Environmental Compatibility Research Workshop III Emissions Presentation

Monterey, California
July 7-9, 1998

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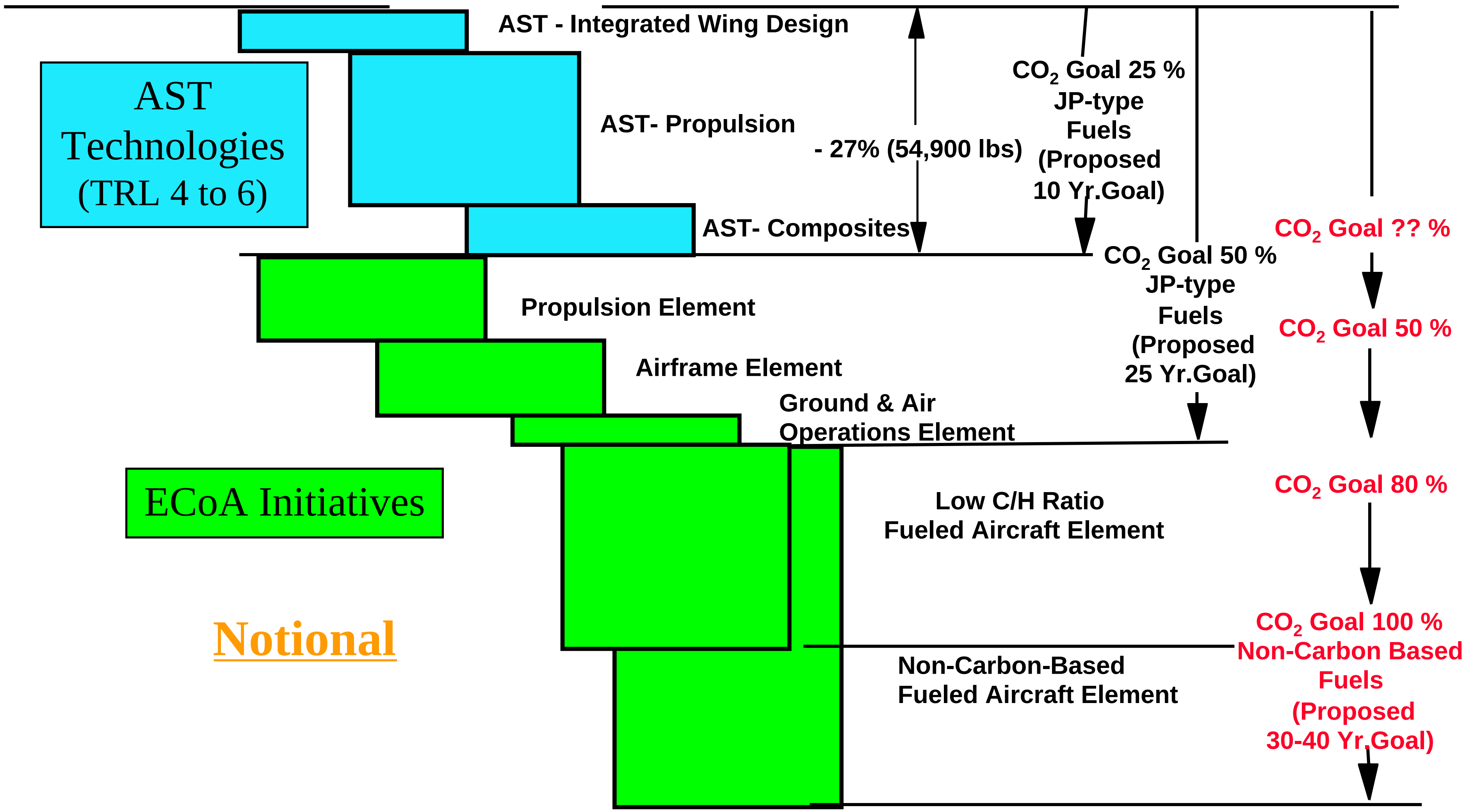
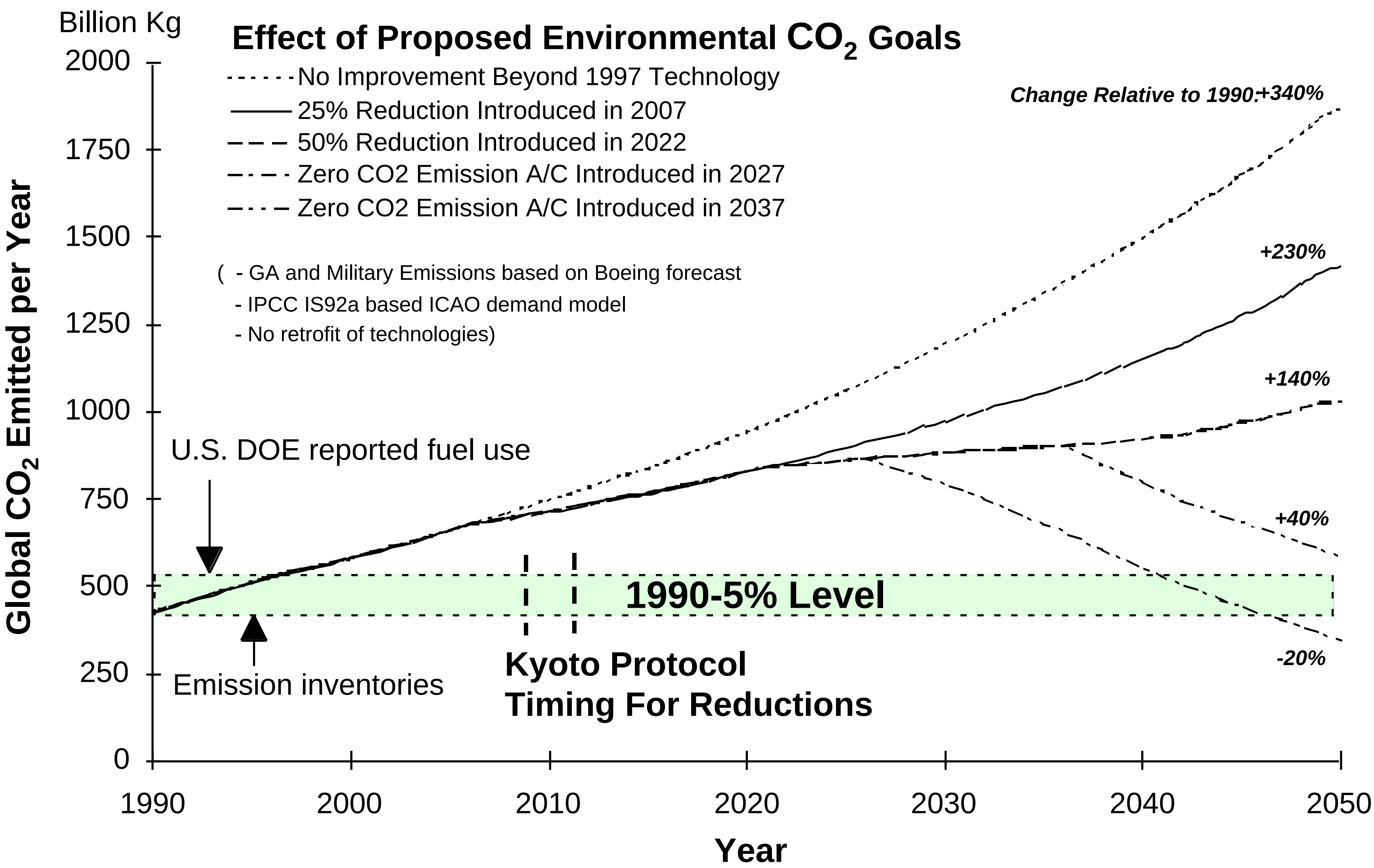
NASA Lewis Research Center

