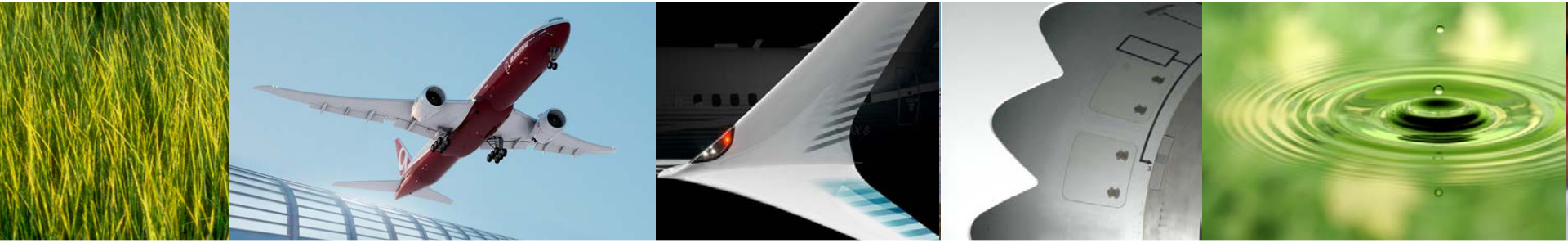
Commercial Aviation and Sustainable Fuels
The Path to Viability

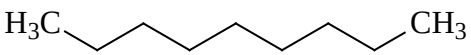


Michael Lakeman
Director, Biofuel Technology Strategy
Boeing Commercial Airplanes
May 3, 2016

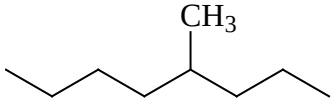
Typical jet fuel chemistry

Paraffins (75-95%)

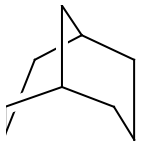
Ideal Carbon Length C8-C16



Normal Paraffins

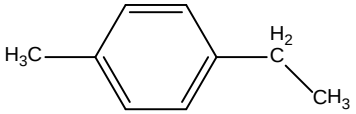


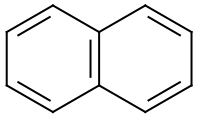
Iso-paraffins



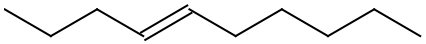
Cyclic Paraffins

Aromatics (<25%)

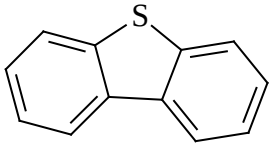


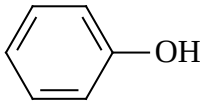


Olefins (<5%)



