Dr Marina Braun-Unkhoff (DLR) and the Steering Committee based on a collaborative work within Alfa-bird, a FP7 EU project (co-ordinator O. Salvi (EU-VRi) and Airbus)

2nd AirTN Forum

Greening and independence from fossil fuels

8th – 9th October 2012

Frankfurt Airport, Germany

Alfa-bird
Alternative Fuels and Biofuels for Aircraft Development

- Introduction
- Basics – Consortium, Main objectives, Tasks
- Results – achieved (*examples*)
  - SP 1 Overview of potential alternative fuels
    - Selection of fuels
  - SP 2 Assessment of the suitability
    - 2.1 Exp. tests for injection and combustion laminar flame speed, ignition delay time, species profiles, particles,
    - 2.2 Engine system integration
    - 2.3 Aircraft system integration
    - 2.4 Safety, standards and regulations
- Key Points and Outlook

Aviation Fuels
past

price

operation

efficient, low emission, safe (specification)

Aviation Fuels
nowadays

sustainability

security of supply

price

operation

efficient, low emission, safe (specification)

Aviation Fuels
Criteria

Our Vision

↗ Is for carbon neutral growth

operation

efficient, low emission, safe (specification)

commitments

policy

Noise
-10dB

CO_2
-50%

ACARE

NO_X
-80%

production

avaible, economic, sustainable

- **energy policy for europe**
- **limit T increase to 2 °C**
- **renewable energy roadmap**
- **binding 20% target till 2020**
- **ETS: aviation included 2012**

aireg

Aviation Initiative for Renewable Energy in Germany e.V.

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Alternative Aviation Fuels
Incentives and programmes, Europe

- **JTI CleanSky**
  public-private partnership, 1.6 bil. € (EC: 800 bil. €)
  improvements of aviation & turbine industry
  to achieve ACARE goals

- **S**ingle **E**uropean **S**ky **A**TM **R**esearch (**SESAR**)
  public-private partnership, 1.9 bil.€ (EC: 1.4 bil. €)

- Alternative Fuels and Biofuels for Aircraft Development (**ALFA-BIRD**)
  EU/FP7 co-operation/RTD

- Biofuels in EU **S**trategic **E**nergy **T**echnologies (**SET-Plan**)
  2010 **E**uropean **I**ndustrial **B**ioenergy **I**nitiative (**EIBI**)
  EU Biofuel Flightpath

- Sustainable Way for Alternative Fuels and Energy for Aviation (**SWAFEA**)
  Study, European Commission

Alfa-Bird : basics

Basics

- Alternative fuels and biofuels for aircraft development
- Start July 2008, End June 2012
- 24 main beneficiaries from 8 countries
- http://www.alfa-bird.eu-vri.eu/
- European Commission – Directorate General Research
  7th Framework Program, Aeronautics and Air Transport (AAT)
  RTD project, total budget 9.7 MEuro, EU Grant 6.8 MEuro.

Research

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Alfa-Bird : main objectives

Basics

- **Alternative fuels and biofuels for aircraft development**
- **Start July 2008, End June 2012**
- **24 main beneficiaries from 8 countries**
- **http://www.alfa-bird.eu-vri.eu/**
- European Commission – Directorate General Research

  7th Framework Program, Aeronautics and Air Transport (AAT)

  RTD project, total budget 9.7 MEuro, EU Grant 6.8 MEuro. **Research**

Main objective

- To develop the use of alternative fuels in aeronautics **with a middle / long term perspective**.
  - Considering the possibility of revisiting **fuel specifications**
  - **Re-considering the whole aircraft system** (fuel, engine and ambience)

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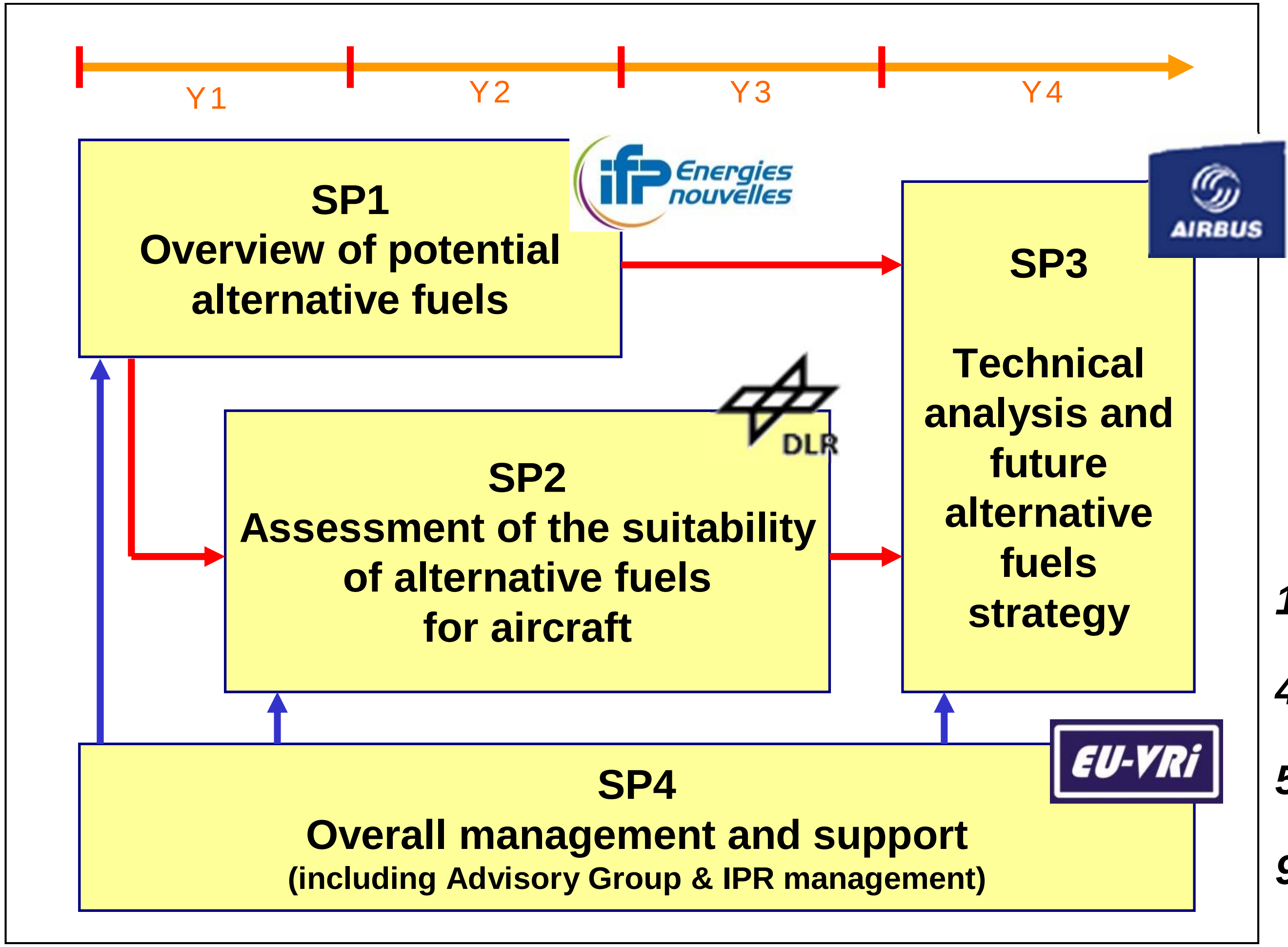
Alfa-Bird : workplan



