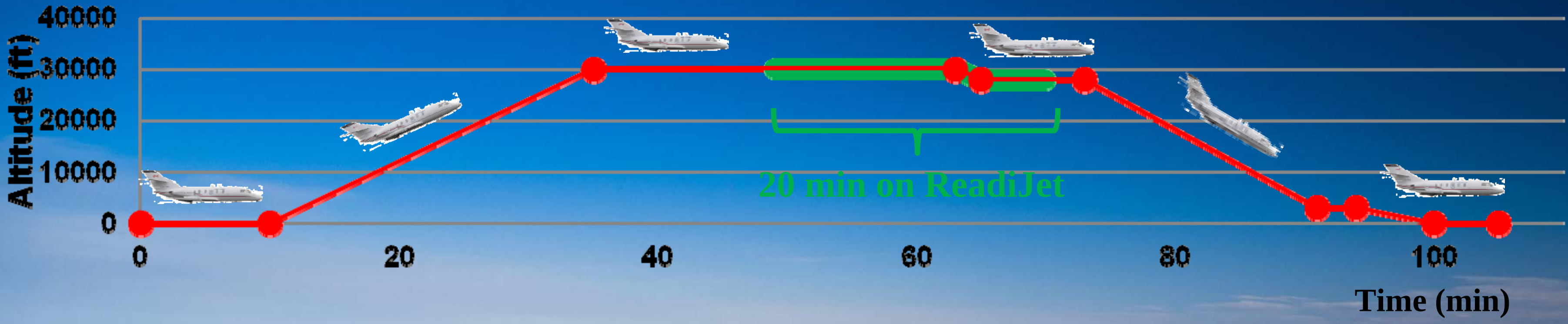
Flight Test: *A History Full of Firsts*

Canada claims world's first 100% biofuel-powered civil jet flight

Monday October 29th 2012 - National Research Council



Objectives

- Rapid throttle operations
- In-flight shutdown & relight
- One and then both engines on ReadiJet
- In-flight & ground based emissions measurements

Objectives

- GE CF700 engine core
- Measurements
    - Performance & operability
    - Emissions
- Special assembly requirements
- Standard and special instrumentation
- Hardware condition monitoring

Description	ASTM D1655 or D7566-11a* Limits	Jet A-1	ReadiJet
Net Heat of Combustion [MJ/kg] ASTM D4529	42.8 min	43.09	43.2
Density [kg/m³] ASTM D4052	775 - 840	814.8	803.7
Aromatics [% by volume] ASTM D1319	25 max	18.3	17.0
Total Sulfur [% by mass (ppm)] ASTM D5453	0.3 (3000)	0.019	0.002
Smoke Point [mm] ASTM D1322	18.0 min	22.0	21.0
Freezing Point [°C] ASTM D5972	- 40 max	-53.2	-50.3
Flash Point [°C] ASTM D5006	38 min	54.0	44.5
Kinematic Viscosity @ -20°C [cSt] ASTM D445	8.0 max	4.65	4.01
Electrical Conductivity [pS/m] ASTM D2624	50-600	146 @ 25.5° C	458 @ 24.0° C
Thermal Stability JFTOT @ 260°C ASTM D3241			
Tube Deposit	3 max	< 1	< 1
Filter Pressure Drop [mm Hg]	25 max	0.7	0.1
Distillation Temperature [°C] ASTM D86			
IBP	report	173.8	163.3
10%	205 max	185.8	181.4
50%	report	206.0	201.3
90%	report	241.9	230.9
FBP	300 max	259.8	248.3
Residue [% by volume]	1.5 max	1.2	1.0
Loss [% by volume]	1.5 max	0.3	0.7
Acid Number [mg KOH/g] ASTM D3242	0.1 max	0.007	0.06
Existent Gum [mg/100 mL] ASTM D381	7 max	< 1	< 1
Aniline Point [°C] ASTM D611A	report	55.6	56.7
Visual [-] ASTM D4176P1	Clear & Bright	Pass @ 24.0° C	Pass @ 25.0° C
Napthlene [% volume] ASTM D1840	3 max	1.89	0.18
* Water Content [mg/kg] ASTM D6304	Max 75	-	44

Comparison Summary

- **Comparison of all engine parameters agree within the instrumentation uncertainty of +/- 3% when running on Jet A or Readiiet. The one exception is the derived quantity of specific fuel consumption which shows an improvement that exceeds the instrumentation uncertainty.**

- **The independent fuel laboratory test results were received from Intertek. Two parameters are "out of spec". The first is MSEP-A but we have since concluded (and verified with AFRL) this is a "false" reading as a consequence of a known effect of the static dissipative additive that was used after the AFRL tests.**

- **The second is FAME which is reported at 14 ppm when the limit is less than 5ppm. Investigation continues but this result is believed to be due to the test procedure used. Nonetheless, for the moment it must be accepted as reported. Therefore, it is proposed that we invoke the provisions of the FAA SAIB NE-09-25R1 which allows for two uplifts (refueling operations) with FAME content between 5 and 30 ppm without any safety of flight implications.**

Risk Assessment

Assessment of the hazards:

A) Frequency of exposure at likelihood of occurrence: Select the description (1-6) below that best matches the frequency of exposure and the likelihood of occurrence of the hazard.