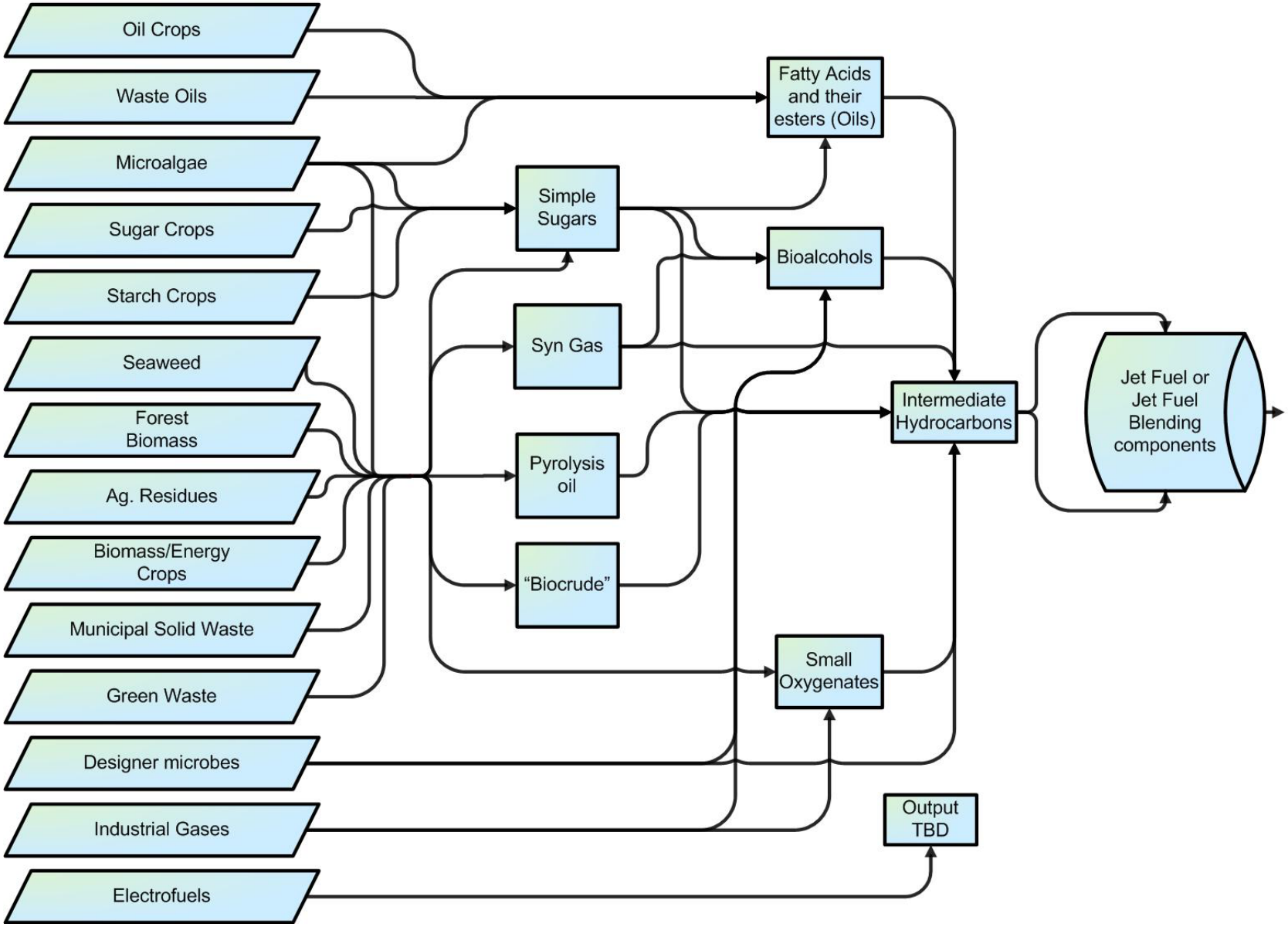
Sulfur, Nitrogen, Oxygen Containing Compounds