14 WP

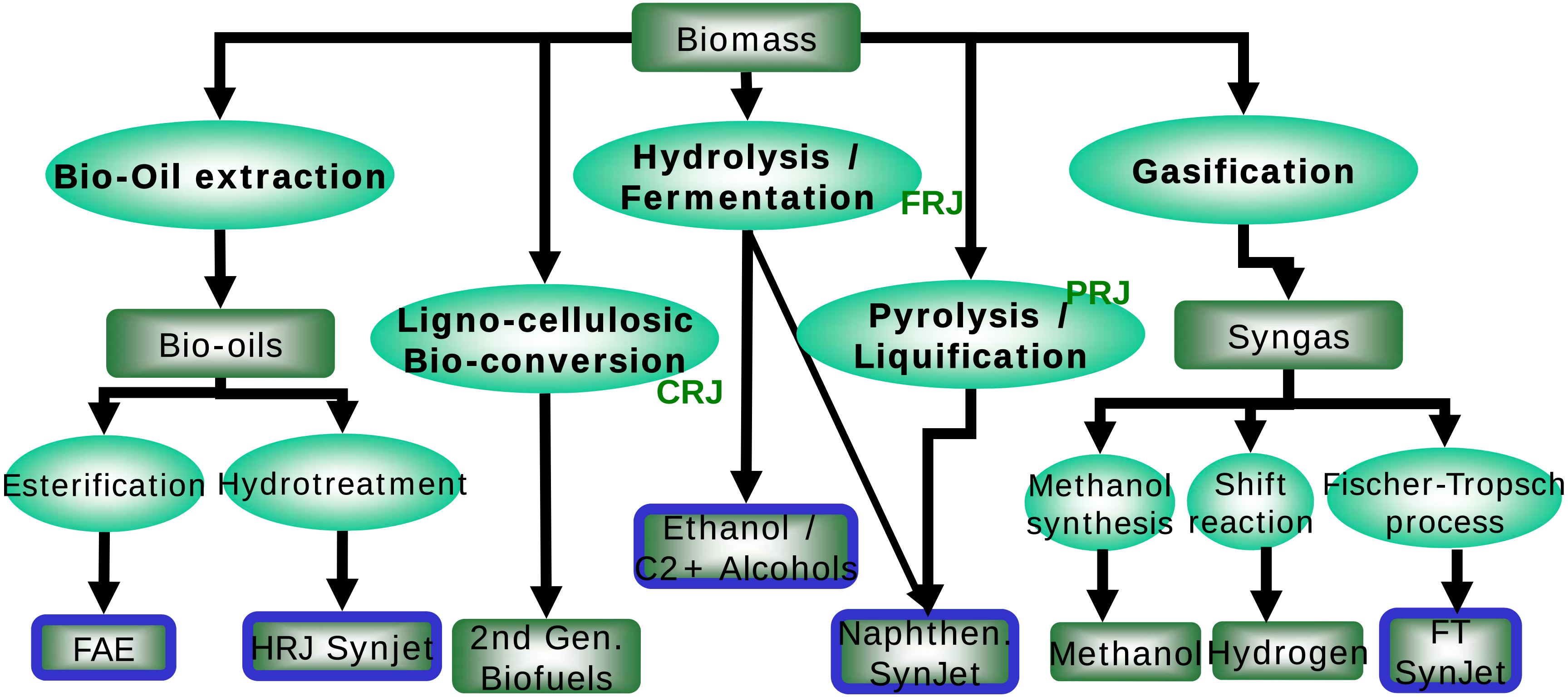
44 tasks

52 deliverables

9 Milestones

SP1 Selection of the 4 main promising pathways

Fuel survey and economy: selection of 12 blends



Certified:	**SSJF 1999**
	FSJF 2008
	FT-SPK 2009
	HEFA-SPK 2011

SP1 Selection of the 4 main promising pathways

Fuel survey and economy: selection of 12 blends

- **Blends could be outside Jet fuel specification compositional boundaries**
- **FRL: Fuel readiness level** defined by CAAFI
  a measure of the fuel's progress towards full commercialization
- **Fuel matrix built around three axes**

Paraffinic compounds ➔ FRL 7-9	*Short term view*	
Naphthenic compounds ➔ FRL 3	*Middle term view*	
Oxygenated compounds ➔ FRL 1	*Long term view*	

- **Based on standard characterization**
  ASTM D7566: allowing up to 50% Fischer-Tropsch fuels "synthetic paraffinic kerosene" SPK in jet fuel blends

FSJF
FT-SPK
FT-SPK+50% naphthenic cut
FT-SPK + 20% 1-hexanol
FT-SPK + 10% Furane
FT-SPK + 20% Furane
FT-SPK + 30% Furane
FT-SPK + 10% FAE
FT-SPK + 20% FAE
FT-SPK + 30% FAE
FT-SPK + 50% HRJ
FT-SPK + 75% HRJ

FSJF: Fully Synthetic Jet Fuel
FT–SPK: Fischer-Tropsch Synthetic Paraffinic Kerosene
HRJ: Hydrotreated Renewable Jet fuel
FAE: Fatty Acid Esters