FREQUENCY OF EXPOSURE How often someone performs the task associated with the hazard	LIKELIHOOD OF OCCCURENCE What are the chance of the hazard happening
1: Continuous	1: Very likely (has happen/is expected)
2: Frequent (daily)	2: Likely (probable – it could happen)
3: Occasional (once per week)	3: Rare (seldom but possible)
4: Unusual	4: Very rare (very seldom but possible)
5: Rare (few per year)	5: Very unlikely (slight possibility)
6: Very rare (yearly or less)	6: Practically impossible

EXPOSURE + OCCURRENCE = PROBABILITY

B) Probability is the combination of the frequency of exposure and the likelihood of occurrence. Locate the number (1-6) down the left side of the chart that describes the frequency of exposure of the hazard. Locate the number that describes the likelihood of occurrence across the top of the chart. The box where they meet (A-E) is the probability rating.

FREQUENCY OF EXPOSURE	LIKELIHOOD OF OCCURRENCE					
	1	2	3	4	5	6
1	A	A	B	C	C	D
2	A	B	B	C	D	D
3	B	B	C	D	D	D
4	B	C	C	D	D	E
5	C	C	D	D	E	E
6	C	D	D	E	E	E

C) Determination of risk is the combination of probability of an injury/illness and the potential consequences if it should occur e.g. loss to people, property or environment. Select the description (1-5) below, that best matches the consequences, if an accident should happen involving the hazard.

PROBABILITY	CONSEQUENCES
A: Common or repeating occurrence	1: Fatality, permanent disability or significant loss
B: Known to occur, or "it has happened"	2: Serious injury or illness with or without lost time or other loss
C: Could occur, or "I've heard of it happening"	3: Moderate injury or illness with or without lost time or other loss
D: Not likely to occur	4: Minor injury or illness with or without lost time or other loss
E: Practically impossible	5: No injury or illness, lost time or other loss

PROBABILITY + CONSEQUENCES = DETERMINATION OF RISK

CONSEQUENCES	PROBABILITY				
	A	B	C	D	E
1	1	2	4	7	11
2	3	5	8	12	16
3	6	9	13	17	20
4	10	14	18	21	23
5	15	19	22	24	25

Risk rating is the number where the Probability letter meets the Consequence number, on the above chart. The risk rating (H,M,L) helps determine the priority for determining controls.

HIGH (1–6) Serious/significant hazard – a high priority for immediate control or elimination
MEDIUM (7 – 15) Moderate hazard – medium priority for controls as soon as possible
LOW (16–25) Minor hazard – lower priority for control after higher priority

Risk Assessment Matrix

			Probability				
	Personnel	Equipment	Very Likely	Likely	Possible	Unlikely	Remote
Severity	Death	Destruction	Formal Risk Assessment Mandatory				Peer Review & Test Plan Sign-Off
	Serious Injury	Extensive Damage					
	Minor Injury	Minor Damage					
	Illness or Disorientation	Loss of Functionality				Peer Review	

Risk Assessment

1. Hazard. Hot start when using biofuel.

Severity. Extensive damage to the aircraft engine.

Probability. Unlikely.

Mitigating Procedure. Biofuel blends are ASTM certified and will have been tested in GTL CF700 engine. Right seat pilot and FTE will closely monitor EGT and call through 700 degrees. Through 750 degrees throttle will be moved to cutoff position, start selector to motor/start-stop, and start button depressed. Normal peak EGT during start for engines is 670 degrees and max temperature on start is 854 degrees. Cutting throttle at 750 degrees provide adequate margins.

2. Hazard. Brake failure during high speed ground runs.

Severity. Extensive damage to the aircraft or serious injury to crew due to overrun.

Probability. Remote.

Mitigating Procedure. Briefings, training and REJECT workups on normal fuel. Thorough review of "anti-skid -OFF" and back up (Parking brake) systems.

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Risk Assessment

3. Hazard. Loss of directional control during 8 degree pitch up on ground runs.

Severity. Extensive damage to the aircraft or serious injury to crew.

Probability. Unlikely.

Mitigating Procedure. Briefings, training and REJECT workups on normal fuel. Ten knot increment calls above 60KIAS with REJECT for any unusual circumstance. Throttle reduction to 1.2 EPR through 90KIAS

4. Hazard. Left boost pump failure on takeoff while right boost pump is selected off. Possible double engine failure.

Severity. Loss of thrust, destruction of aircraft, death of all personnel on board.

Probability. Remote.

Mitigating Procedure. 1 minute high power run with brakes applied just prior to takeoff to confirm fuel pressures and quantities. Right seat pilot ready to turn on right boost pump and right transfer valve should left boost pump fail. Note FAA minimum MEL dispatch is one serviceable boost pump**.** AFM states aircraft is capable of full power operation up to 40,000 feet with no boost pumps.