Acids, phenols, etc

The Technology Landscape



Fuel approvals will further expand supply

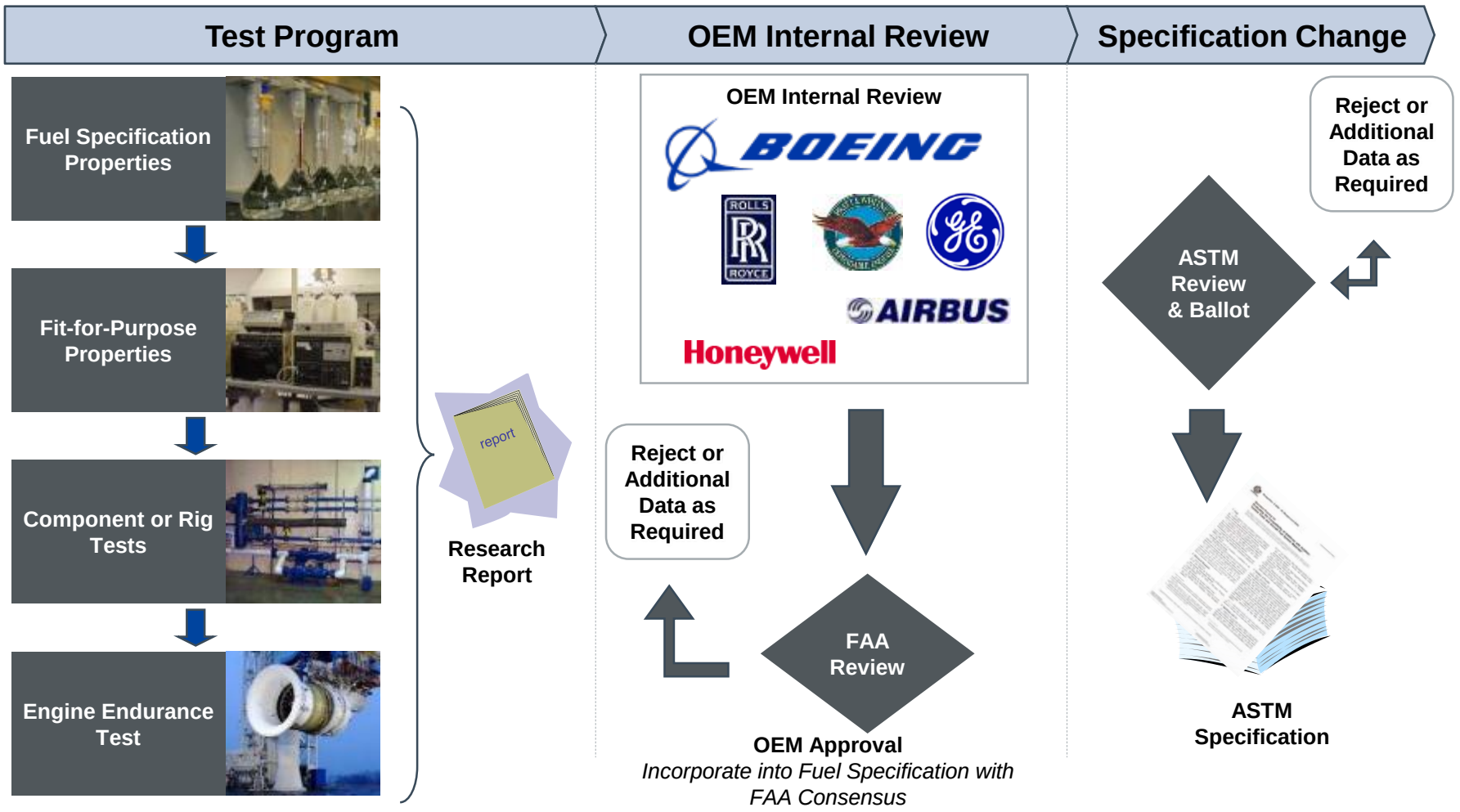
Approved

- Fischer-Tropsch (2009)
- HEFA (2011)
- Direct fermentation of sugar (2015)
- Isobutanol to jet (2016)
- FT-SKA (2016)

In the "pipeline"

- Green Diesel
- Hydrotreated depolymerized cellulosic
- Catalytic hydrothermolysis
- Catalytic sugar
- Alcohol to jet (ethanol)
- Many others…

ASTM fuel approval process- ASTM D4054



Biofuel and the Jet Specifications

Fossil Jet-A/A1

Produced to Def Stan 91-91 or D1655[1]

100% Biofuel

Tested to an Annex in D7566[1]