Environmental Program CO_2 Emission Reduction Waterfall

LONG HAUL/MEDIUM CAPACITY CONVENTIONAL SUBSONIC TRANSPORT

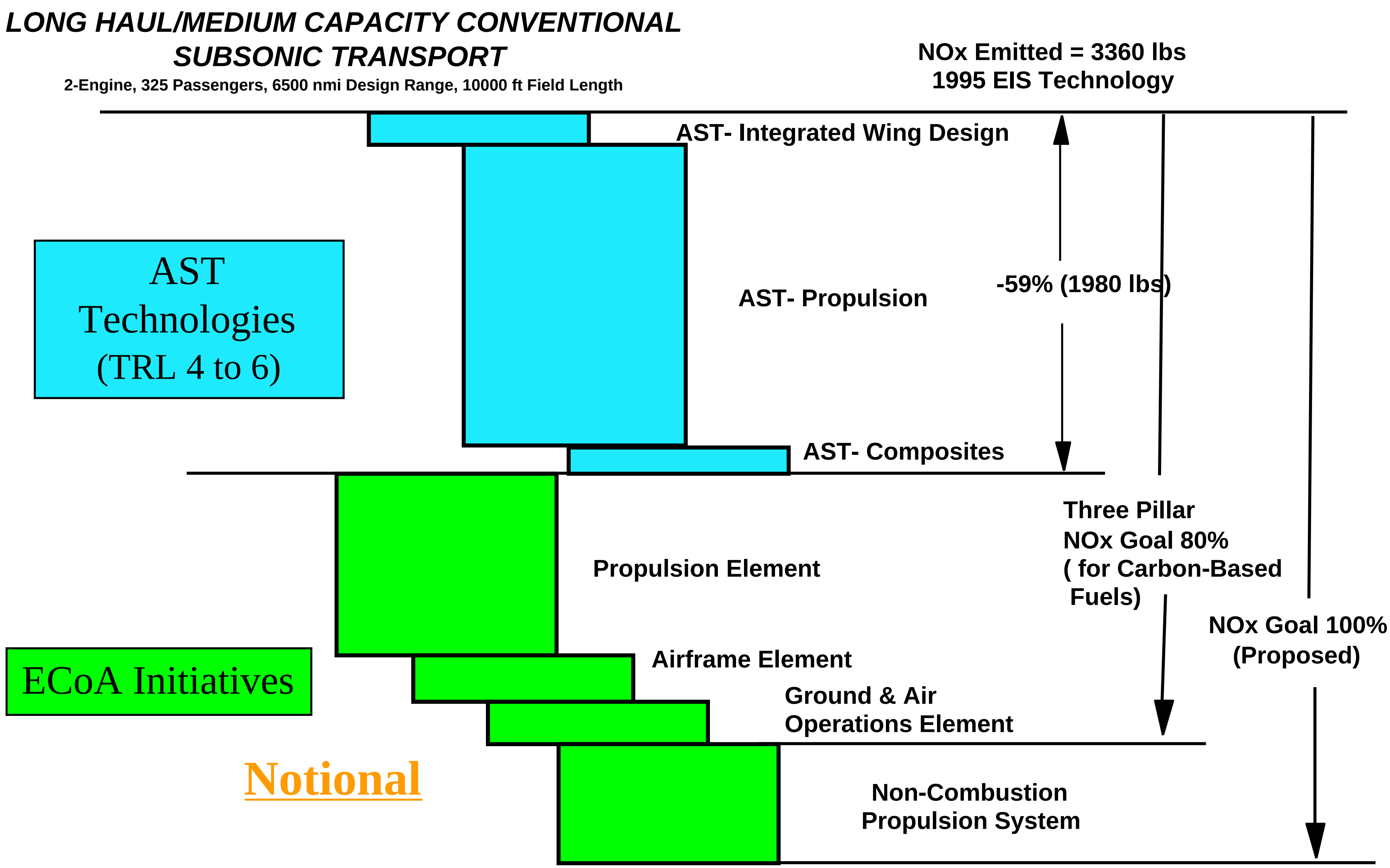
2-Engine, 325 Passengers, 6500 nmi Design Range, 10000 ft Field Length