Risk Assessment

5. Hazard. Unable to restart RH engine in flight.

Severity. Extensive damage to engine if core temperature allowed to reduce.

Probability. Remote.

Mitigating Procedure. All shutdown and relights will take place well inside windmilling airstart envelope and within gliding distance of emergency airfield (Maniwaki for NRC Test Area) to be briefed and NOTAMS checked to ensure suitability and VFR weather. Target airspeed of 220KIAS (+/- 5KIAS) and no higher than FL250 for shutdown and relights. Should no restart occur on first attempt an immediate descent toward the emergency airfield will be commenced with airspeed to attain 20%N1 rotation. All boost pumps and transfer valves will be switched **on** prior to second start attempt. All pilots will be current on the aircraft prior to testing and familiar with Page E-4 of Emergency Checklist. An observer/FTE will be in the jump seat to record data and therefore reduce the work load on the non-flying pilot who will back up the flying pilot on monitoring all limitations.

Checklists

Ground Run – 100% BIOFUEL		
Pilot:	Date:	Time:
Objectives/Limitations: • **____ lbs of 100% blend in RH feeder tank** • **RH transfer valve closed, RH boost pump off** • **Crossfeed open, LH boost pump on** • **Start RH engine** • **Start LH engine** • **Taxi to test site** • **RH engine to takeoff thrust on fossil fuel (1 min)** • **RH engine to idle** • **RH boost pump on** • **Crossfeed off** • **RH engine now on 100% blend from RH feeder** • **RH engine to takeoff thrust for 1 minute or until 50 lbs remaining** • **RH engine shutdown** • **Taxi back on LH engine** • **Once on ramp, RH engine start (EGT) on biofuel**		

Check	Action
Pre-Start	As per normal checklist
Briefing Prior to Before Start Checks	• Right Transfer Pump and Valve - **OFF** (to isolate right feeder tank from right wing tank) • Wing Pre Interconnect Valve - ON • **Crossfeed -ON**
Before Start	As per normal checklist
Battery Start	• Start right engine first using LH boost • Skip full stab trim check • Skip Standby Pump check (to save time) • Skip full aileron/rudder trim check • **<u>Leave crossfeed ON</u> after check**
Post Start	• **DO NOT TURN ON RH TRANSFER PUMP** • **DO NOT TURN ON RH BOOST PUMP** • **Start LH engine**
Taxi	As per normal checklist - monitor feeder tank levels, both feeders should not decrease. LH feeder is being fed from wings, RH feeder is not being used
Pre-takeoff For high power tests	As per normal checklist as well as: • Confirm T-33 in position confirm ready on 129.675
TEST POINT	• Hold Brakes - note Right feeder quantity • RH Throttle to computed EPR/N1 and not above 740 EGT, note fuel pressures • 1 minute • RH throttle to IDLE • RH Fuel Boost pump -ON • Crossfeed - OF, note decrease in RH feeder • RH throttle to computed EPR/N1 and not above 740 EGT • IDLE • RH Throttle - Cutoff • Taxi back to ramp • RH engine start
After Landing Checklist	As per normal checklist, shut off RH Boost Pump - OFF
Shutdown	As per normal checklist

NOTES

<u>Hazard Assessment</u>

- Hot Start - Low Risk - Review emergency checklist prior to start
- Overtemp during high power runs - brief shutdown procedures should EGT begin to rise

Checklists

Ground Run #2 – REJECTED TAKEOFF ON BIOFUEL		
Pilot:	Date:	Time:

Objectives/Limitations:
- **472 lbs 100% blend in RH feeder tank**
- **Both engines started using biofuel RH feeder tank**
- **Taxi with Jet A to both engines from LH feeder tank**
- **Accel to 100KIAS, 8 degree pitch 2 seconds, Reject**
- **Reconfigure to blended fuel from RH feeder tank**
- **Accel to 100KIAS, 8 degree pitch 2 seconds, Reject**
- **Max Crosswind component - Less than 3 Knots**
- **Runway conditions bare and dry**
- **RWY 14/32**