SP1 Selection of the 4 main promising pathways

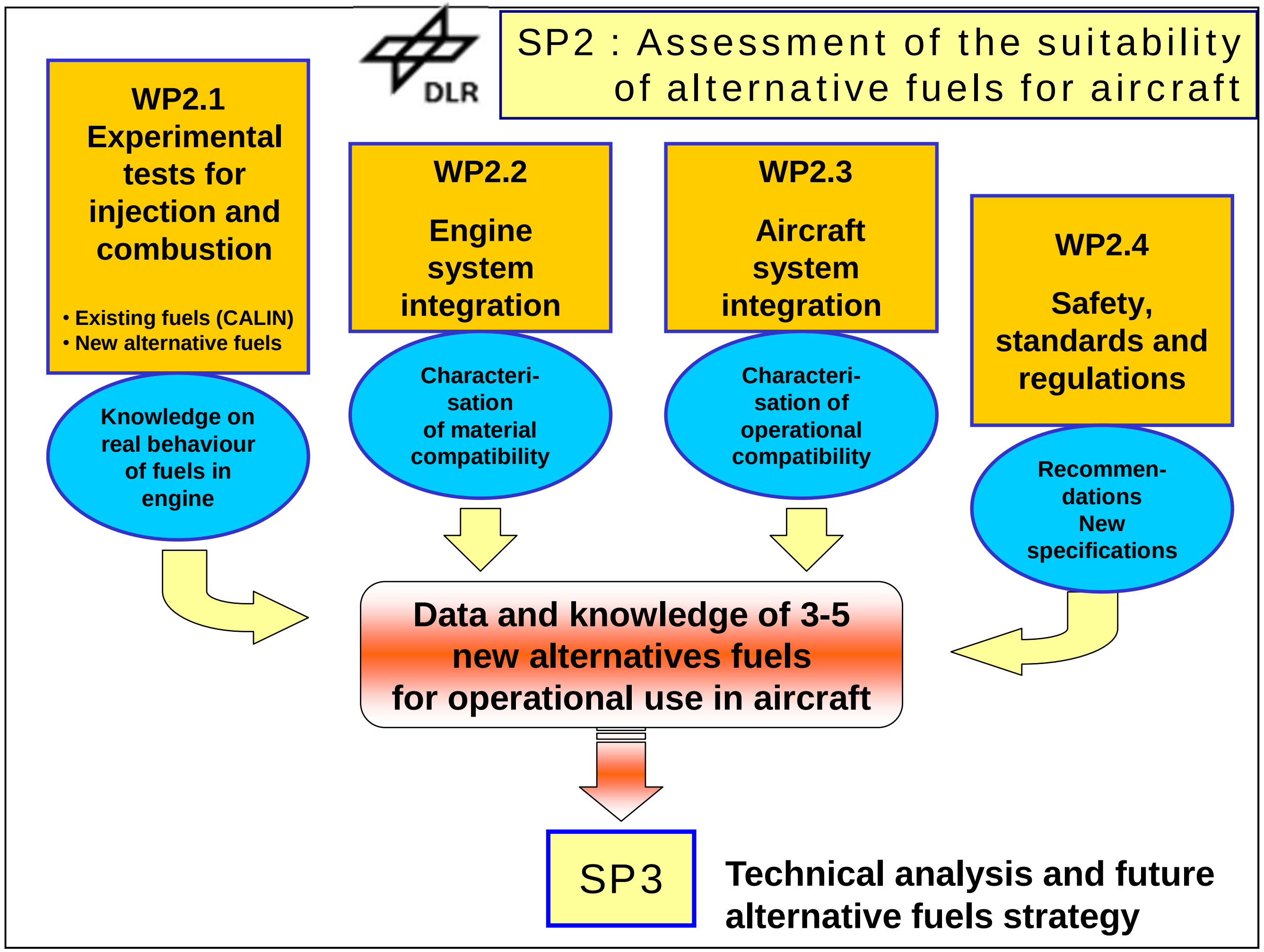
Alternative Fuels selected

FSJF
FT-SPK
FT-SPK+50% naphthenic cut
FT-SPK + 20% 1-hexanol

FRL

- Two 100% synthetic jet fuels
  - CtL (FSJF) — 3-6, mid-term view (certified 2008)
  - GtL (FT-SPK) — 7-9, short term view (certified 2010)
- Two blends
  - GtL + 20% 1-hexanol, — 1, long-term view
  - GtL + 50% naphthenic cut — 3, mid-term view
- FSJF *for relative comparison* — 3-6,
- Jet A-1 *for absolute comparison* — 9

SP2 Assessement of the suitability



TP 2.1.1–2.1.3
ONERA,
TU Graz,
DLR,
ICARE,Toronto
KIT (Uni Ka)

TP 2.2.1–2.2.6
RR-UK
IFP
ONERA
USFD
Technologica
Airbus F

TP 2.3.1–2.3.2
DASSAV
Airbus UK
Technologica

TP 2.4
INERIS
Airbus UK

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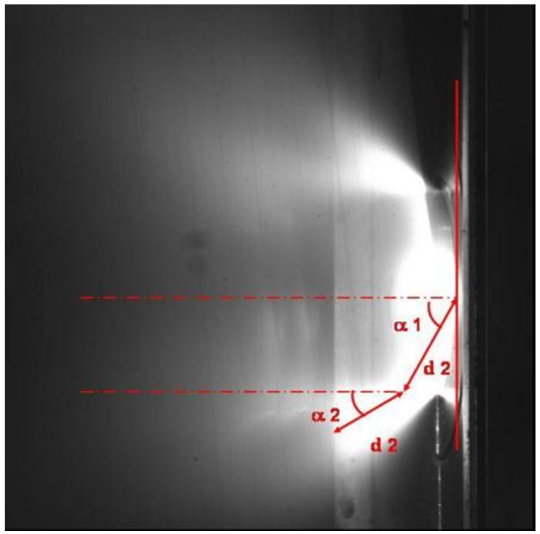
Focus on selected SP2 / SP3 results

SP 2.1 Injection and Combustion

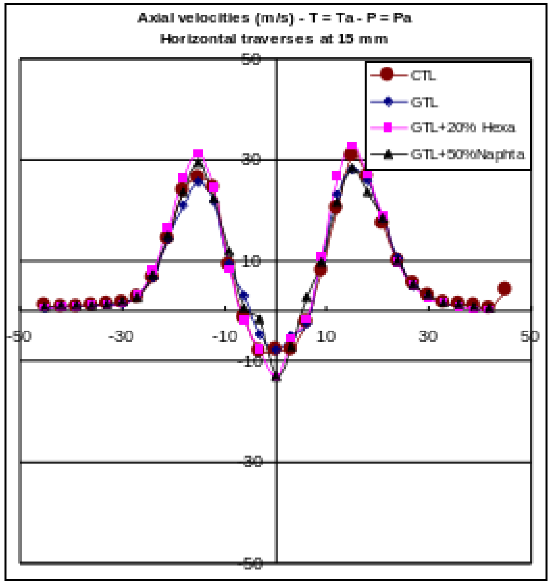
Atomization – Evaporation under non-reactive conditions

LACOM tests – Main results

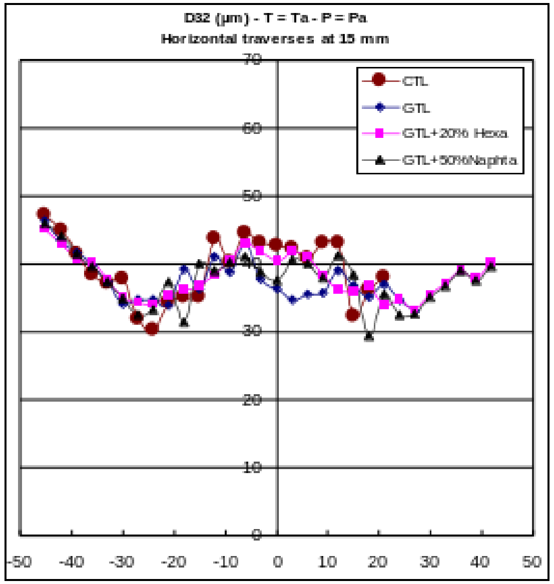
- **Similar behavior of the AF with respect to:**
- **spray geometry, granulometry, velocity distributions @ op. conditions**
- **1 < p < 10 bar ; 293 < T < 553 K ; industrial injection system**



Spray semi-angle



Droplet velocity axial



Sauter mean diameter

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Focus on selected SP2 / SP3 results

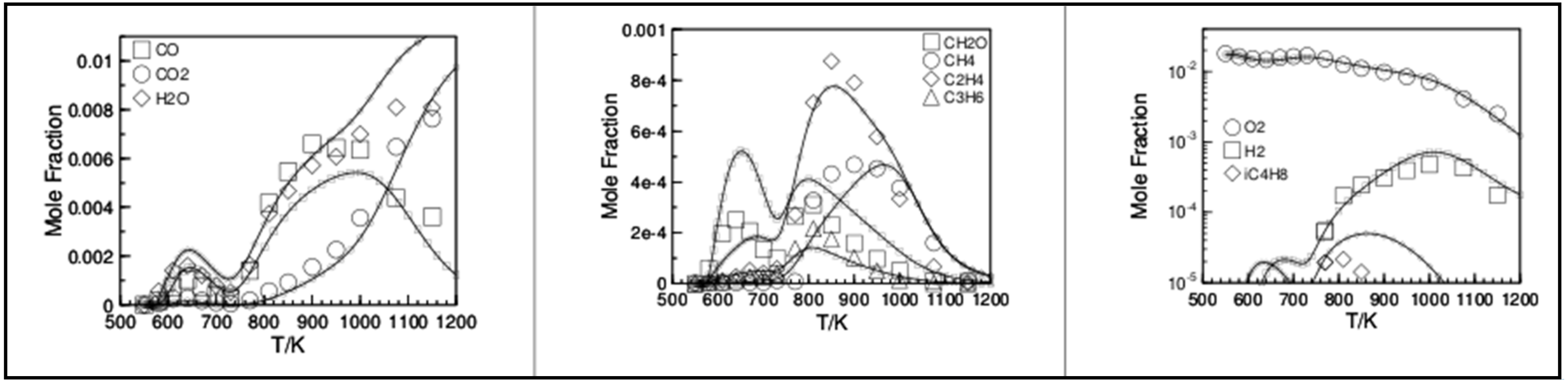
SP 2.1 Injection and Combustion

Detailed investigation of oxidation – species: towards reaction model

JSR tests – Main results

- All 4 fuels studied; initial fuel conc. = 1000 ppm
- p = 10 bar, T = 550-1150 K, τ = 1 ms; φ = 0.5; 1; 2.
- Complex kinetic scheme built for each fuel (surrogate)
- Kinetic model used for prediction of laminar flame speed and ignition delay time

