Aviation Propulsion Technologies in the 21st Century

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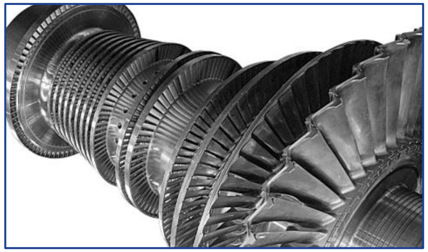
Our business units

Energy Management
5% / $7.4 B

Healthcare
12% / $18.3 B

Capital
31% / $46.0 B

Oil & Gas
10% / $15.2 B



Aviation
14% / $20.0 B

Home & Business Solutions
5% / $8.0 B

Power & Water
19% / $28.3 B

Transportation
4% / $5.6 B

~$147.4 Billion Revenue in 2012

$16.1 B Operating Earnings

“Longitude”… Author - Dava Sobel

- Engineering crisis of the 18th century.
- Longitude committee formed, prize defined by parliament.
- John Harrison – by 1735 solves with an accurate ship-worthy clock.
- Not really in widespread use until roughly 1780 or later.
- Why?

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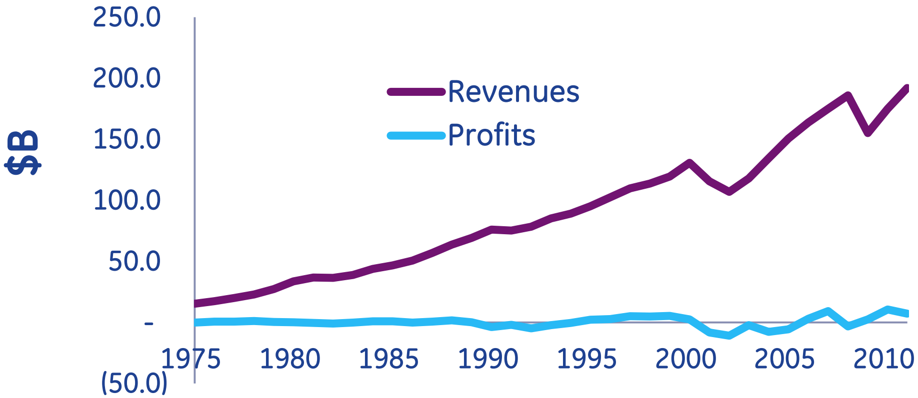
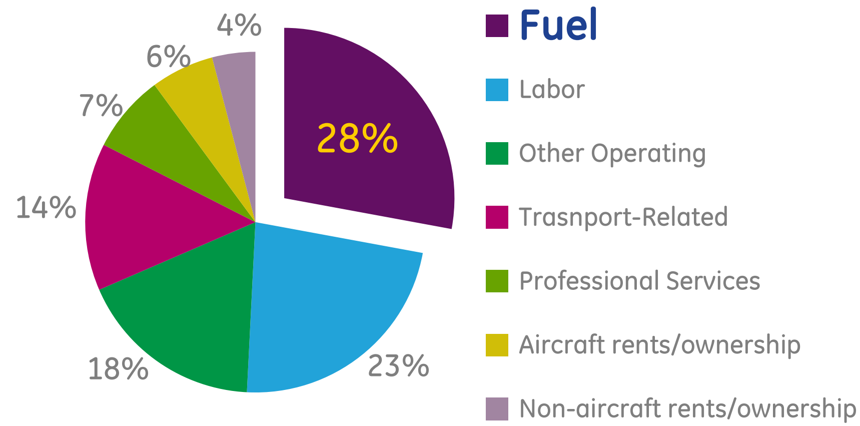
Propulsion Challenge