Check	Action
Pre-Start	As per normal checklist
Briefing Prior to Before Start Checks	• Right Transfer Pump and Valve - **OFF** (to isolate right feeder tank from right wing tank) • Wing Pre Interconnect Valve - ON • ***ENSURE CREW IS REMINDED NOT TO TURN ON <u>LH</u> BOOST PUMP DURING BATTERY START - USE CROSSFEED INSTEAD***
Before Start	As per normal checklist
Battery Start	• Start right engine first • Skip full stab trim check (to save time) just check switch functionality • Skip Standby Pump check (to save time) • Skip full aileron/rudder trim check (to save time) just check switch functionality • **<u>Leave crossfeed on</u> after check** • **DO NOT TURN ON LH Boost Pump for LH engine start**
Post Start	• **DO NOT TURN ON RH TRANSFER PUMP** • **When cleared by T33 (on 129.675)** • **LH Boost Pump - ON** • **RH Boost Pump - OFF** • **(running both engines on LH Feeder Jet A)**
Taxi	As per normal checklist - monitor feeder tank levels
Pre-takeoff (When cleared onto runway)	As per normal checklist as well as: • First rejected takeoff in fossil config above • <u>Prior to Second</u> rejected takeoff • **RH Boost Pump - ON** • **LH Boost Pump - OFF** • **Now running both engines on Right Feeder blended fuel** • Note Right Feeder tank level and fuel pressures
TEST POINT	• Taxi 200 feet down runway • Ensure T33 is in position • Hold Brakes - note Right feeder quantity • Throttles to computed EPR/N1 and not above 740 EGT • Prepare to hack/129.675 "3,2,1, brakes" • Brake release • Accel to 100 KIAS pitch to 8 degrees 2 sec • Reject//Brake as required
After Landing	As per normal checklist • **LH Boost Pump - ON** • **RH Boost Pump - OFF**
Shutdown	As per normal checklist **Do not leave parking brake set as brakes may fuse to discs because of reject speed**

NOTES

<u>Hazard Assessment</u>
- Hot Start - Low Risk - Review emergency checklist prior to start
- Engine Failure on T/O - Low Risk - Ready for reject anyway
- Loss of Control - Medium Risk - 40, 60, 80, 100 "REJECT" by anyone in cockpit prior to pitch up
- Brake failure - Low Risk - Brief anti-skid OFF and emergency braking procedures using T-handle

Checklists

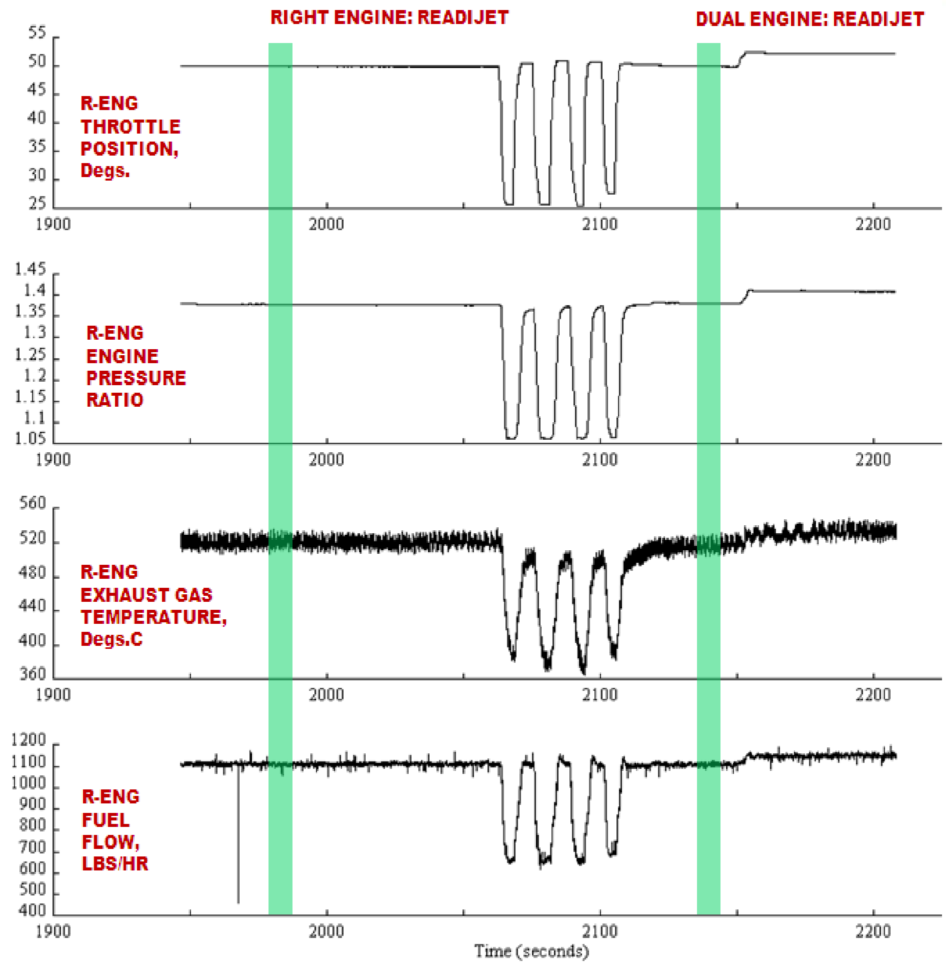
BIOFUEL WITH ACCEL/DECEL, THROTTLE RESPONSE PERFORMANCE, AND SHUTDOWN AND RELIGHTS Version 3		
Pilot:	Date:	Time:

Objectives:

- **472 lbs 100% blend in RH feeder tank**
- **Start and Taxi - both engines on Jet A from LH feeder**
- **T/O and Climb - both engines on Jet A from LH feeder**
- **Level at an altitude**
- **160/250/160 Accel/Decel Jet A from LH feeder**
- **160/250/160 Accel/Decel on Biofuel from RH feeder**
- **Switch to both engines on fossil fuel from LH feeder**
- **Shutdown DAS**
- **Switch to LH Engine fossil fuel, RH Engine biofuel**
- **RH Engine Shutdown/Relight biofuel**
- **Eliminate fuel asymmetry condition**
- **Normal descent and landing with all switches per normal checklist**

Check	Action
Pre-Start	As per normal checklist
Briefing Prior to Before Start Checks	• RH Transfer Pump and Valve - **OFF** (to isolate right feeder tank from right wing tank) - *TO REMAIN OFF UNTIL DESCENT UNLESS EMERG* • Wing Pre Interconnect Valve - ON ***ENSURE CREW REMINDED NOT TO TURN ON <u>RIGHT</u> BOOST PUMP DURING BATTERY START - USE CROSSFEED INSTEAD***
Before Start	As per normal checklist
Battery Start	• Start left engine first • **<u>Leave crossfeed on</u> after crossfeed check** • **DO NOT TURN ON RH Boost Pump for RH engine start, leave OFF**
Taxi	As per normal checklist - monitor feeder tank levels
Pre-takeoff (When cleared onto runway)	As per normal checklist as well as: • Taxi 500 feet down runway • Ensure T33 is in position • Note Feeder tanks levels and fuel pressures
Takeoff	• "3,2,1 brake release" on 129.675 • Throttles to computed EPR/N1 and not above 740 EGT • Note fuel pressures • Normal takeoff
Post Takeoff	As per normal checklist and ASAP: • **Through 400 feet AGL reduce thrust for T33 and confirm normal engine operation** • **NOTE ANY WING FUEL ASSYMETRY LEVEL DEVELOPMENTS IN CLIMB**
FL180	As per normal checklist
Cruise	As per normal checklist
Test Points	Fossil Fuel Accel/Decels 160/250/160 then: **Check Right Feeder Tank Quantity Sufficient** - Crossfeed…………………CONFIRM ON - LH Fuel Boost Pump………………..OFF Biofuel Accel/Decels 160/250/160 then: - LH Fuel Boost Pump……………………ON - Crossfeed……………………CONFIRM ON - RH Fuel Boost Pump…......................OFF - DAS……………………………SHUTDOWN RH Engine Shutdown/Relight on fossil fuel: - **RH Engine Power Lever……….…..….…..STOP** - Relight as Per Page E-4 (refer to Airstart Envelope) - **Power Lever………………………IDLE (12-24% N1)** - **Start Selector……………………….……AIRSTART** **Once Engine Running Normally:** - RH Fuel Boost Pump…………………ON - LH Fuel Boost Pump……...CONFIRM ON - Crossfeed…………………………….OFF RH Engine/Shutdown/Relight on biofuel - **RH Engine Power Lever……………………STOP** - Relight as Per Page E-4 (refer to Airstart Envelope) - **Power Lever…………………..IDLE (12-24% N1)** - **Start Selector………………………….AIRSTART** **Once Engine Running Normally:** • **Crossfeed..........................ON** • RH Transfer Valve and Transfer Pump...ON
Balance Fuel	Refer to E-19 of Abnormal Checklist then Descent, Approach, and Landing Checklists as per normal

Performance Data



TEST AIRCRAFT: NRC FA-20 (C-FIGD)
DATE: 29 OCTOBER 2012
ALTITUDE: 30,000 feet
AIRSPEED: 200 knots

Transparent transition from Jet A1 to ReadiJet and back to Jet A1 fuel

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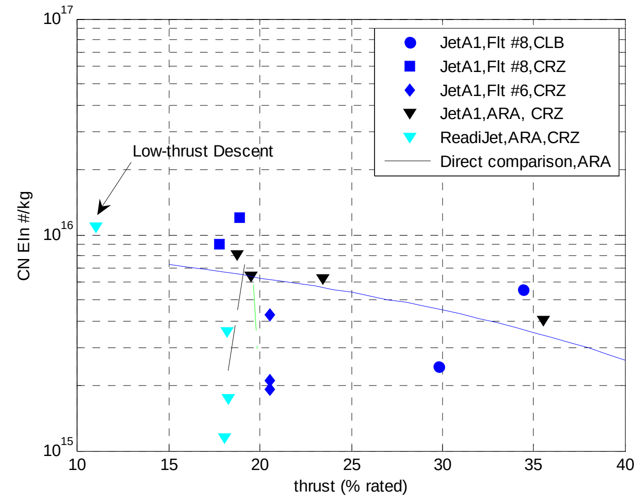
Airborne Emissions Condensation Nuclei (Aerosol)