Gtl+50% naphthenic cut, $\varphi = 1$; $p = 10$ bar; $t = 1$ ms



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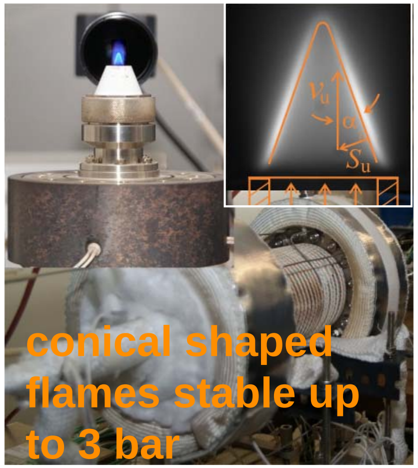
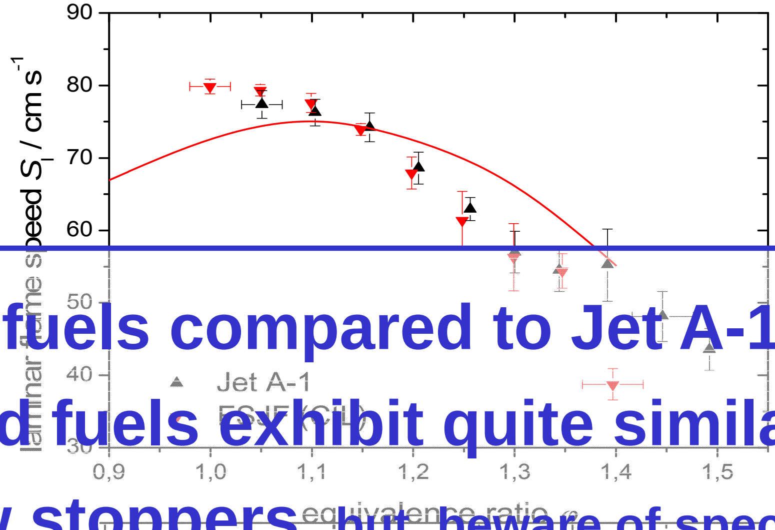
Focus on selected SP2 / SP3 results

Combustion Properties

- Laminar flame speed

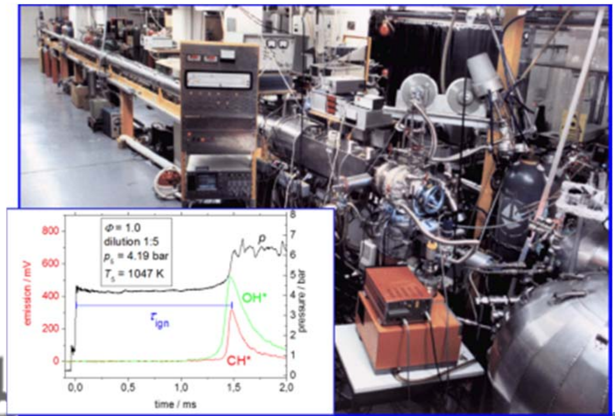


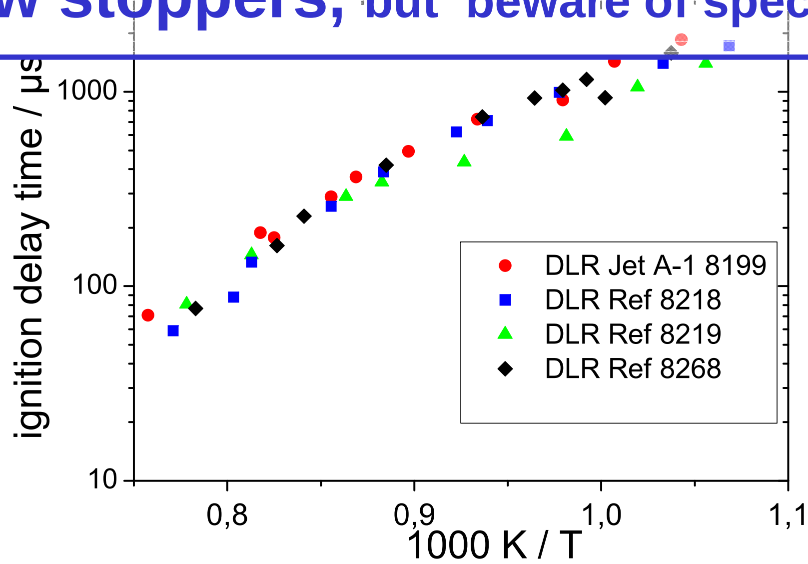


Alternative fuels compared to Jet A-1

- All tested fuels exhibit quite similar
- No show stoppers, but beware of specs.

- Ignition delay time





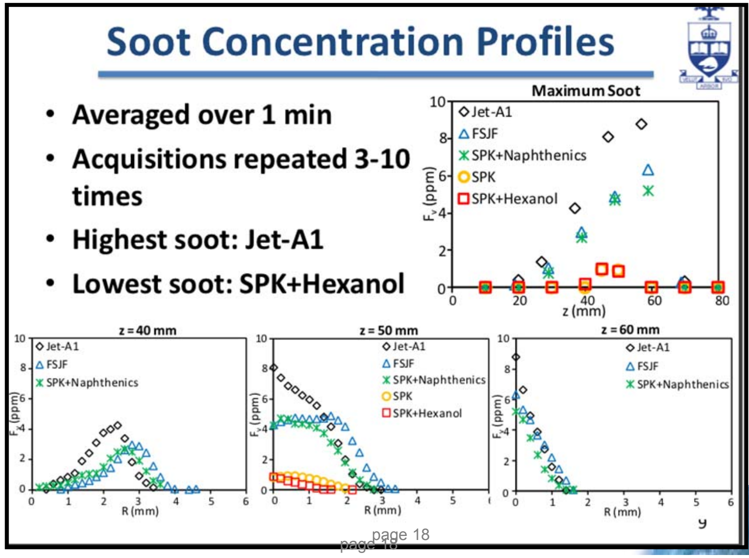
Focus on selected SP2 / SP3 results

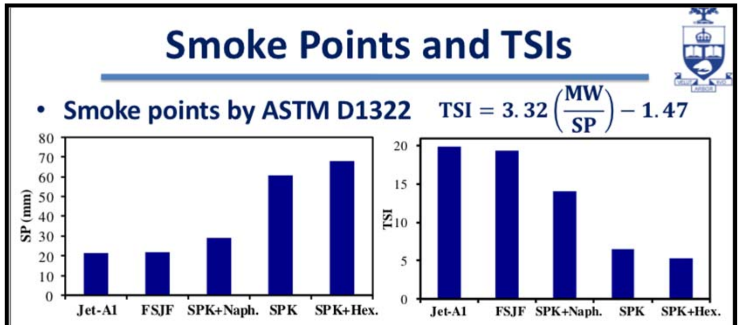
SP 2.1 Injection and Combustion

Emissions: Laminar coflow flames test rig

Soot formation - Main results

- Gaseous species concentrations, soot volume fraction, temperature
- Sooting tendency: Jet A-1 > FSJF > SPK+nc > SPK >SPK+1-hexanol
- Species concentrations and temperature profiles similar
- FSJF and SPK + naphthenic cut have the same behavior





Fuel	Aromatics (v%)
Jet-A1*	18.5
FSJF†	10.7
SPK+ Naph.†	4.6
SPK†	< 0.1
SPK+ Hexanol†	< 0.1