Industry Revenue/Profits



Sources: Air Transport Association/Bureau of Transportation Statistics

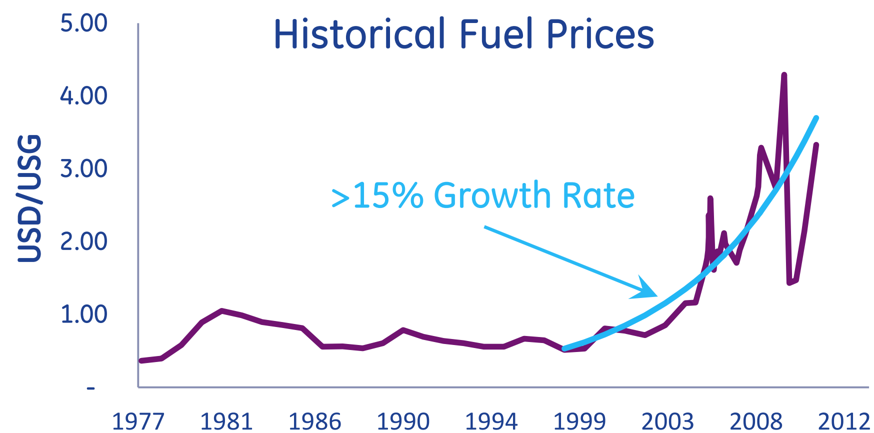
Airline Operating Costs



Source: A4A Quarterly Cost Index, US Airlines

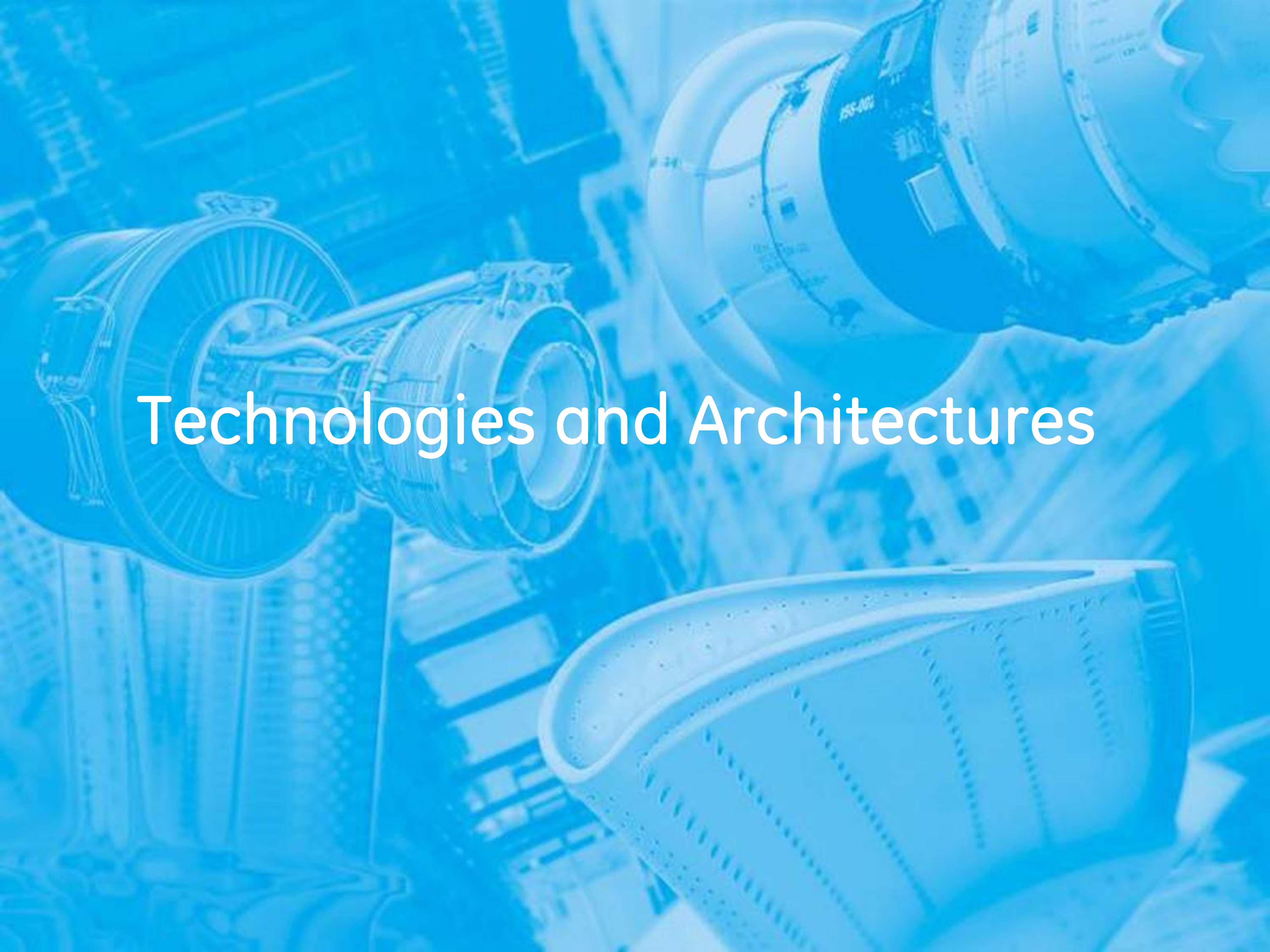
Regulatory Challenges

▪ CAEP/6	2008 / 2013
▪ CAEP/8	2014 / 2018
▪ EU Carbon Trading	2012
▪ ICAO CO_2 Standard	2016-2020
▪ FAR Stage 5	2020



Sources: Air Transport Association, International Air Transport Association

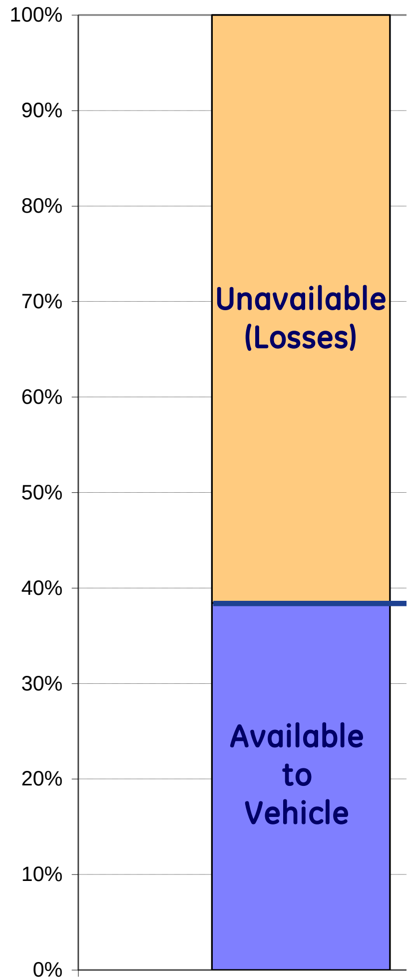
Reduce commercial and military customer costs in an increasingly difficult environment