Effectiveness of Advanced Technology In Reducing Total CO_2 Emitted From Aircraft

Environmental Program NOx Emission Reduction Waterfall

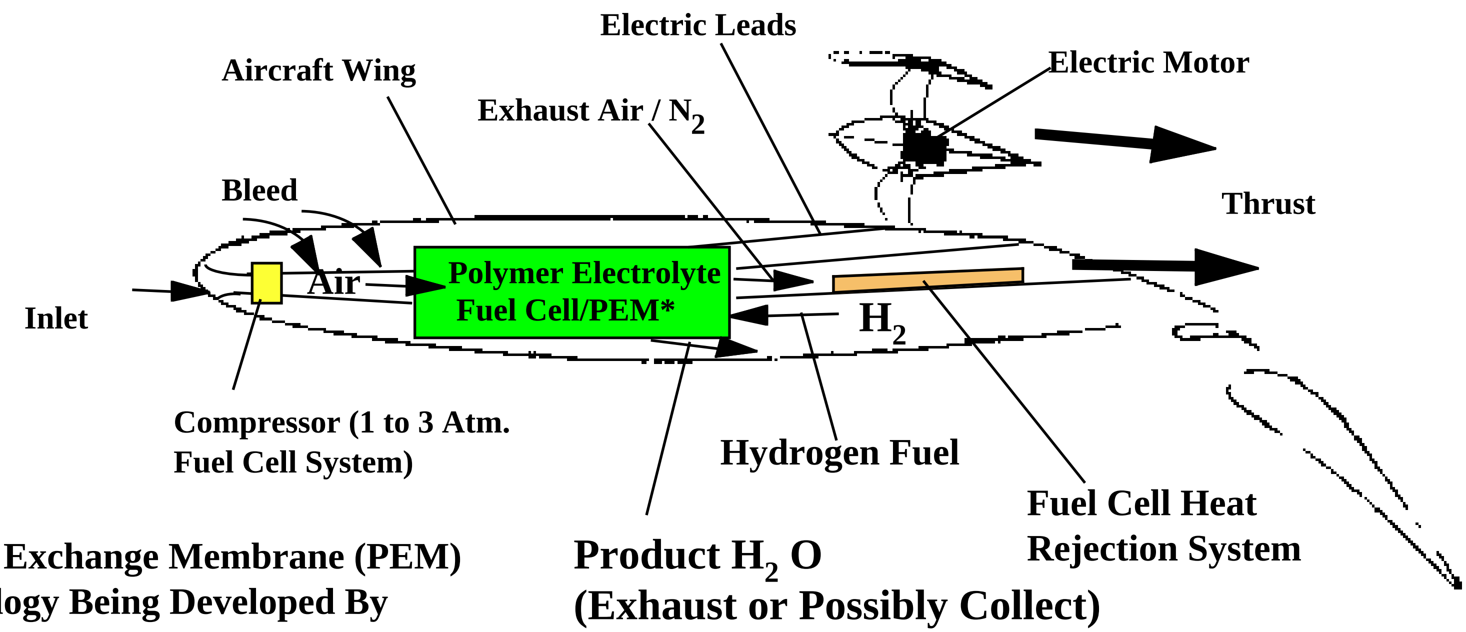


Zero-Emissions 777-Type Aircraft?

Results for 6500 nmi. Mission

Power	Takeoff Weight Gross lbs.	Fuel lbs.	CO2 1000 lbs.	CO2 % Reduction	NOx lbs.	NOx % Reduction	* Other Emittants Reduction
Kerosene (SOA) Turbofan	613,300	239,800	757	-	4500	-	-
Kerosene Adv. Turbofan	343,850	82,700	261	(Base)	1085	(Base)	(Base)
Methane	353,150	73,500	202	23	962	11%	23% Unburned H/C, CO & Part. (Except H_20 & Aero.)
Hydrogen Turbofan	294,500	29,100	0	100%	806	26%	100% Unburned H/C, CO & Part. (Except H_20 & Aero.)
Nuclear / Kerosene Turbofan	480,000	9,000	28.4	89.1%	1286	Increase	86% Unburned H/C, CO & Part. (Except H_20 & Aero.)
Hydrogen/ Fuel Cell	577,250	51,750	0	100%	0	100%	100% Other Emittants (Collect H_20 ?)

*** Aerosols, Particulates, Unburned H/C, CO, and H_20**



* Proton Exchange Membrane (PEM) Technology Being Developed By Automotive Industry

Fuel Cell / Electric Motor / Mini Fan Propulsion System

(PEM Fuel Cells also being applied to space transportation technology up-grades for the Space Shuttle.)

Revolutionary Concepts

(Detailed System PAI Studies Needed to Understand)

Revolutionary for Carbon-Based Fuel System Concepts

AIRFRAME

2022

- Double-Bubble Fuselage
- Blended Wing Body
- Box Win
- Strut Braced Wing

PROPULSION

2022

- Distributed Propulsor
- Smart Adaptive Engines (MEMS, Aspirative)
- New Cycles
- Adv. Methane Cooled Engine