- **9610 CNC Sensor on board**
- **Measurements @ 30,000 ft cruise**

Fuel	**CN EIn JetA1 baseline linear regression with %thrust**		**CN EIn, various comparisons**			
			Comparison with JetA1 baseline regression		**Direct comparison, back-to-back points, JetA1-to-biofuel**	
	Mean, at 30,000 feet (no./kg)	**Overall σ about the regression line, (#/kg)**	**Mean difference (#/kg)** (% of JetA1 at 30,000ft)	**σ (#/kg)** (% of JetA1 at 30,000ft)	**Mean difference (#/kg)** (% of JetA1 at 30,000ft)	**σ (#/kg)** (% of JetA1 at 30,000ft)
JetA1	$6.60\,10^{15}$	$2.92\,10^{15}$				
ARA ReadiJet, 100%, @ 18% rated thrust			$-4.50\,10^{15}$ (-67.5%)	$1.28\,10^{15}$ (19.2%)	$-5.11\,10^{15}$ (-70.2%)	$1.27\,10^{15}$ (17.5%)

Minimum 50% reduction in CN number when using ReadiJet fuel compared to Jet A1

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Canada's NRC Makes Milestone Biofuel Flight

AVIATION INTERNATIONAL NEWS » DECEMBER 2012

by CURT EPSTEIN

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Monday 3rd December 2012

AVFLASH NEWS

November 4, 2012

Canadian Researchers Fly On Pure Biofuel

By Russ Niles, Editor-in-Chief

AVIATION WEEK

Green Day - First Flight for 100% Bio-Jet

Posted by Graham Warwick 1:44 PM on Nov 02, 2012

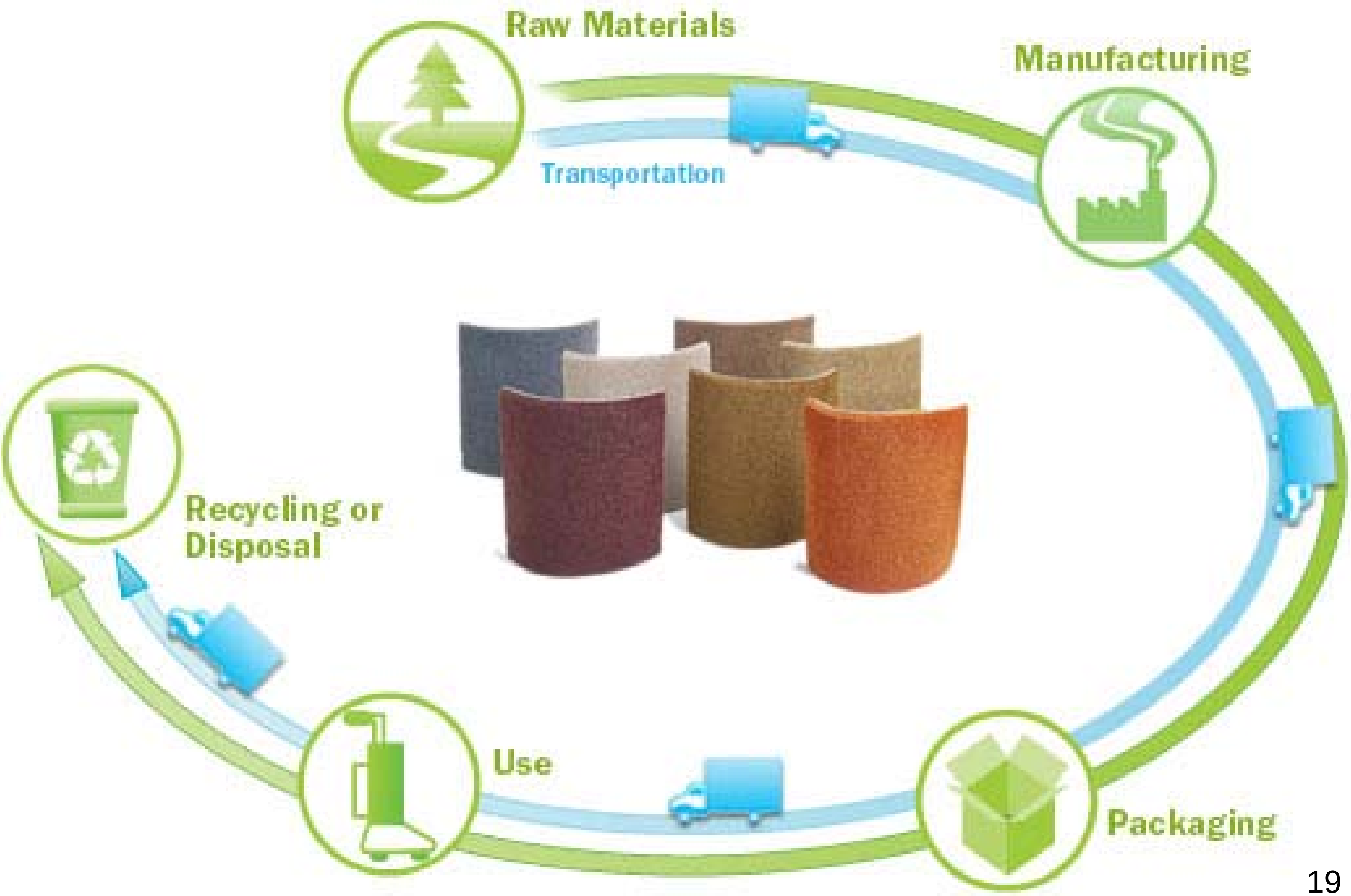
ISO 14001

ISO 14001 is an internationally accepted standard that sets out how you can go about putting in place an effective Environmental Management System (EMS). The standard is designed to address the delicate balance between maintaining profitability and reducing environmental impact; with the commitment of your entire organization, it can enable you to achieve both objectives.