Technologies and Architectures

Energy Availability

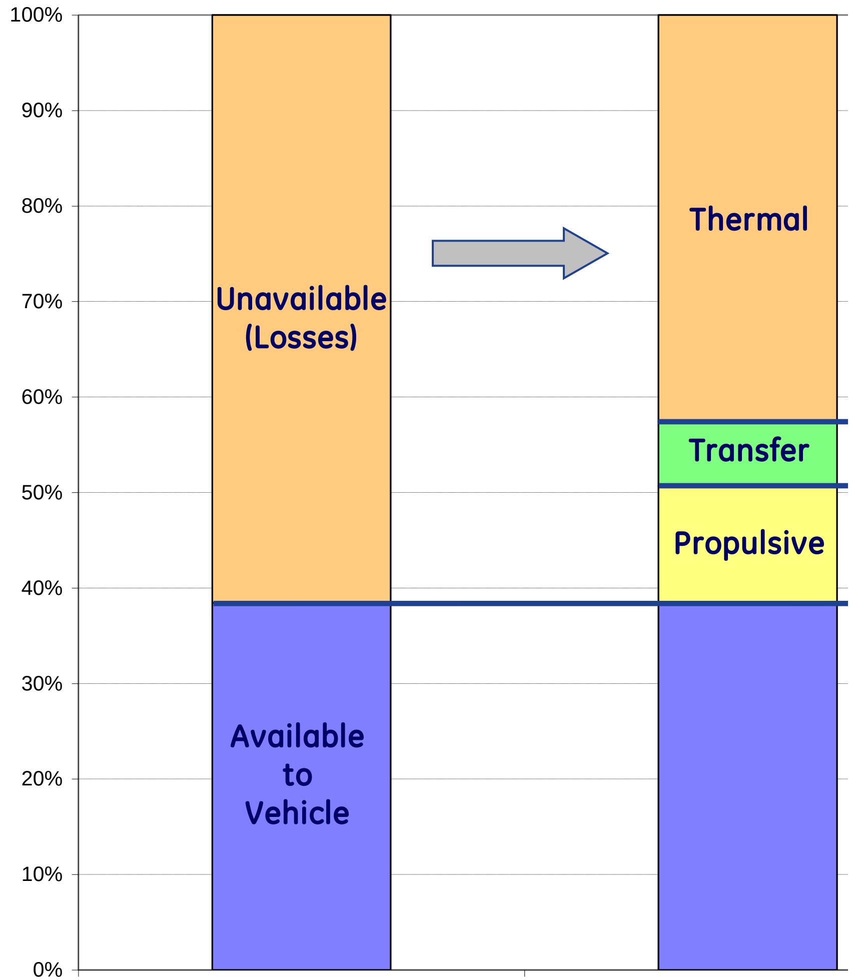
For Every Unit of Fuel Chemical Energy…



Today's Turbofan Is roughly 40% efficient

Energy Availability

converted into transfer efficiencies…



60% loss can be categorized as:

Thermal eff: Thermodynamic loss due to the Brayton Cycle

Transfer efficiency: Loss converting energy from the core to the bypass

Propulsive efficiency: Loss of converting fan and core exhaust into useable thrust

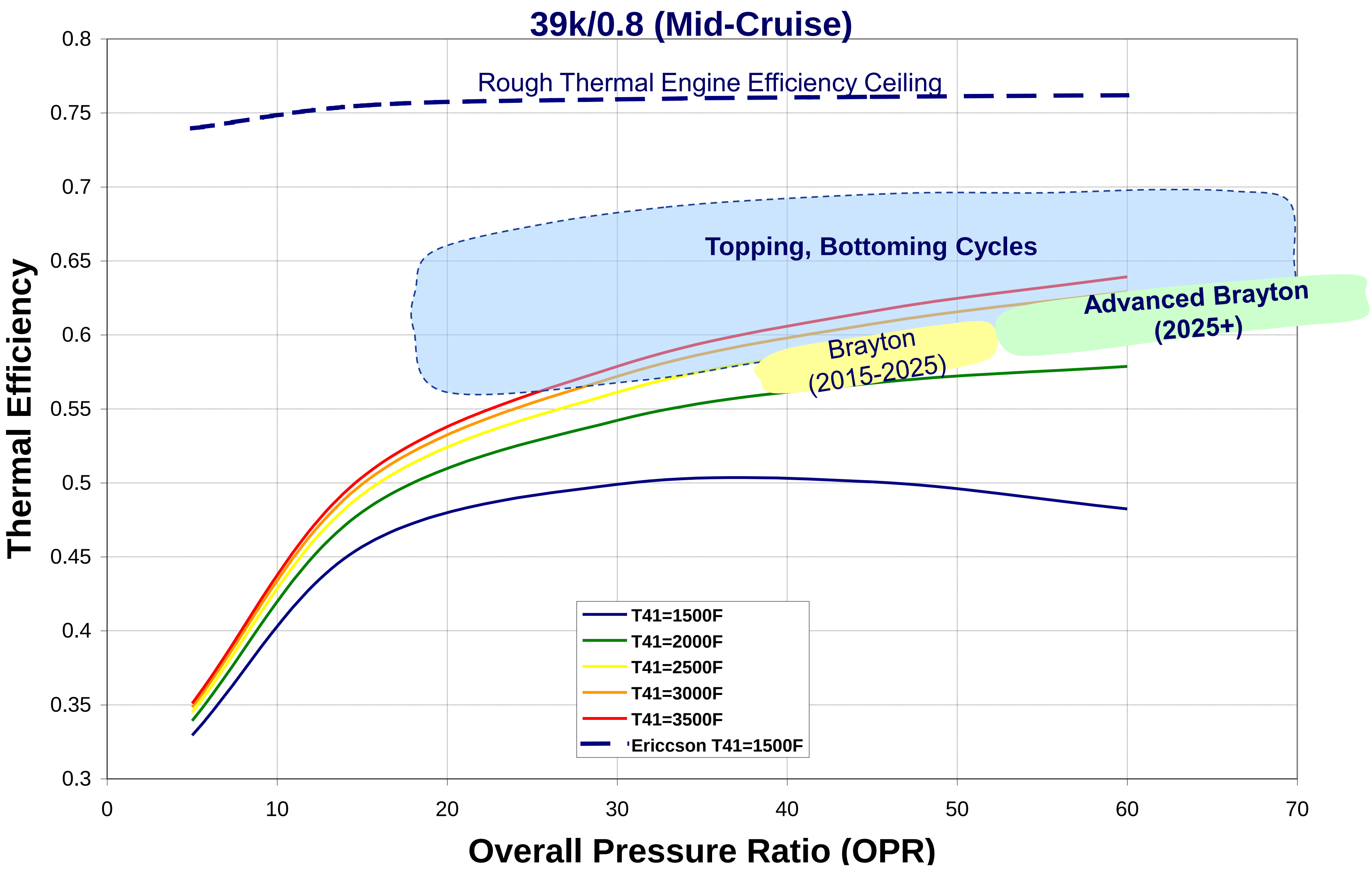
Opportunities for the future…

$$Range = \left(\frac{V_0}{SFC}\right) * \left(\frac{L}{D}\right) * \ln\left(\frac{W_{initial}}{W_{final}}\right)$$

$$= \left(FHV * \eta_{thermal} * \eta_{transfer} * \eta_{propulsive}\right) * \left(\frac{L}{D}\right) * \ln\left(1 + \frac{W_{fuel}}{W_{payload} + W_{empty}}\right)$$