Revolutionary for Non-Carbon Based Fuel System Concepts

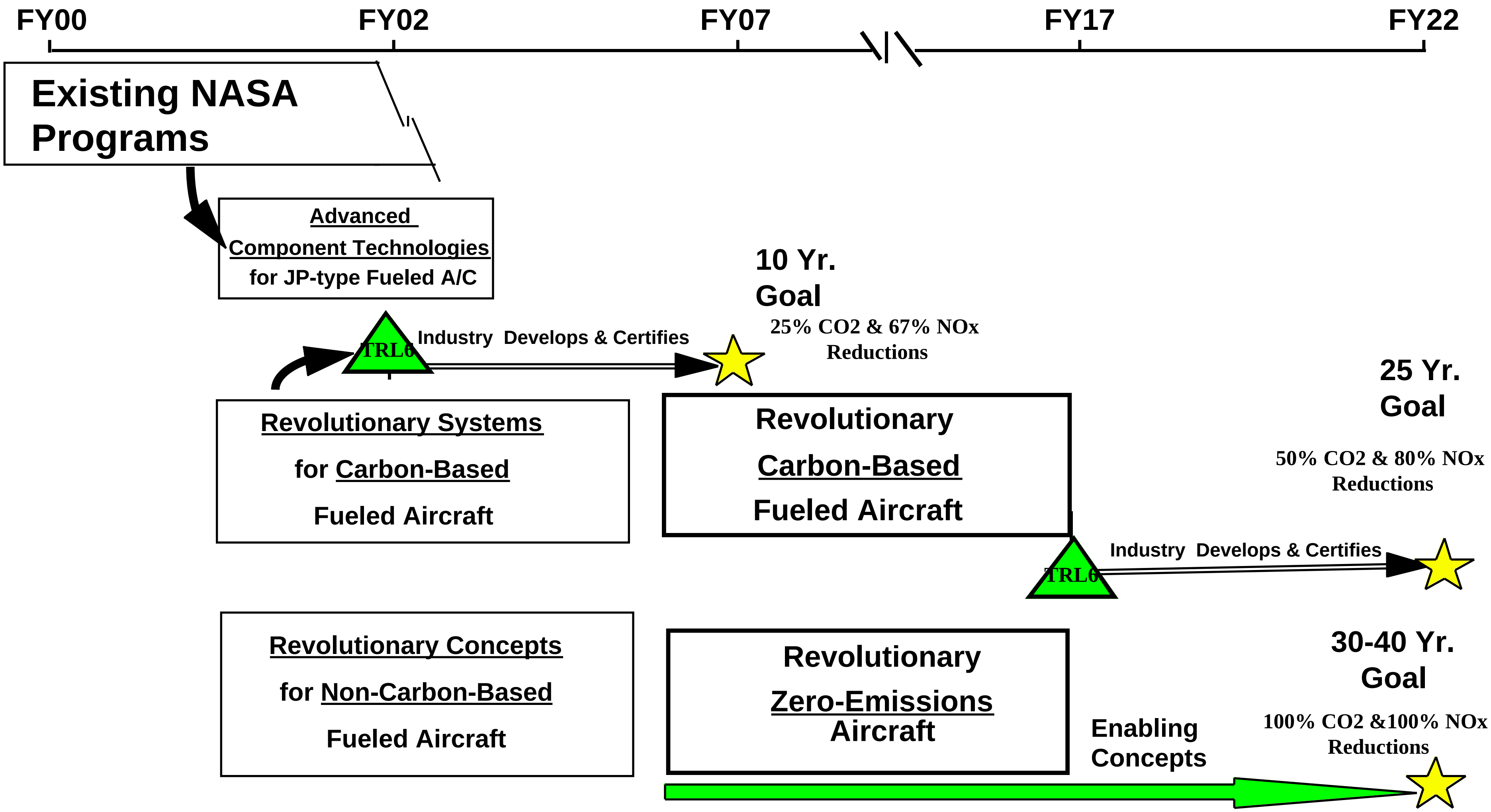
2027-2037

- Tailless Aircraft
- Intermodal Transport Aircraft
- Fluidic Aerodynamic Control
- Plasma Enhanced Performance