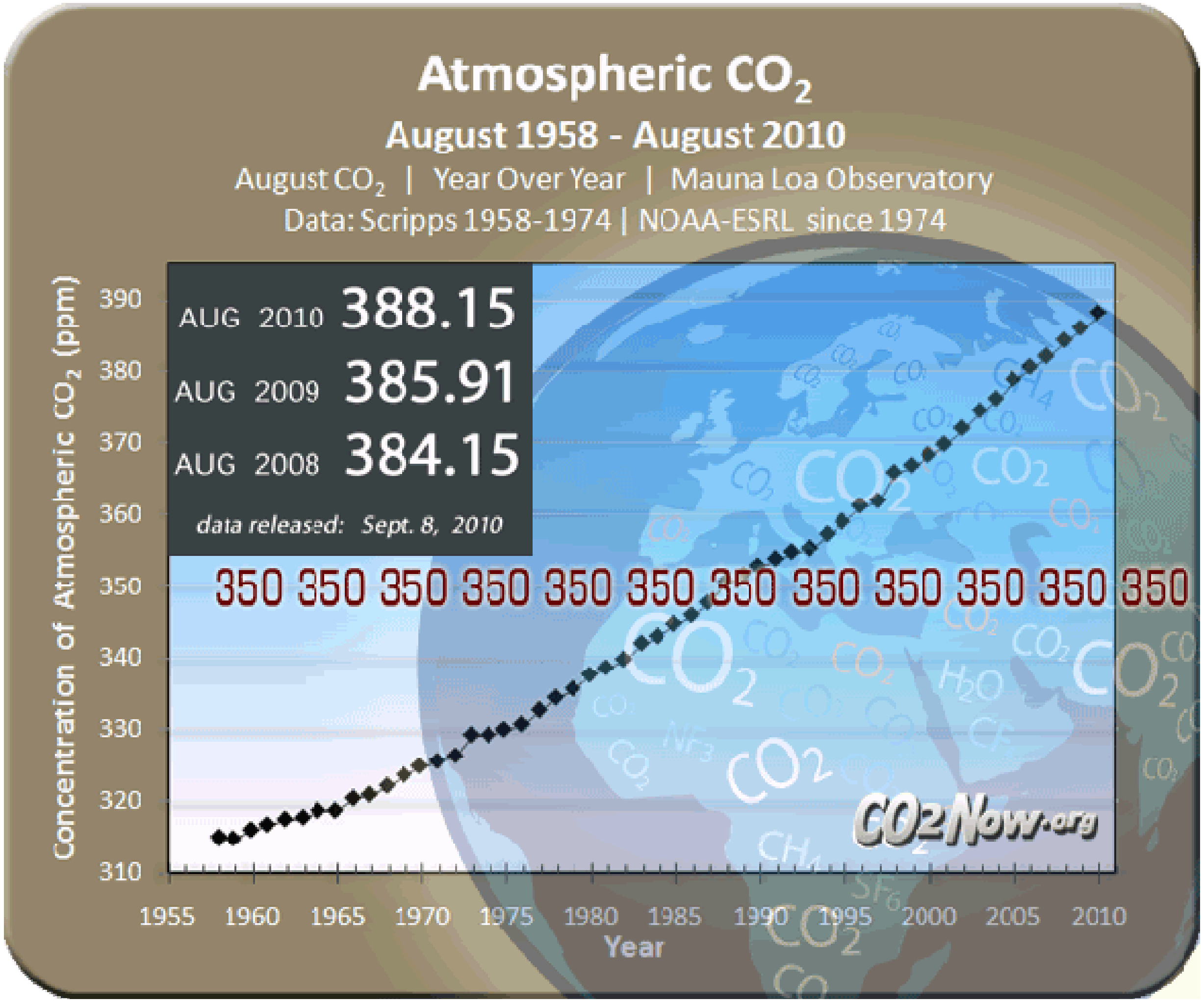
What's in ISO 14001:

- **General requirements**
- **Environmental policy**
- **Planning implementation and operation**
- **Checking and corrective action**
- **Management review**

Life Cycle Assessment



The Keeling Curve, or
The Cold Hard Facts…



Carbon-neutral growth and the next steps

Unrealistic expectations… or future flight test opportunities?