$\eta_{thermal}$	$\eta_{transfer}$	$\eta_{propulsive}$	W_{empty}
• Highly Loaded Compressors • High OPR Low Emissions Combustors • Adaptive cycles • Constant Volume Combustion • Hybrid Electric Propulsion	• Low Loss Inlets • Variable Low Loss Exhausts • Distributed Power Transmission	• Very High BPR Turbofans • Ultra High BPR Turbofans • Open Rotors • Distributed Propulsion • Wake Ingestion	• Novel Alloys • Non-metallics • Advanced Engine Architectures

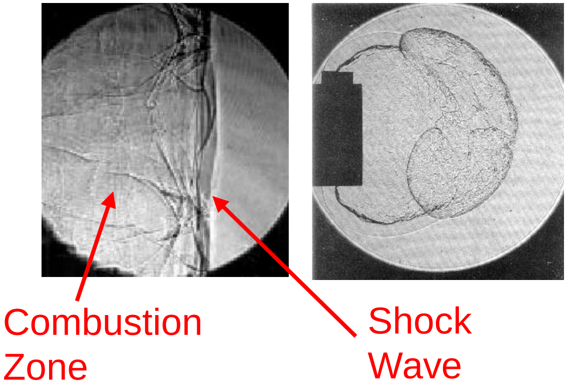
Thermal Efficiency



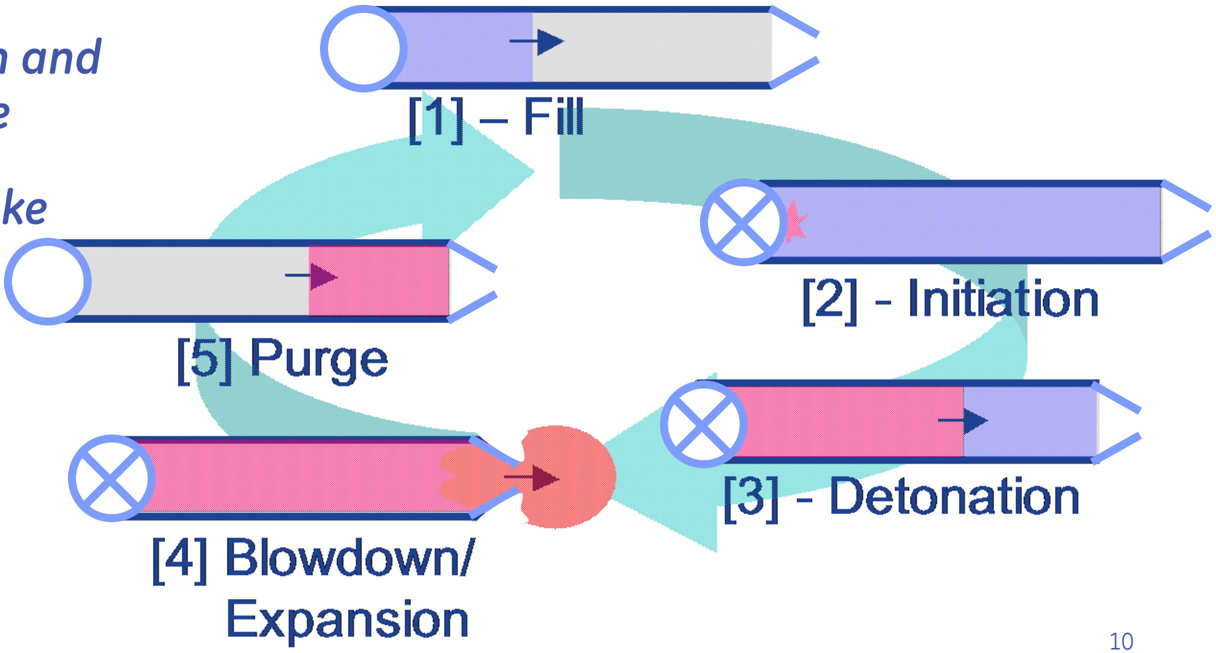
Large Thermal Opportunity Beyond Conventional Brayton Cycle

PDE Technology

- unsteady shock wave + combustion zone
- pressure rise combustion
- more efficient conversion of energy in fuel



Tube PDE	*IC Engine Analogy*
1 Fuel fill	*Intake Stroke*
2 Initiation	*Compression and Power Stroke*
3 Detonation	
4 Blowdown	*Exhaust Stroke*
5 Purge Air	