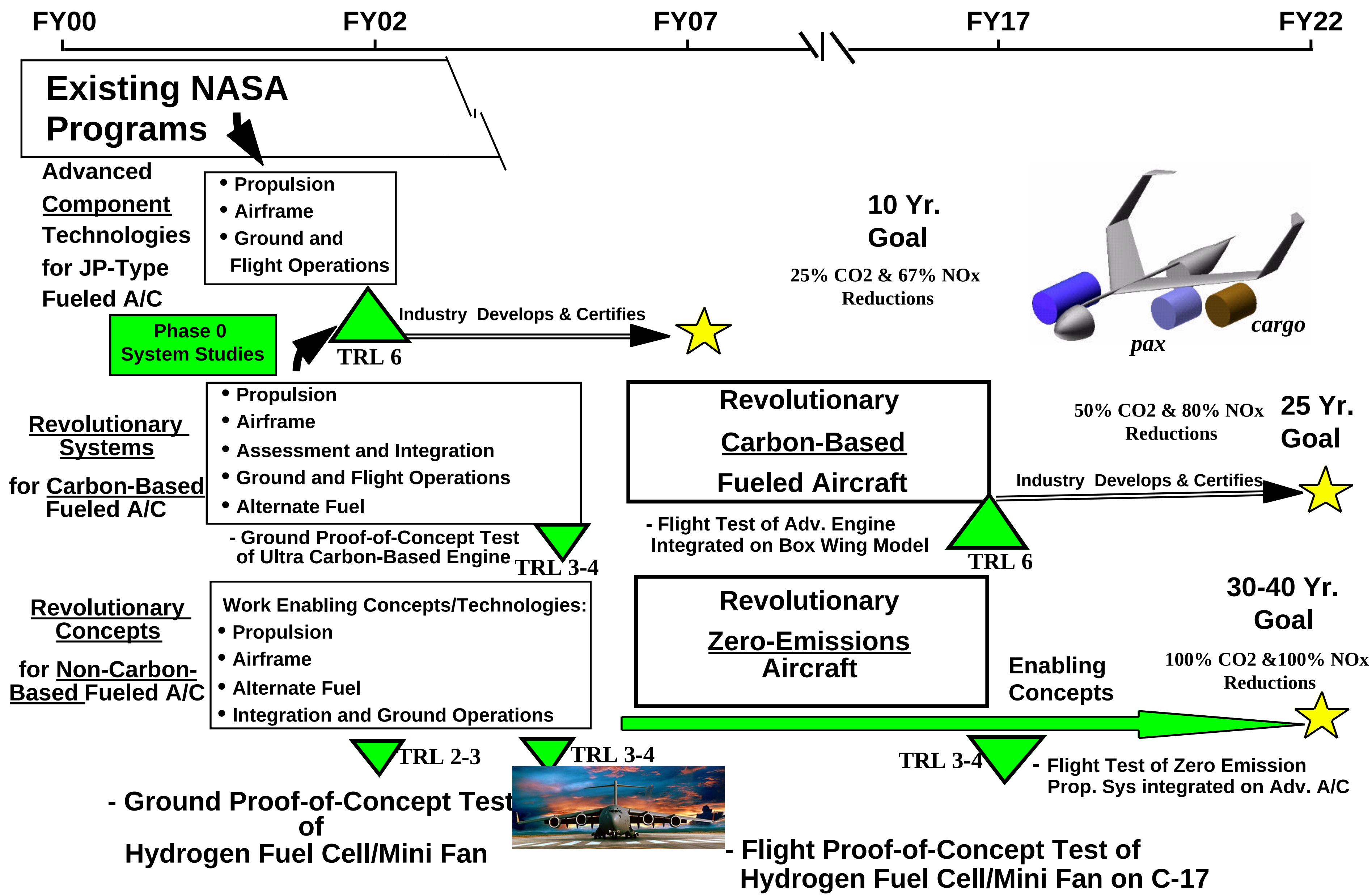
2027-2037

- Hydrogen Fuel Cell / Mini Fan
- Adv. Hydrogen Cooled Engine with Liquid Air/N_2 Separation
- Microengines / Lithium Fuel Cell

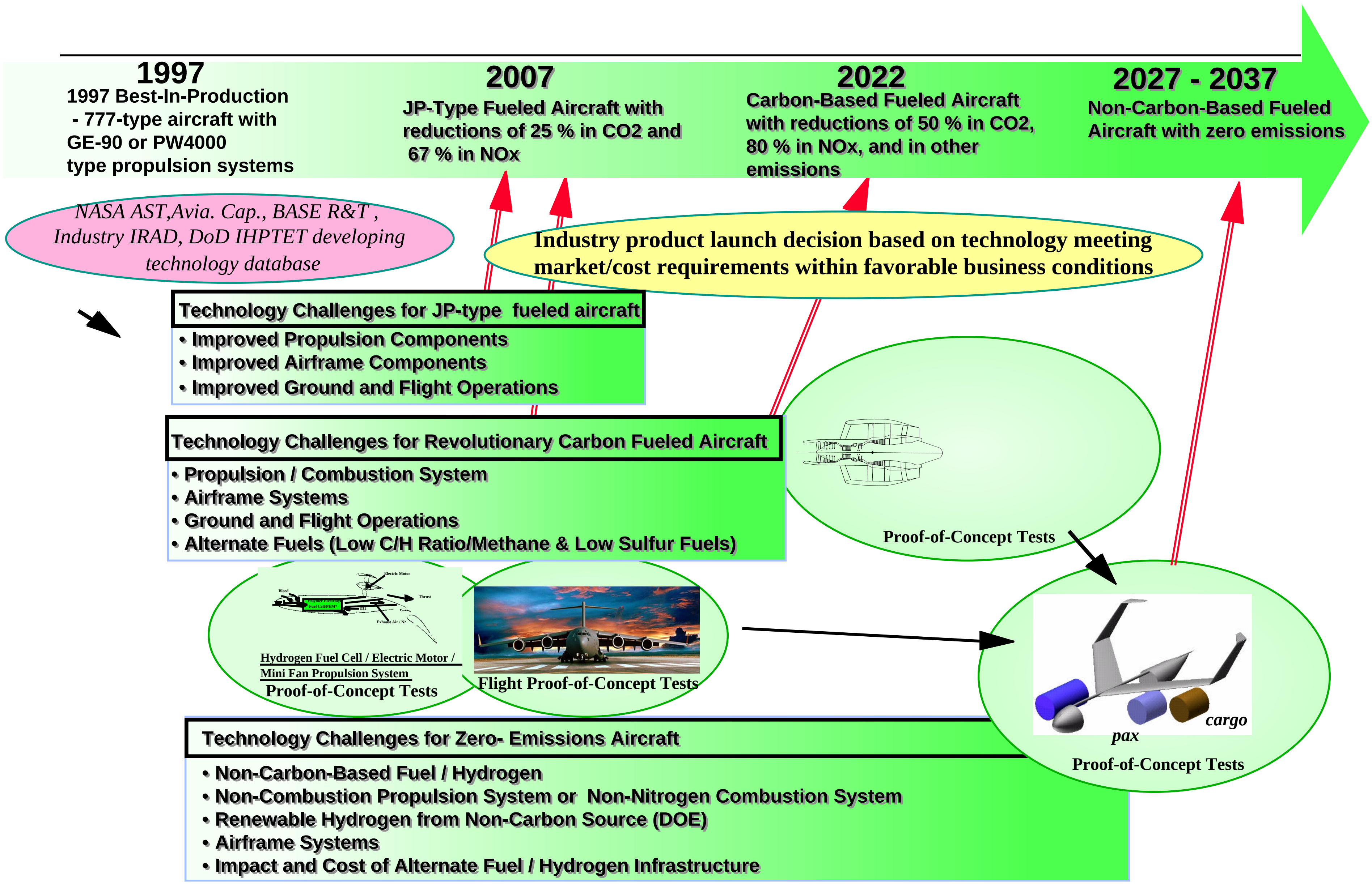
Potential Environmental Emissions Roadmap Overview