*measured by ASTM D1319 method
†measured by IP 436 method

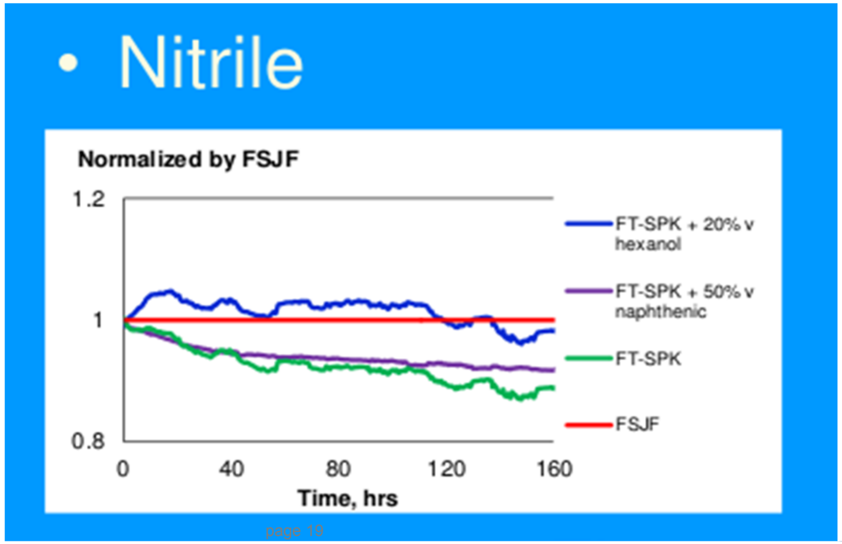
Focus on selected SP2 / SP3 results

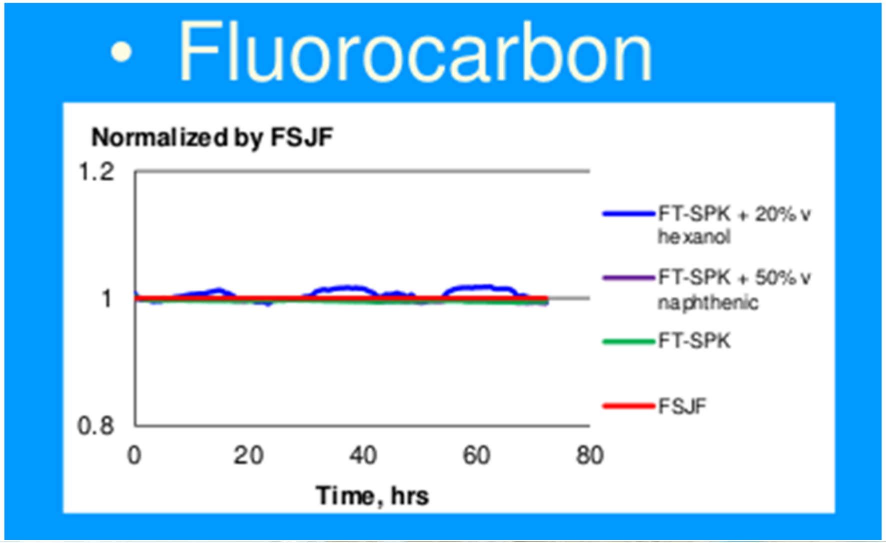
SP 2.2 Engine system integraton

Material compatibility

Stress relaxation tests – Main results

- 3 materials tested: nitrile, fluorosilicon, fluorocarbon
- Best compatibility for fluorocarbon O-rings
- Nitrile O-rings easily affected by fuel's composition (esp. aromatic content)
- Impact of changes of chemical structures on stress relaxation process





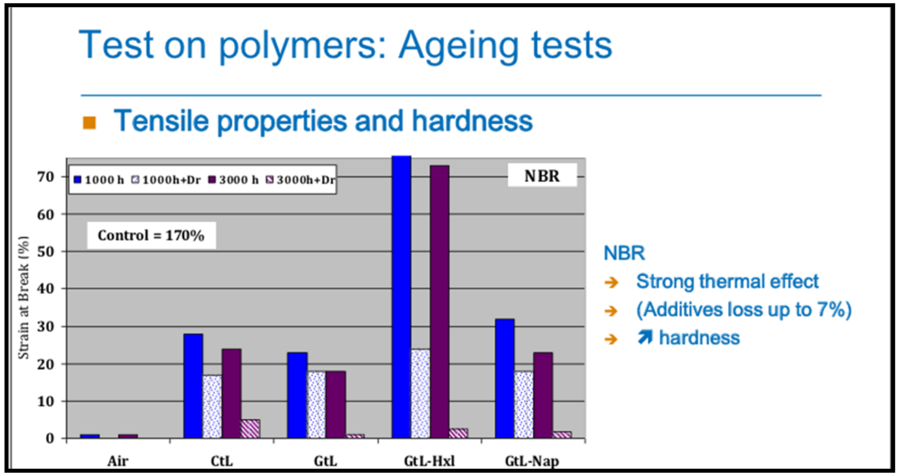
Focus on selected SP2 / SP3 results

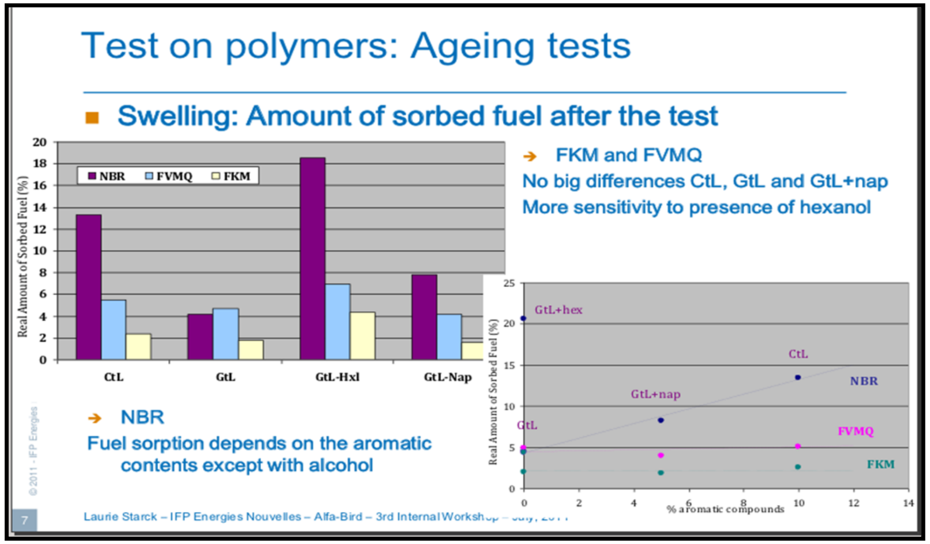
SP 2.2 Engine system integration

Material compatibility: Performance elastomers/non-metallic materials

Ageing tests – Main results

- Similar behavior of CtL, GtL, GtL + 50% naph. cut with the 3 elastomers
- Hexanol greatly weakens NBR and FVMQ
- FKM is the best elastomer in terms of ageing