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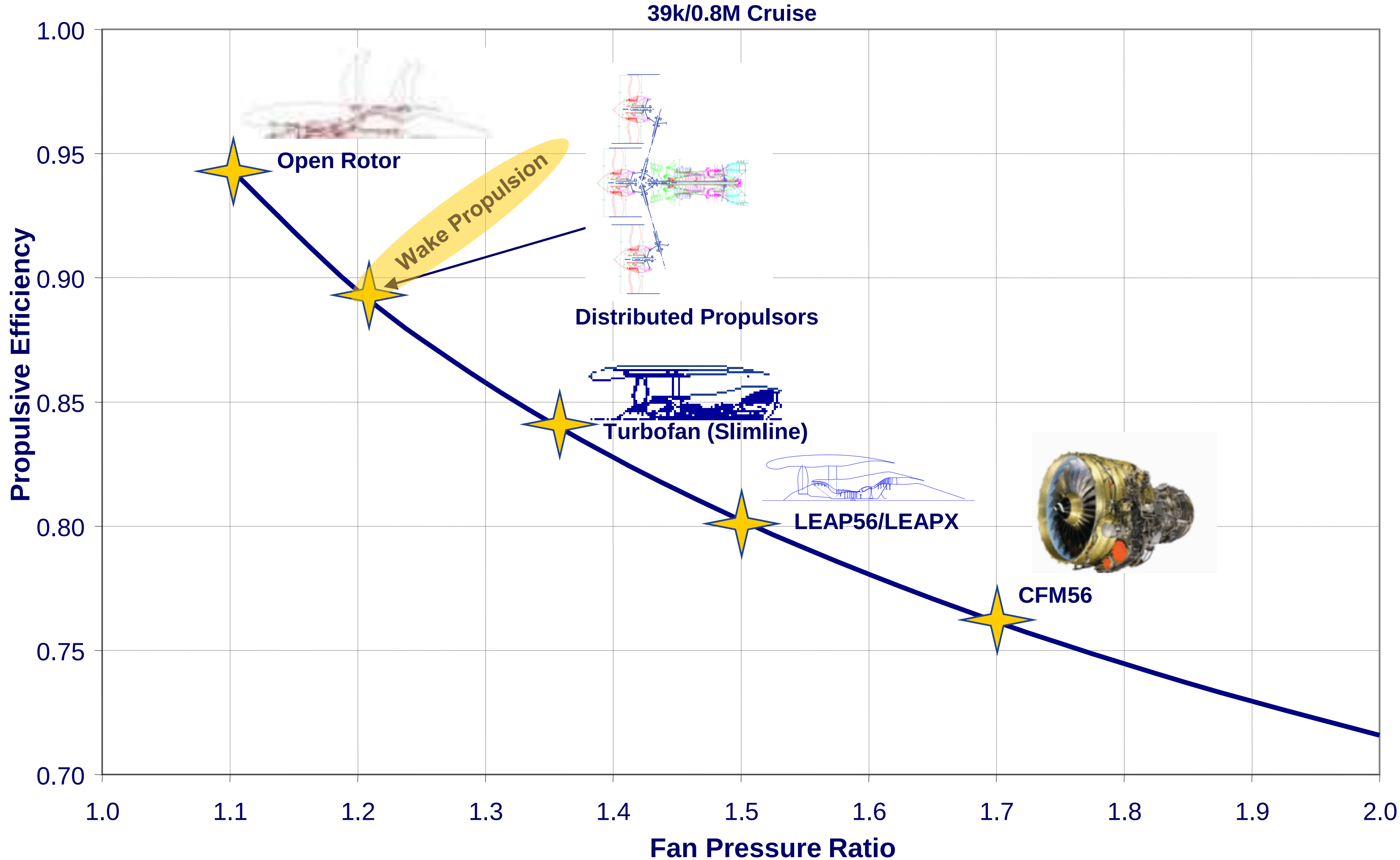
Propulsive Efficiency



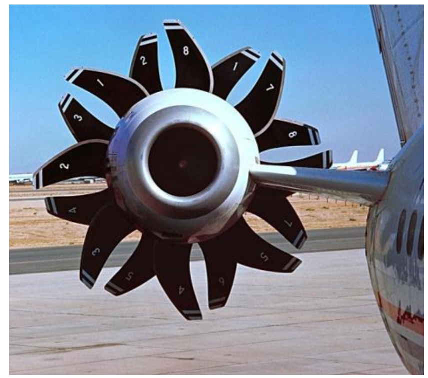
Drive to lower SFC's and more integrated engine / aircraft designs

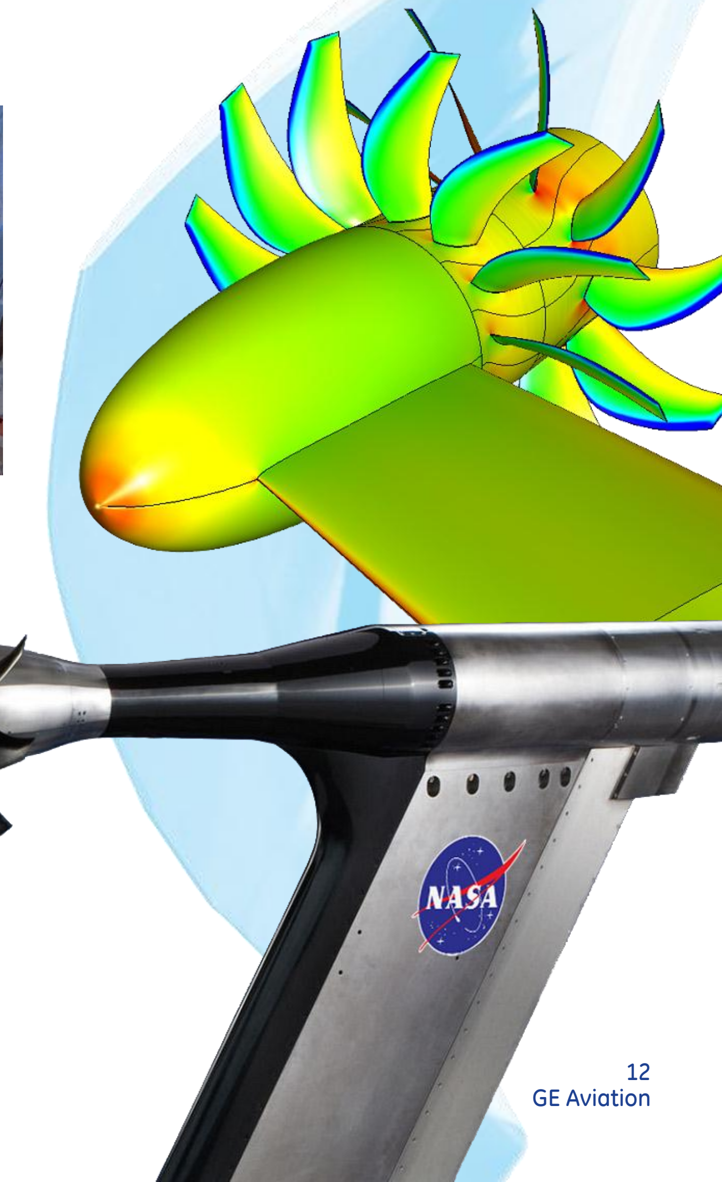
Open rotor tests with NASA

GE/NASA testing began in 2009

Test builds on 1985 demonstration

- Acoustics validation
- Aero model validation
- New blade concepts
- Installation effects
- Pitch change effects
- Pylon, sidewall interaction