Environmental Emissions Level 1 Roadmap



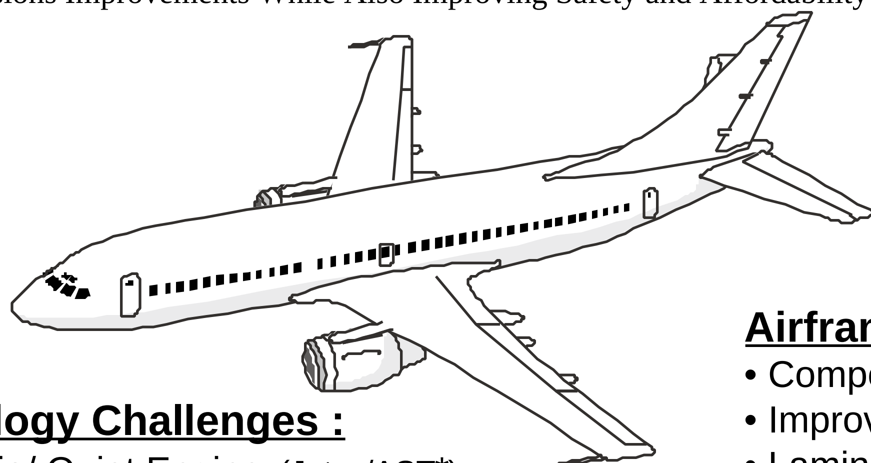
Reduce Emissions of Future Aircraft by a Factor of Three Within 10 Years, by a Factor of Five Within 25 Years, and Totally Within 30 to 40 Years.



2007 - Technology Challenges for JP-Type Fueled Aircraft with reductions of 25 % in CO2 and 67 % in NOx

Technical Objectives

- ➢ Reduce CO_2 Emissions from Future Aircraft by 25 % in 10 years.
- ➢ Reduce NOx Emissions from Future Aircraft by 67 % in 10 years.
- ➢ Address New Emission Concerns by Characterize Emission Levels of Aerosols, Particulates, and Other Minor Trace Species to their Lowest Practical Limits.
- ➢ Enable These Emissions Improvements While Also Improving Safety and Affordability of Operations
- ➢



Propulsion Technology Challenges :

- Ultra High Bypass Ratio/ Quiet Engine (Jnt.w/AST*)
    - Light Weight, High Temp. Mat'l. & Struct. (Jnt.w/AST)
    - Non-Traditional Prop/Airframe Integ.
    - Intelligent Controls/ MEMS
- Combustion
    - Improved injectors and liners
      - 70% NO_x reduction (Jnt.w/AST)
    - Characterize Other Emissions (Jnt.w/AST, Base R&T & HSR)

* Joint with AST, Base R&T, or HSR

Airframe Technology Challenges:

- Composite Wing (Jnt.w/AST)
- Improved Aerodynamics (Jnt.w/AST)
- Laminar Flow Control
- Monolithic Structures

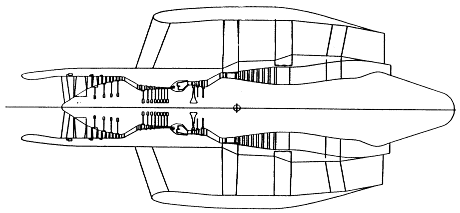
Operations, Modeling, & Assessment:

- Improved Ground Operations
- Improved Flight Operations
- Improved Modeling and Assessments (Jnt.w/AST)

2022 - Technology Challenges for Carbon-Based Fueled Aircraft with reductions of 50 % in CO2, 80 % in NOx, and in other emissions

Technical Objectives

- Reduce CO_2 Emissions from Future Aircraft by 50 % in 25 years.
- Reduce NOx Emissions from Future Aircraft by 80 % in 25 years.
- Address New Emission Concerns by Reducing Emission Levels of Aerosols, Particulates, and Other Minor Trace Species to their Lowest Practical Limits.
- Enable These Emissions Improvements While Also Improving Safety and Affordability of Operations



Propulsion Technology Challenges :

- Proof-of-Concept Tests of Revolutionary Carbon-Based Fueled Propulsion System
  - Smart Adaptive Engine (MEMS, Aspirative)
  - New Cycles/ Adv. Methane Cooled Engine
- Proof-of-Concept Tests of Revolutionary Carbon-Based Fueled Combustion System
  - Multi-Staged & Variable Geom.- 80% NO_x reduction
  - Reduce Other Emissions
- Alternate Fuels (Low C/H Ratio/Methane & Low Sulfur Fuels)

Airframe Technology Challenges:

- Proof-of-Concept Tests of Revolutionary Carbon-Based Fueled Airframe Systems
  - Slatless/Flapless Airfoils
  - Active Piezoelectrics
  - Fluidic Thrust Vectoring
  - Box vs. Strut vs. Blended Wing
  - Opto-Electronics
  - Designer Materials/Structures

Operations, Modeling, & Assessment:

- Revolutionary Ground Operations
- Revolutionary Flight Operations
- Improved Assessments

2027-2037 - Technology Challenges for Non-Carbon Based Fueled Aircraft with Zero Emissions

Technical Objectives

- **Zero-Emissions Aircraft**
- Reduce CO_2 Emissions from Future Aircraft by 100 % in 30 to 40 years.
- Reduce NOx Emissions from Future Aircraft by 100 % in 30 to 40 years.
- Reduce Aerosols, Particulates, and Other Minor Trace Species Emissions from Future Aircraft by 100 % in 30 to 40 years.
- Enable These Emissions Improvements While Also Improving Safety and Affordability of Operations
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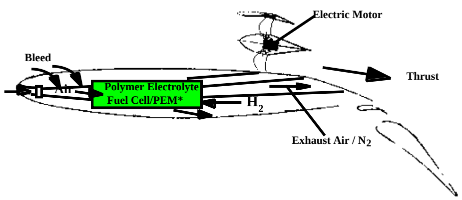
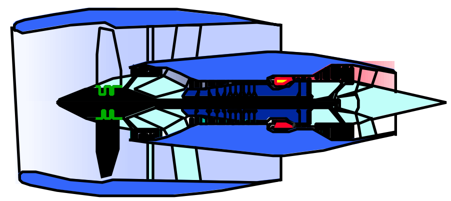