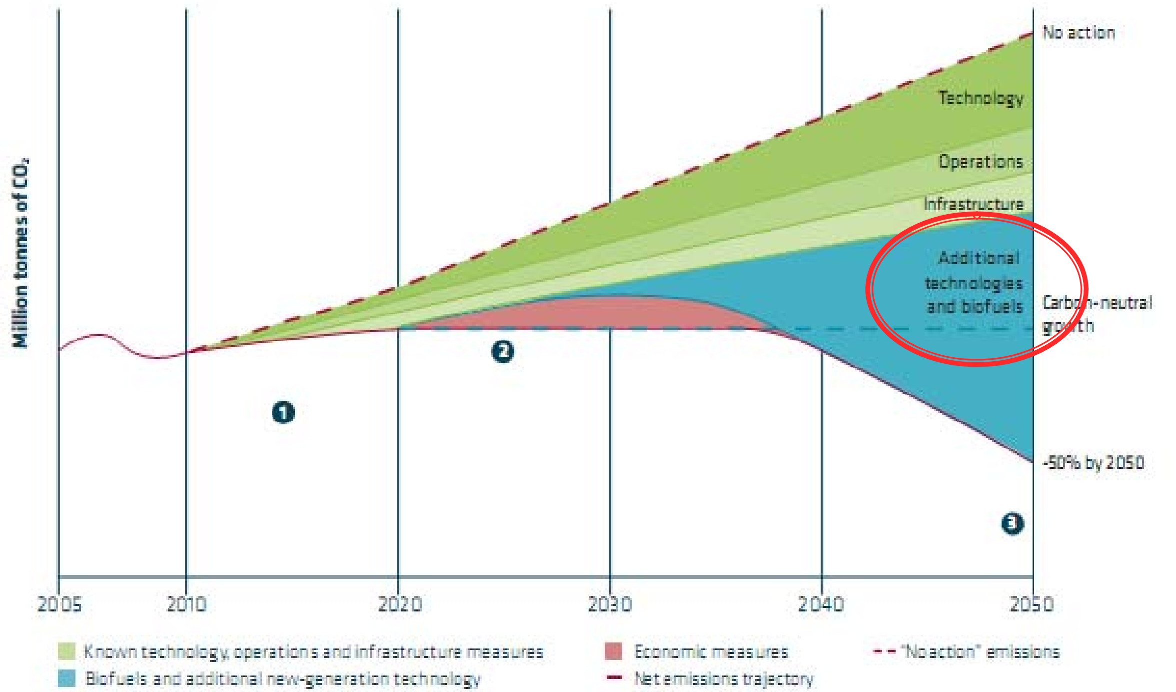
This *Guide* has looked at all the steps that the aviation industry is taking in its efforts to reduce emissions, particularly the emissions of carbon dioxide which is the most important greenhouse gas. These measures, along with the significant progress being made in developing the benefits of new types of fuel from low-carbon sources, will allow aviation to continue to provide the global economy with the benefits of fast, reliable, safe and efficient connectivity. None of this work is occurring in isolation. In fact, the aviation industry is one of the few sectors that has a globally coordinated approach to reducing its emissions.

The four pillars

The whole aviation sector signed a declaration in 2008, that committed to what is known as the four pillar strategy for reducing emissions.

Of the four pillars, **technology** has by far the best prospects for reducing aviation emissions. The industry is making great advances in technology, many of which you have seen in this *Guide*. Sustainable aviation biofuels are also part of this pillar, more information on these exciting new fuels can be found in the *Beginner's Guide to Aviation Biofuels* – available on www.enviro.aero/biofuels.

Emissions reduction roadmap (schematic, indicative diagram)



Improved **operational** practices, including reduced auxiliary power unit usage, more efficient flight procedures, and weight reduction measures, could achieve further reductions in CO_2 emissions.

Infrastructure improvements present a major opportunity for CO_2 reductions in the near-term, many of these are described on pages 15-21 of this *Guide*. Full implementation of more efficient air traffic management and airport infrastructure could provide substantial emissions reductions through implementation of measures such as the Single European Sky and the Next Generation Air Traffic Management system (NextGen) in the United States.

While efforts from the first three pillars will go a long way to achieving the goal of carbon-neutral growth from 2020, the aviation sector may need to turn to the fourth pillar – positive **economic measures** – in the medium term to help close the gap.

An industry united

When the world's governments gathered in Kyoto in 1997 to negotiate how the global community would limit climate change, negotiators recognised the difficulties in dealing with aviation emissions. Along with international shipping, the emissions from aviation take place over international waters and are most often not confined to the borders of a single country. With this in mind and the growing need for all parts of the economy to play their role in reducing emissions, the aviation industry has taken the unprecedented step of setting three global commitments for reducing its emissions.

Few will have the greatness to bend history itself; but each of us can work to change a small portion of events, and in the total; of all those acts will be written the history of this generation.

- Robert F. Kennedy

"There is no one solution that will solve it all , but we are looking for a combination of ways to reduce our impact by investigating promising options. The ultimate goal in aviation fuel research is to look for ways we can decrease the unwanted byproducts of combustion to a level that is acceptable for the environment."

- Tim Leslie