Driving productivity through analytics

Fuel & carbon

- Flight operations data analysis
- Operations insights for fuel savings

Improving **productivity** of assets

1% fuel burn reduction[a)] = $10MM savings

IVHM

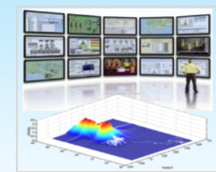
Integrated Vehicle Health Management

- Advanced prognostics & enterprise integration

Improving **utilization** of airplanes

1 hour increase in aircraft utilization per day = $100MM+ annual benefit[c)]

Digital workscope



- Optimize time on-wing

Improving **service** of our engines

5% annual productivity = $50MM cost savings per year

Over **25,000**[b)] engines monitored … and growing

- **Fuel efficiency**
- **Asset utilization**
- **Operations efficiency**

(a- Assumes a typical 70 aircraft, $1B fuel bill, fuel cost is $3.25 per gallon
(b- Includes CFM, GE & EA engines
(c- Assumes fleet > 50 aircraft

Global challenges

Temperature, dust, pollution, gravel, sand, construction debris

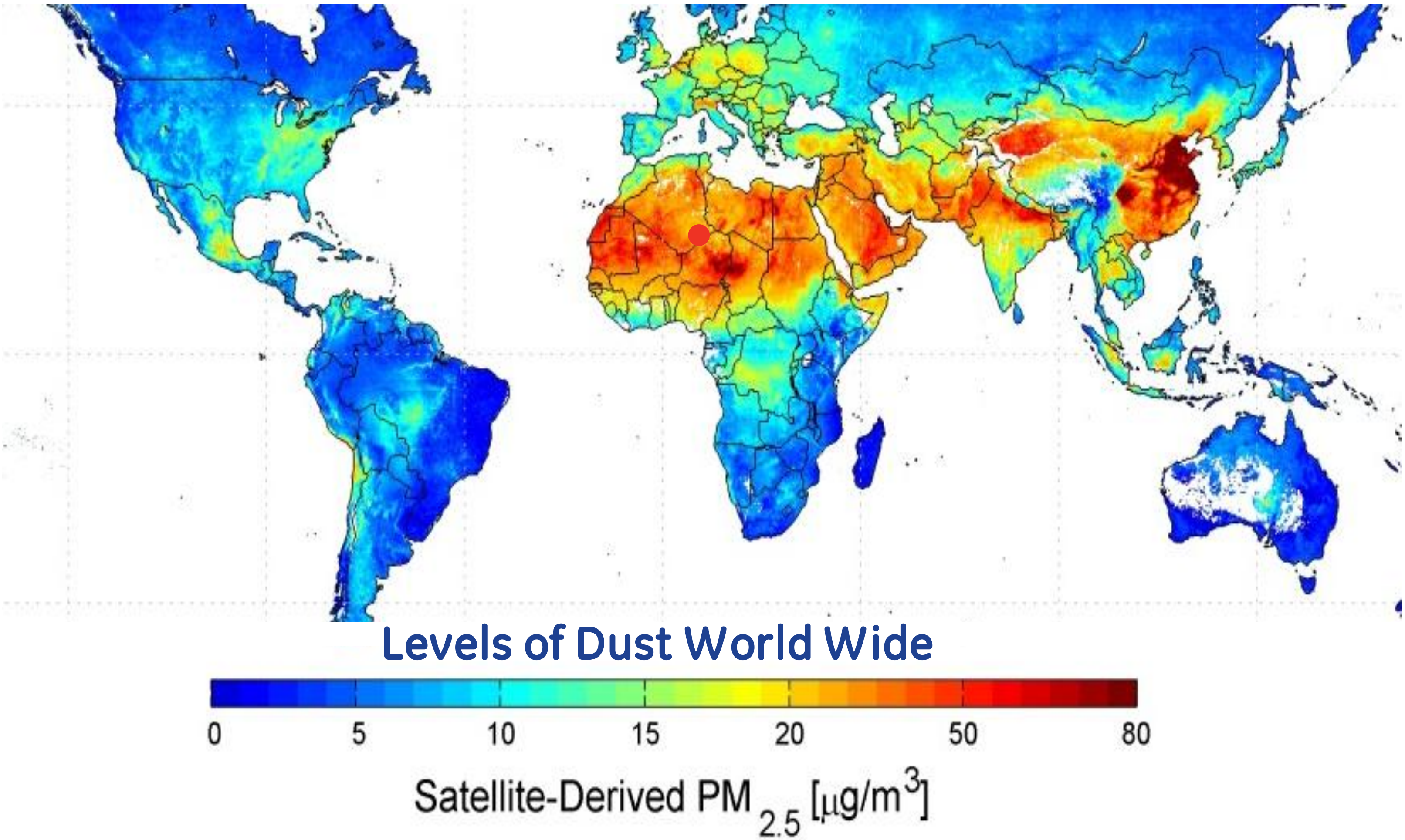


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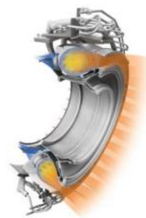
Illustration of particulate matter concentration (Source: NASA)