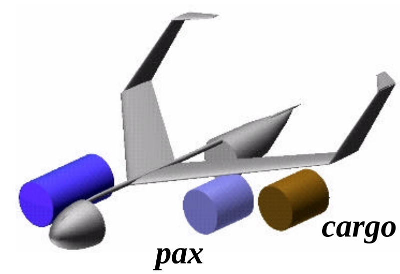
Hydrogen Fuel Cell / Electric Motor / Mini Fan Propulsion System



Alternate Advanced Hydrogen Cooled Engine With Liquid Air/ N_2 Separation

Propulsion Technology Challenges :

- Ground Proof-of-Concept Test of Non-Combustion Propulsion System
- Flight Proof-of-Concept Test of Non-Combustion Propulsion System
- Hydrogen Cooled Propulsion System With Non-Nitrogen Combustion System
- Renewable Hydrogen from Non-CO_2 Producing Source (DOE)



Airframe Technology Challenges:

- Proof-of-Concept Tests of Revolutionary Non-Carbon-Based Fueled Airframe Systems
  - Non-Traditional Fuel Storage
  - Noncircular Pressure Vessels
  - Electric Airplane

Operations Challenges :

- Hydrogen Handling

Potential Environmental Emissions Propulsion Level 2 Plan

FY99 FY00 FY01 FY02 FY03 FY04 FY05 FY07

Existing NASA Programs

Adv. Component Technologies for JP-Type Propulsion

Phase 0 Propulsion System Studies

Propulsion:
- Ultra High Bypass Ratio/Quiet Engines
- Low-Emissions Combustor
- Light Weight, High Temp. Mat'l & Struct.
- Non-Traditional Propulsion Airframe Integ.
- Intelligent Controls / MEMS

TRL6

Industry Develops & Certifies for New or Block Change / Retrofit Engine Applications

10 Yr. Goal

25% CO_2 & 67% NOx Reductions

Revolutionary Systems for Carbon-Based Propulsion

- Detailed System Studies of Revolutionary Concepts
- Propulsion:
  - Smart Adaptive Engine (MEMS, Aspirative) Test
  - Distributed Propulsor
  - New Cycles/ Adv. Methane Cooled Engine
  - Multi-Staged & Variable Geometry Combustor
  - Alternate Fuel and Technologies (Low C/H Ratio Fuel/Methane)

Supports 25 Yr. Goal

- Ground Proof-of-Concept Test of Ultra Carbon-Based Engine

Revolutionary Concepts for Non-Carbon-Based Propulsion

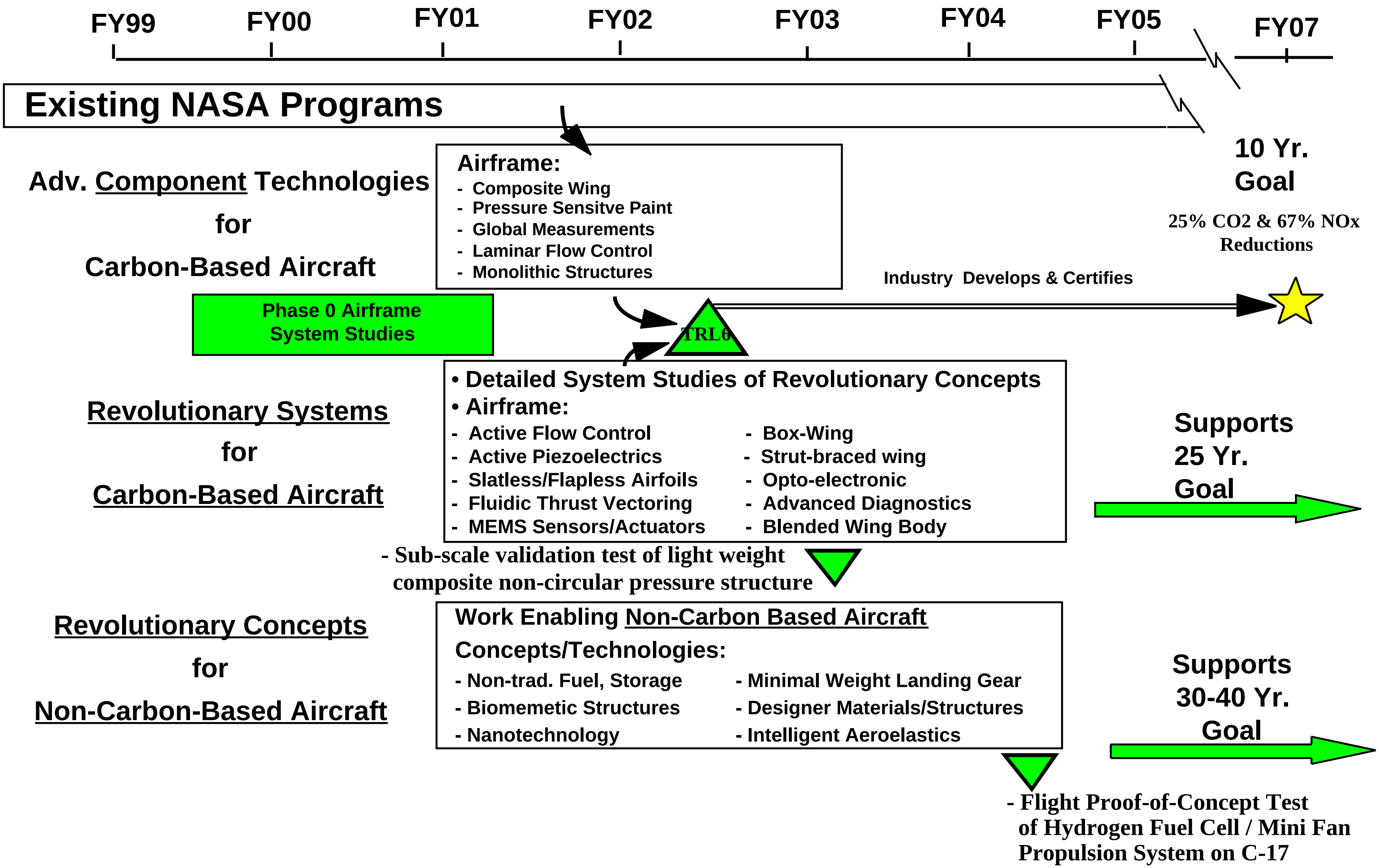
Work Enabling Non-Carbon Based Propulsion Concepts/Technologies:
- Hydrogen Fuel Cell / Electric Motors / Mini Low-Noise Fans
- Adv. Hydrogen Cooled Engine
- Hydrogen Technologies
- Others (e.g.,lithium fuel cells, etc.)