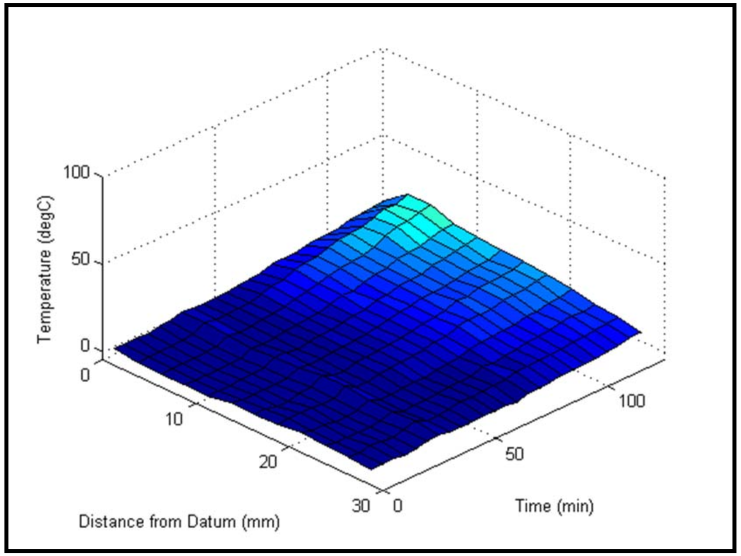
Focus on selected SP2 / SP3 results

SP 2.2 Engine system integration

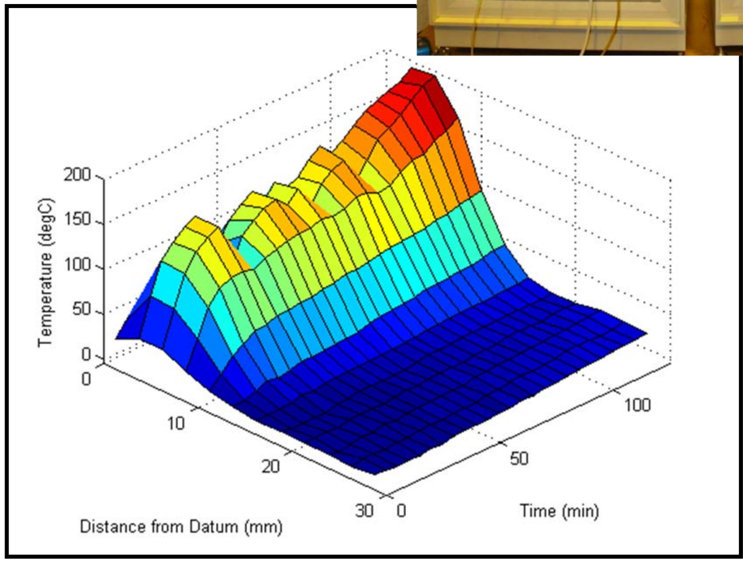
Evaluation of the fuel thermal stability

HIRETS – Main results

- GtL > GtL + 20% hexanol > CtL > GtL + 50% naph. cut
- Concerns about GtL + 50% naphthenic cut



CtL



GtL + 50% naphthenic cut

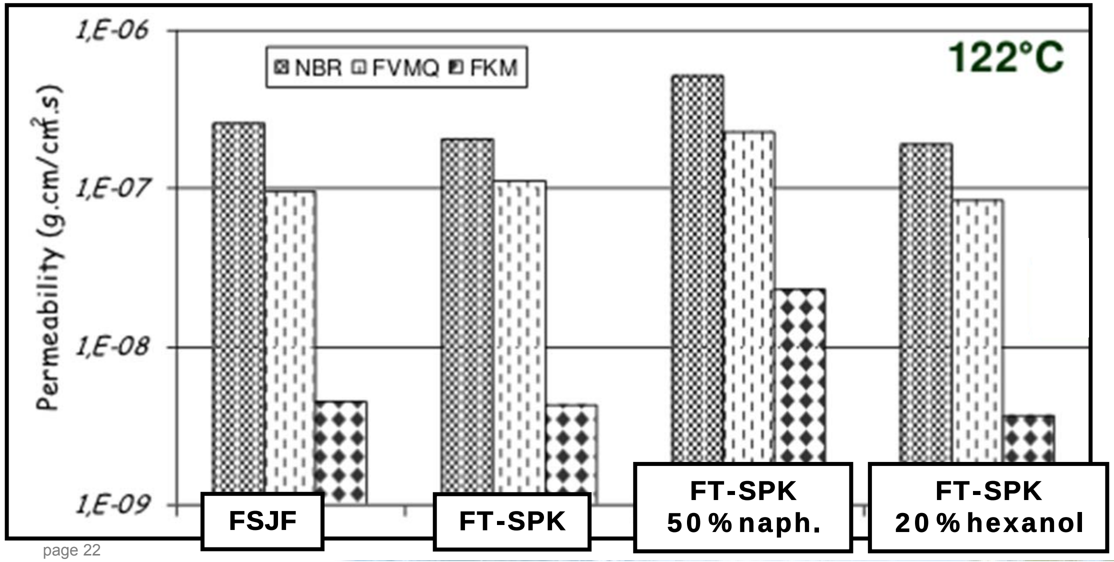
Focus on selected SP2 / SP3 results

SP 2.3 Aircraft system integraton

Operational compatibility (aircraft system): Elastomers

Permeability tests – Main results

- 3 elastomers tested: NBR, FVMQ, FKM,
- Best compatibility for fluorocarbon O-rings
- No large differences for FSJF, FT-SPK, FT-SPK + 50% naphthenic cut
- Increase of permeability for the blend Gtl + hexanol (diffusion)



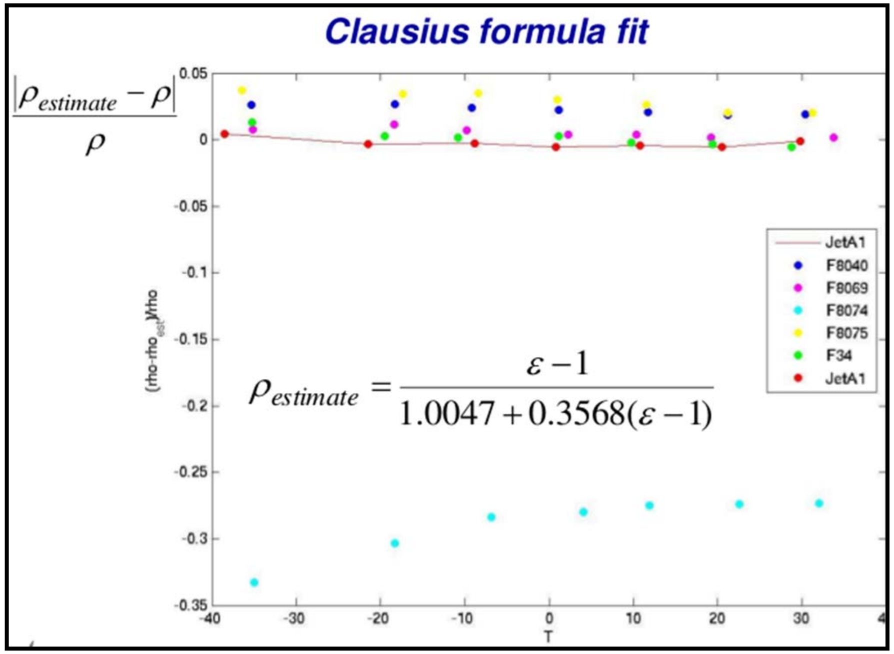
Focus on selected SP2 / SP3 results

SP 2.3 Aircraft system integraton

Operational compatibility: Gauging, test on fuels

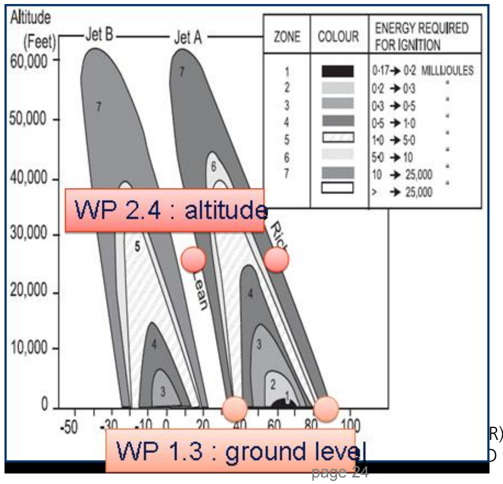
Gauging issues – Main results

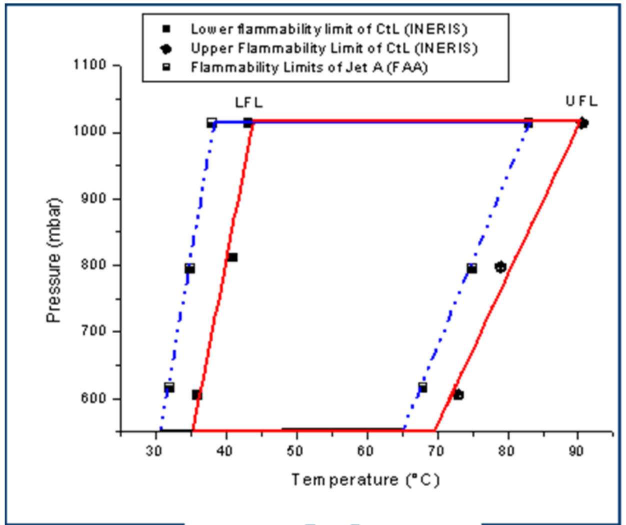
- GtL and, to a minor extent, CtL are close to drop-in fuels
- GtL + 20% hexanol, GtL + 50% naph. cut are not drop-in fuels