Technology integration thru 2020

Keeping the pipeline filled

Technology

Composites



Lean Combustion

CMCs

Adv. Cooling

High-Temp Materials

Flight Mgmt

2010

Advanced turbofan

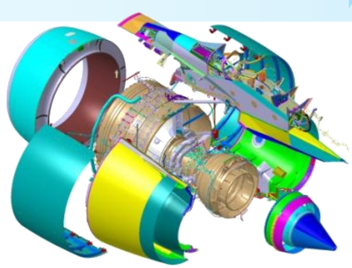
Integrated engine and aircraft systems

Adaptive cycles

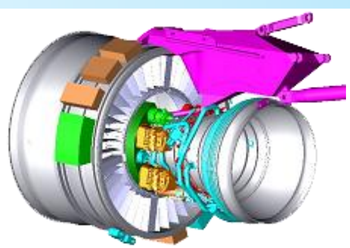
Advanced architectures

2020

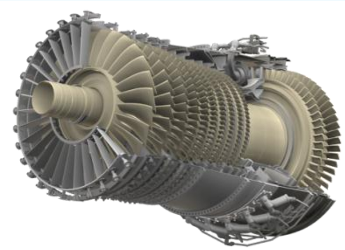
Architecture



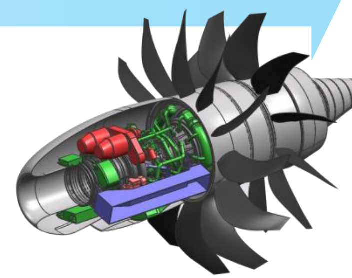
Integrated propulsion



Integrated power generation



Core efficiency



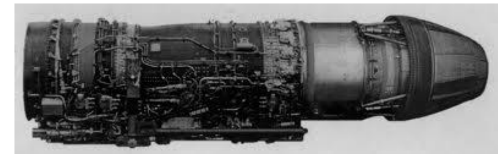
New designs

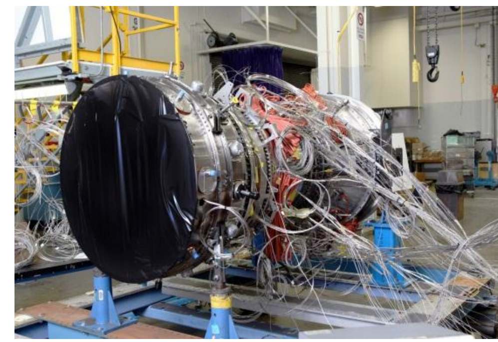
Technology demonstrator programs

Renewing our technology DNA for new products and upgrades of fielded products. Mostly USG funded, what comes next?

Adaptive Engine Technology Development

- AETD…new class of engines with up to 25% better fuel efficiency
- Variable cycle technology
- Technology demonstration that builds on ADVENT
- Foundation for future generation of combat propulsion





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New Products and Services

GEnx build-up, acceptance & flight test...

New Product Introduction (NPI)

Taking our products from design to manufacturing

Make parts → Run Development Tests → Certify

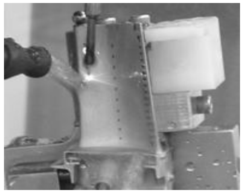
Test types

- Performance
- Ingestion – *water, hail, ice, dust, birds*
- Acoustic
- Fan blade-out
- Emissions
- Vibration
- Endurance
- Flight

New Product Introduction (NPI)

Lean labs

Turbine Airfoils



Rotating Parts

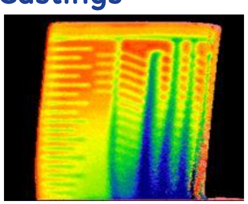
Composites

Special Products

Structures

Automation

Castings



Additive Manuf.

Explore, develop and industrialize Advanced Manufacturing Technologies and transition to Supply Chain.

Process development

Demo production → Industrialization for cost, quality & delivery

Full scale production

New military and commercial pipeline…

- F414 Gripen
- F414 INS6
- CT7, T700 derivatives
- LEAP
- GE9X
- GE38

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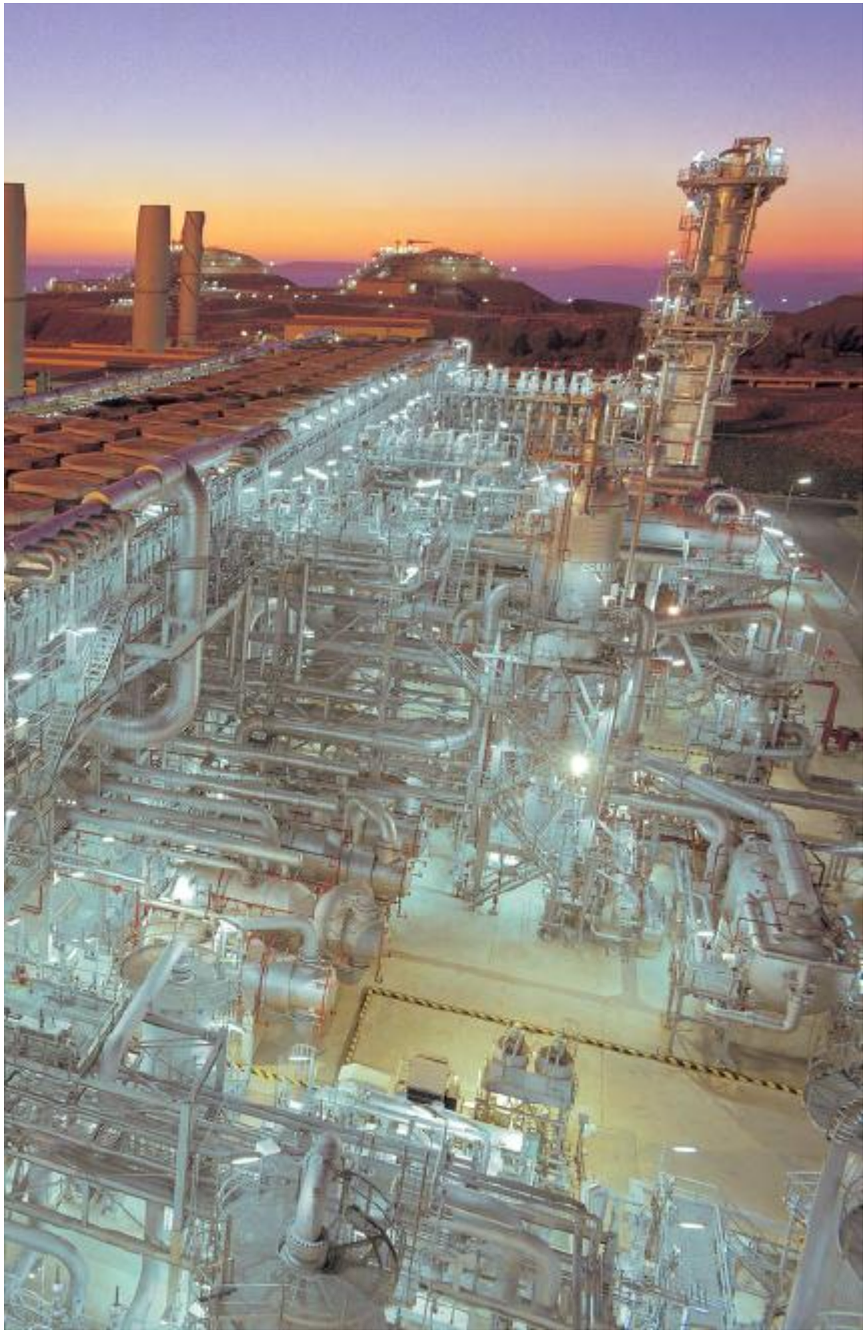
Alternative Fuels