Supports 30-40 Yr. Goal

- Ground Proof-of-Concept Test of System Scale-Up and Control of Hydrogen Fuel Cell / Mini Fan

- Flight Proof-of-Concept Test of Hydrogen Fuel Cell / Mini Fan Propulsion System on C-17

Potential Environmental Emissions
Airframe Level 2 Plan



Potential Environmental Emissions
Ground and Flight Operations Level 2 Plan

FY99 FY00 FY01 FY02 FY03 FY04 FY05 FY07

Existing NASA Programs

Adv. <u>Component</u> Technologies for JP-Type Propulsion

Ground and Flight Operations:
- Emissions Minimization Procedures
  - Optimized Trajectory
  - Minimum Loiter Strategy
- One Engine and Towed Taxi
- Real Time Energy Approach and Departure

TRL6

Industry Develops & Certifies

10 Yr. Goal

25% CO_2 & 67% NOx Reductions

<u>Revolutionary Systems</u> for <u>Carbon-Based Propulsion</u>

- **Detailed System Studies of Revolutionary Concepts**
- **Ground and Flight Operations:**
  - Advanced Emissions Minimization Procedures
    - Meteorological Dispersion Consideration
  - Extended Free Flight Technologies
  - Extended Surface Traffic Management Tools
  - Alternative Taxi Power

Supports 25 Yr. Goal

<u>Revolutionary Concepts</u> for <u>Non-Carbon-Based Propulsion</u>

Work Enabling <u>Non-Carbon Based Propulsion</u> Concepts/Technologies:
- Hydrogen from Renewable/Clean Production (DOE)
- Infrastructure for Hydrogen Supply
- Slush Hydrogen Production and Handling

Supports 30-40 Yr. Goal

Impact Emissions Metrics Definition

Mandate

	Pillar	CO_2	NOx	Others
Global Warming Reversal	-	-25% in 10 Yrs. -50% in 25 Yrs. -100% in 30-40 Yrs.	- - -	- Max. Practical in 25Yrs. 100% in 30-40 Yrs
Improved Local Air Quality	- 67% in 10 Yrs. - 80% in 25 Yrs.	- - -	- 67% in 10 Yrs - 80 % in 25 Yrs. -100% in 30-40 Yrs.	- Max. Practical in 25 Yrs. 100% in 30-40 Yrs.
Ozone Layer Recovery	- 67% in 10 Yrs. - 80% in 25 Yrs.	- - -	- 67% in 10 Yrs. - 80% in 25 Yrs. -100% in 30-40 Yrs.	- - -

Reduce Emissions of Future Aircraft by a Factor of Three Within 10 Years, by a Factor of Five Within 25 Years, and Totally Within 30 to 40 Years.

1997
1997 Best-In-Production
- 777-type aircraft with GE-90 or PW4000 type propulsion systems

2007
JP-Type Fueled Aircraft with reductions of 25 % in CO2 and 67 % in NOx

2022
Carbon-Based Fueled Aircraft with reductions of 50 % in CO2, 80 % in NOx, and in other emissions

2027 - 2037
Non-Carbon-Based Fueled Aircraft with zero emissions

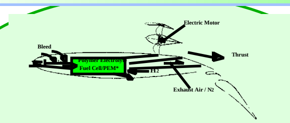
NASA AST,Avia. Cap., BASE R&T , Industry IRAD, DoD IHPTET developing technology database

Industry product launch decision based on technology meeting market/cost requirements within favorable business conditions

Technology Challenges for JP-type fueled aircraft
- Improved Propulsion Components
- Improved Airframe Components
- Improved Ground and Flight Operations

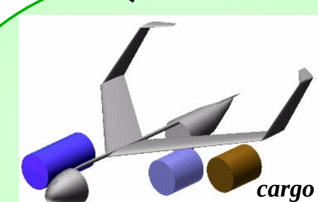
Technology Challenges for Revolutionary Carbon Fueled Aircraft
- Propulsion / Combustion System
- Airframe Systems
- Ground and Flight Operations
- Alternate Fuels (Low C/H Ratio/Methane & Low Sulfur Fuels)

Proof-of-Concept Tests



Hydrogen Fuel Cell / Electric Motor / Mini Fan Propulsion System
Proof-of-Concept Tests

Flight Proof-of-Concept Tests



Proof-of-Concept Tests

Technology Challenges for Zero- Emissions Aircraft
- Non-Carbon-Based Fuel / Hydrogen
- Non-Combustion Propulsion System or Non-Nitrogen Combustion System
- Renewable Hydrogen from Non-Carbon Source (DOE)
- Airframe Systems
- Impact and Cost of Alternate Fuel / Hydrogen Infrastructure