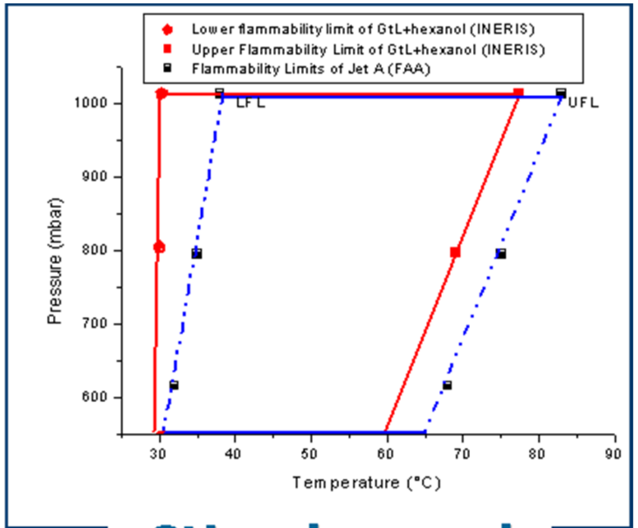
Focus on selected SP2 / SP3 results

SP 2.4 Safety, standards, and regulations
Flammability domain: Shifts wrt to altitude





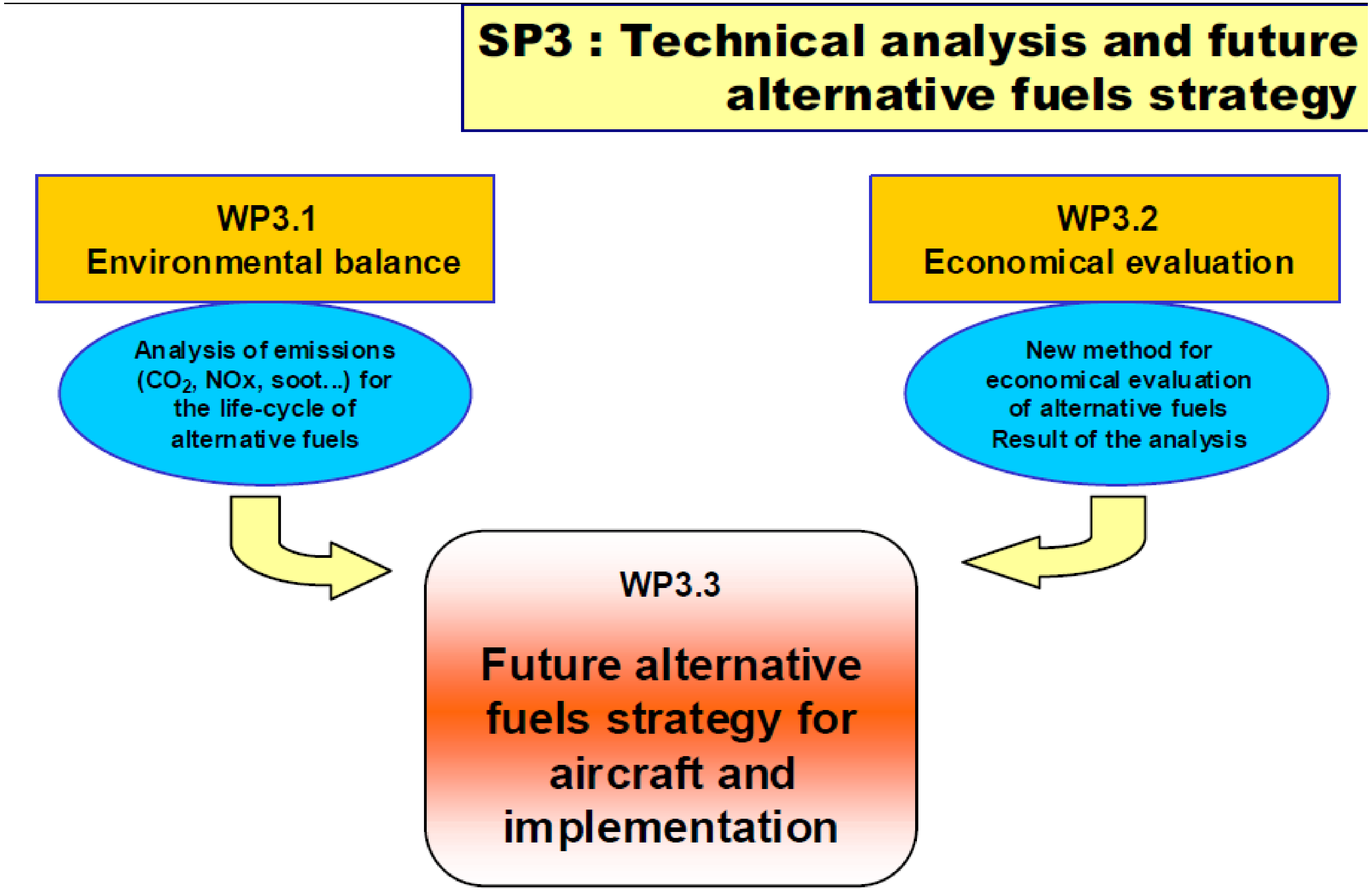
CtL



CtL + hexanol

R)
D team

SP3 Technical analysis and future alternative fuels strategy



Focus on selected SP2 / SP3 results

SP3 : LCA, business model and socio-economical analysis

Biofuel Substitution Model

Model parameter

[%] installed capacity GtL — 30

[%] installed capacity BtL/CtL — 40

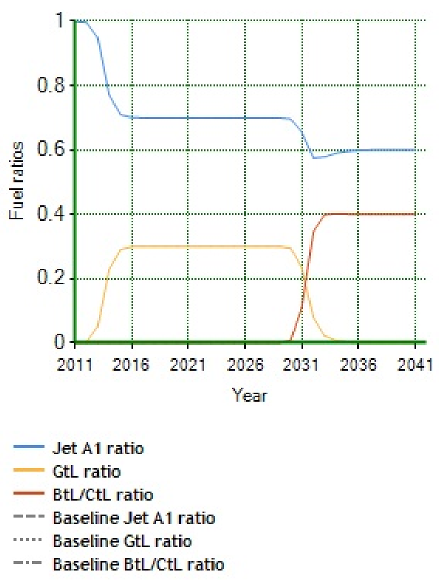
Carbon tax [ct/l] — 0.7

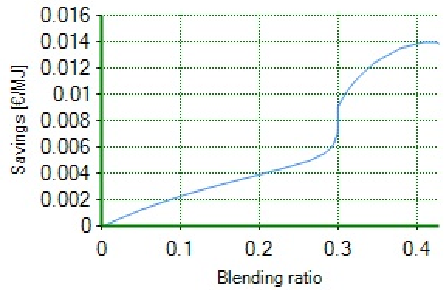
Time period	'11-'16	'16-'21	'21-'26	'26-'31	'31-'36	'36-'41
Oil price change	3%	0%	0%	0%	0%	0%

Go! Reset Delete

Select baseline: 0 Select current run: 0

Comment on current run:





5

ID	'11-'16	'16-'21	'21-'26	'26-'31	'31-'36	'36-'41	GtL plants	BtL/CtL plants	carbon tax	biofuel ratio 2020	biofuel ratio 2040	max savings	comment
0	3	0	0	0	0	0	30	40	0.7	0.3	0.4	0.015	