Aviation Alternative Fuels…

- Drop in
- Near Drop-in
- Non Drop-in



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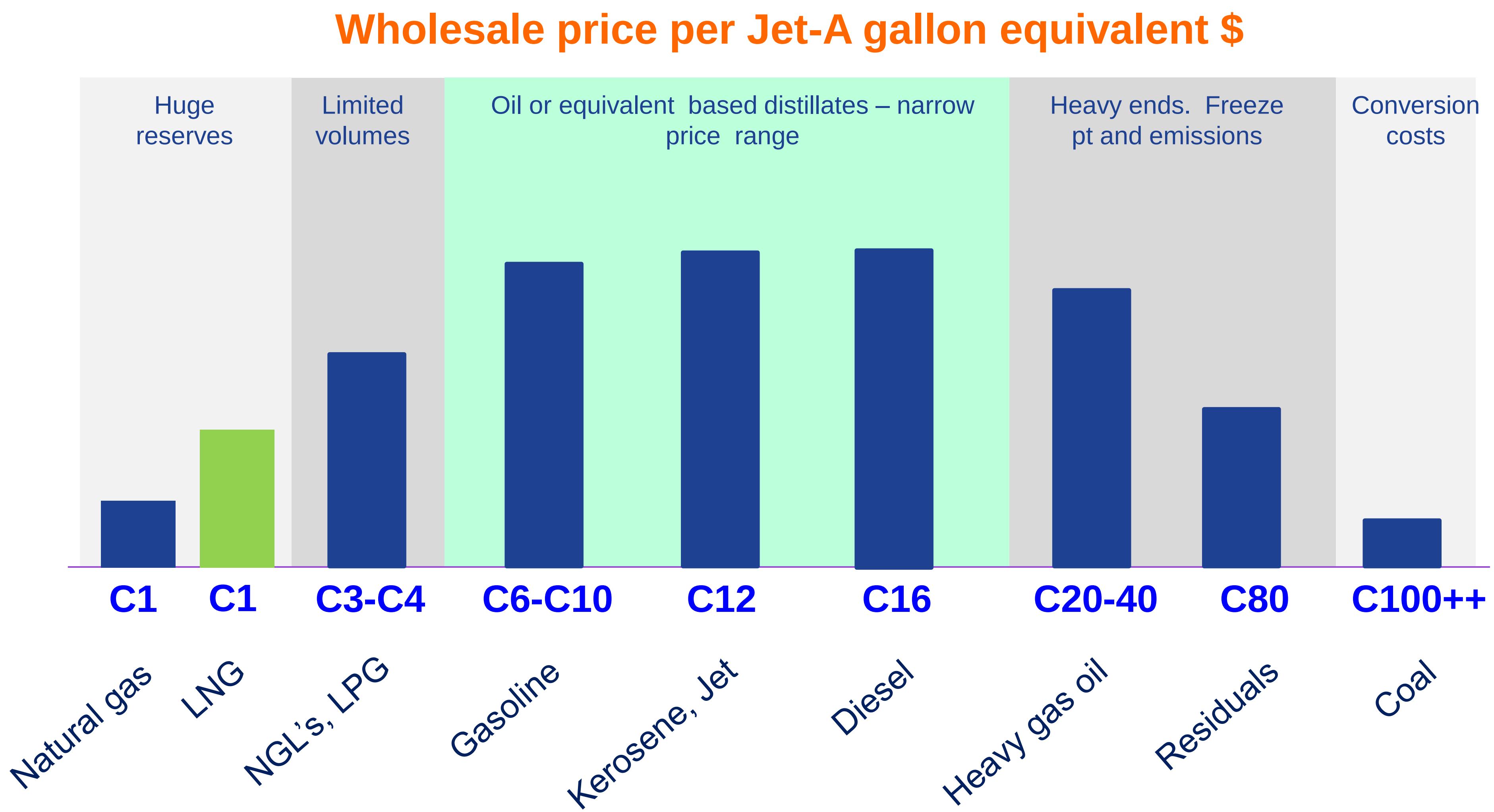
The Cost Of Fuel…



Summary

Traditional fuel burn reduction strategies are beginning to yield diminishing returns – innovative technologies are required

- Light weight, high propulsive efficiency
- Advanced materials
- Highly integrated
- Big data, prognostics, IVHM
- Non-Brayton cycles

New products are the lifeblood of the business

- Roadmaps near term to 2050+
- Maintenance concept selection can have multi billion dollar impact to the bottom line.

Aviation alternative fuels may play a significant role in our energy future

*CFM engines