Save / Load data

Enter filename of data to save (overwrites if file exists): Save

Select file to load: test.dat Load

SP2 / SP3 results : synthesis

Synthesizing fuel assessment, to give an alternative fuel ranking

- **Reference fuel: FSJF** (CtL, 100% from coal), **Jet A-1 used as an anchor**
- **Compared fuels :**
  - **Alfa-bird fuels:** FT-SPK (GtL), GtL+50% NC, GtL+20% 1-hexanol
  - **SWAFEA fuels:** HEFA, HEFA + 50% NC, HEFA+25% Jet A-1, Jet A-1+10% FAE
- **4 Categories with several criteria :**
  - Technical & Technological
  - Regulation
  - Environmental
  - Economical
- **4 possible results for each criteria assessment**
  - Better than CtL or Jet A-1
  - As good as CtL or Jet A-1
  - Worse than CtL or Jet A-1
  - Questionable

SP2 / SP3 results : synthesis

Synthesis table (1)

Category	FT-SPK (GtL)	FT-SPK + 50% naphthenic cut	FT-SPK + 20% hexanol
Technical & Technological	11 X 24 X 2 X	9 X 23 X 3 X	8 X 14 X 10 X
Regulation	1 X 3 X	4 X	1 X 2 X 1 X
Environmental	4 X	4 X	3 X
Economical	X	X	X
Total	16 X 27 X 2 X	13 X 27 X 3 X	12 X 16 X 11 X
Assumed Ranking	1	2	3

Comparison with CtL (FSJF)

SP2 / SP3 results : synthesis

Synthesis table (2)

Category	FT-SPK (CtL)	FT-SPK (GtL)	SPK + 50% NC	FT-SPK + 20% hexanol	HEFA 100% HVO	HEFA + 50% NC	HEFA + 25% Jet A-1	Jet A-1 + 10% FAE
Technical & Technological	2 X	2 X	2 X	2 X	1 X	4 X 1 X	5 X	2 X 3 X NBR, FVMQ, FKM permeability test
Regulation	-	-	-	-	-	-		
Environmental	2 X	1 X 1 X 1 X LCA	1 X 1 X	1 X 1 X	1 X	-		
Economical	X	X	X	X	X	X	X	X
Total	4 X	1 X 1 X 3 X	1 X 3 X	1 X 3 X	2 X	4 X 1 X	5 X	2 X 3 X
Assumed Ranking	?	?	?	?	?	?	?	?

Comparison with Jet A-1

Synthesis: Conclusions (1)

- **Main technical problem in alternative fuel due to %aromatics** (mass density)
  - Need at least 8% aromatics → Assess the optimized aromatic quantity (minimum requirement)
- **Material compatibility is critical** (stress relaxation, elastomers)

  e.g. nitrile elastomer, the most used in aeronautics → problem X for all Alfabird fuels
  - Material compatibility tests are separated = weighting more than other criteria
- **Economical assessment** shows that for the moment alternative fuels studied within Alfabird are not competitive compared to conventional production processes
  - But there are leads to explore to improve the situation (incentives, market based measures...)
- **GHG emissions :** CtL > GtL + CCS ≥ Jet A1 > HEFA/BTL
  - But measurements and experiences are mandatory to adjust the results and have a better estimation
- **FSJF (CtL from SASOL) offers a constant and controlled quality reference** (compared to Jet A-1 which may be variable in content composition)

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Synthesis: Conclusions (2)

- **GtL seems to have better technical performance compared to GtL+NC/hex**
  (except for stress relaxation of nitrile O-ring) but impact on environment is mitigated and seems to be rather negative (based on LCA, compared to Jet A-1)
- **GtL+ NC is very interesting,** the one that mimic the most Jet A-1 composition
  - Comparable properties with better density than neat GtL(except for stress relaxation of nitrile O-ring)
  - NC might come from sustainable feedstock (liquefaction/pyrolysis), in the future
- **Oxygenated fuels are not "drop in" (GtL + hexanol and GtL + FAE)**

  But interesting in a long term view because of the improvement of environmental impact and some fuel properties. Technical barrier could be break as for the freezing point for FAE, showing rooms for improvement for the future
  - → Other tests could be done with other ratios? other alcohols? Other paraffinic cut?
  - → Improvement of oxygenated fuel properties might be compromised - too challenging concerning the aircraft /engine architecture
- **For "non drop-in" fuels**
  - Need to find an adequacy (doing compromises) between fuels, airframe/engine architectures, operations and logistics (fuelling infrastructures)

Synthesis : Conclusions (3)

- **Biomass feedstock could improve environmental impact**
  - **HEFA/BtL are the most interesting fuels**
  - HEFA and XtLs have been certified with a blend of 50 % with Jet A-1
  - Blends outside of certification range from SWAFEA compared to Jet A-1
    - No test failures for the moment except for Jet A-1 + 10% FAE
    - 100% HEFA should to have the same behaviour than 100% XtLs
- **100% BtL supposed to have same behavior & characteristics than XtLs**
  - We cannot verify and test because BtL is not available
- From Alfa Bird WTT analysis and from SWAFEA LCA analysis:
  - LCA better for 100% BtL and 100% HEFA than all other alternative fuels tested due to sustainable biomass (if available!)
  - BUT Land Use Change is not taken into account
    - LUC has an important impact according to the geographical location
    - iLUC and LUC need to be assessed in the frame of a global agreed methodology (RSB standards) (e.g. EU-VRi and R-Tech innovative tool)

Alfa-bird: Alternative Fuels and Biofuels for Aircraft Development

Conclusions and prospects

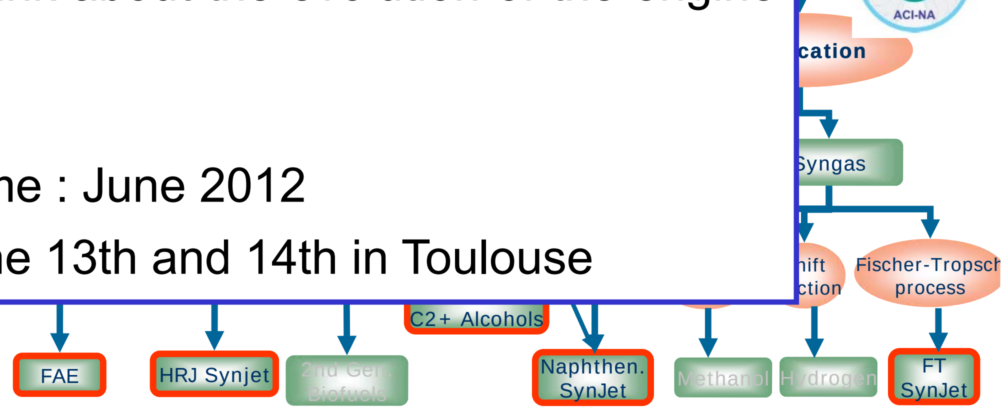
- Alfa-b… with short, …
  - C… SPK): p…
  - C… ith a d…
- 4 sele… from cha…
  - F…
  - F…
  - F… (…
  - FT-SPK + hexanol (20%)

    ➔ FRL 1

Alfa-bird is a R&D project
with the objective of
LOOKING FORWARD

- next steps envisaged on sustainable alternative fuels
- need for follow-up & additional research
- Certification (*e.g*. minimum of aromatics, new protocol)
- Industrials (*e.g.* think about the evolution of the engine and fuel adequacy)

- End of the programme : June 2012
- Final workshop : June 13th and 14th in Toulouse



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Alternative Fuels and Biofuels for Aircraft Development

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° ACP7-GA-213266

.. Thank you for your attention!

http://www.alfa-bird.eu-vri.eu
e-mail: alfa-bird@eu-vri.eu

e-mail: Marina.Braun-Unkhoff@dlr.de

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