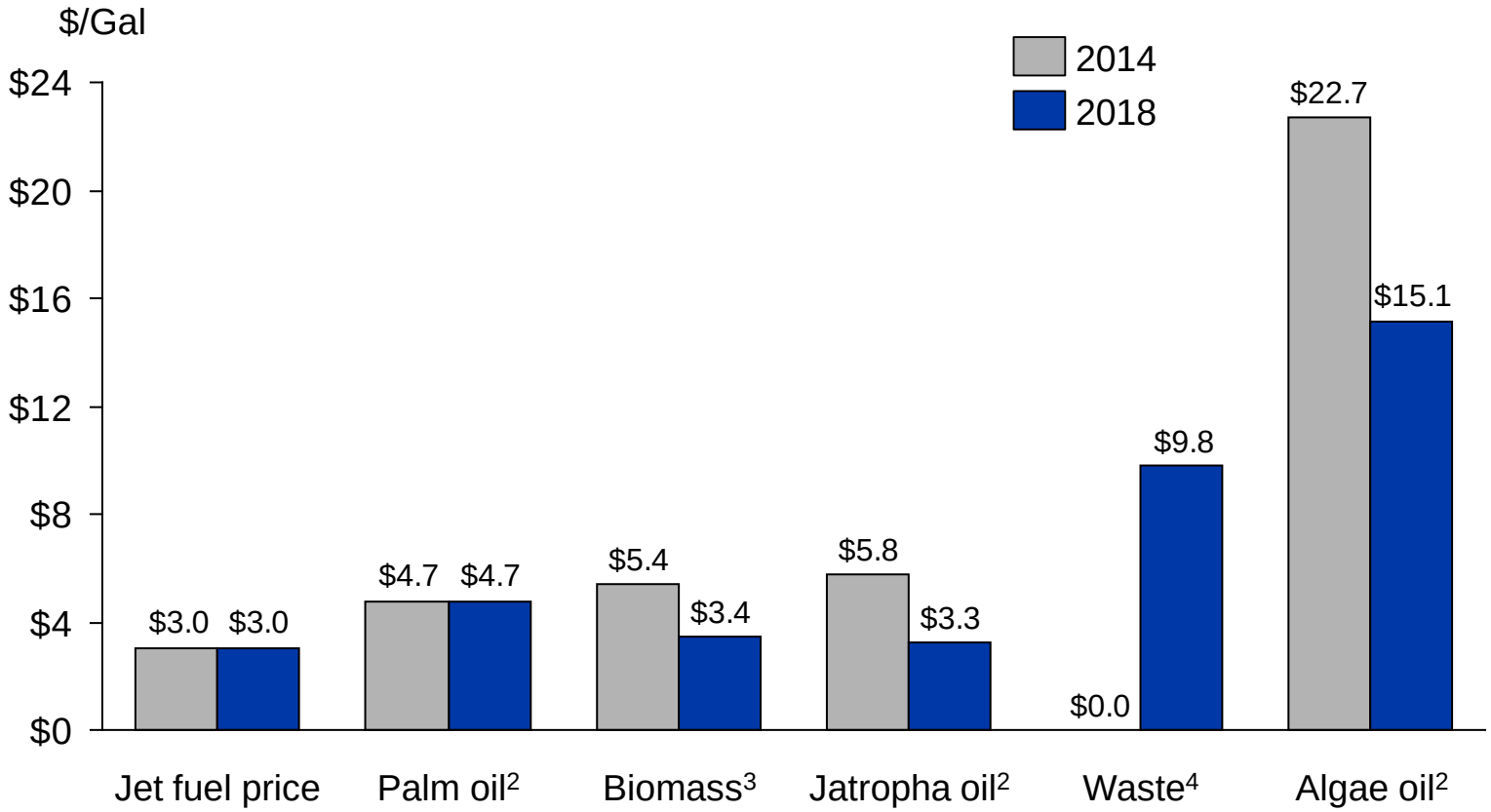
D7566 Annex also defines feedstock and process

Jet-A/A1 Biofuel Blend

Recertified to D1655 or designated as Def Stan 91-91

1. ASTM D1655 and D7566 standards covers a wide variety of fuel properties and specify which tests should be conducted to verify these

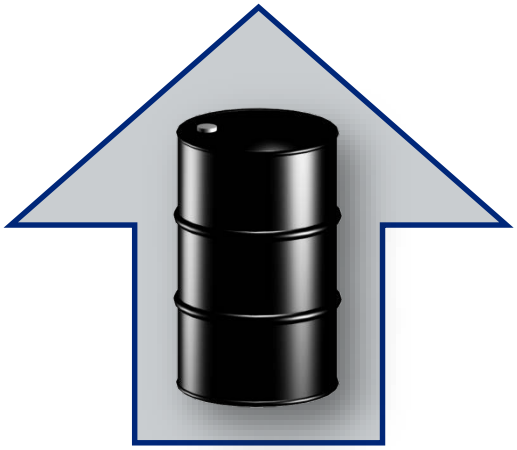
Costs of biofuel near and longer term



Near term premium, but moving closer to parity

gasification and Fischer Tropsch. No plants expected to be built by 2014 and thus no cost included.
Note: In 2018 cost estimates, BNEF assumed all but algae pathway have reach full commercialization.

3 major levers drive long-term trends



Oil price

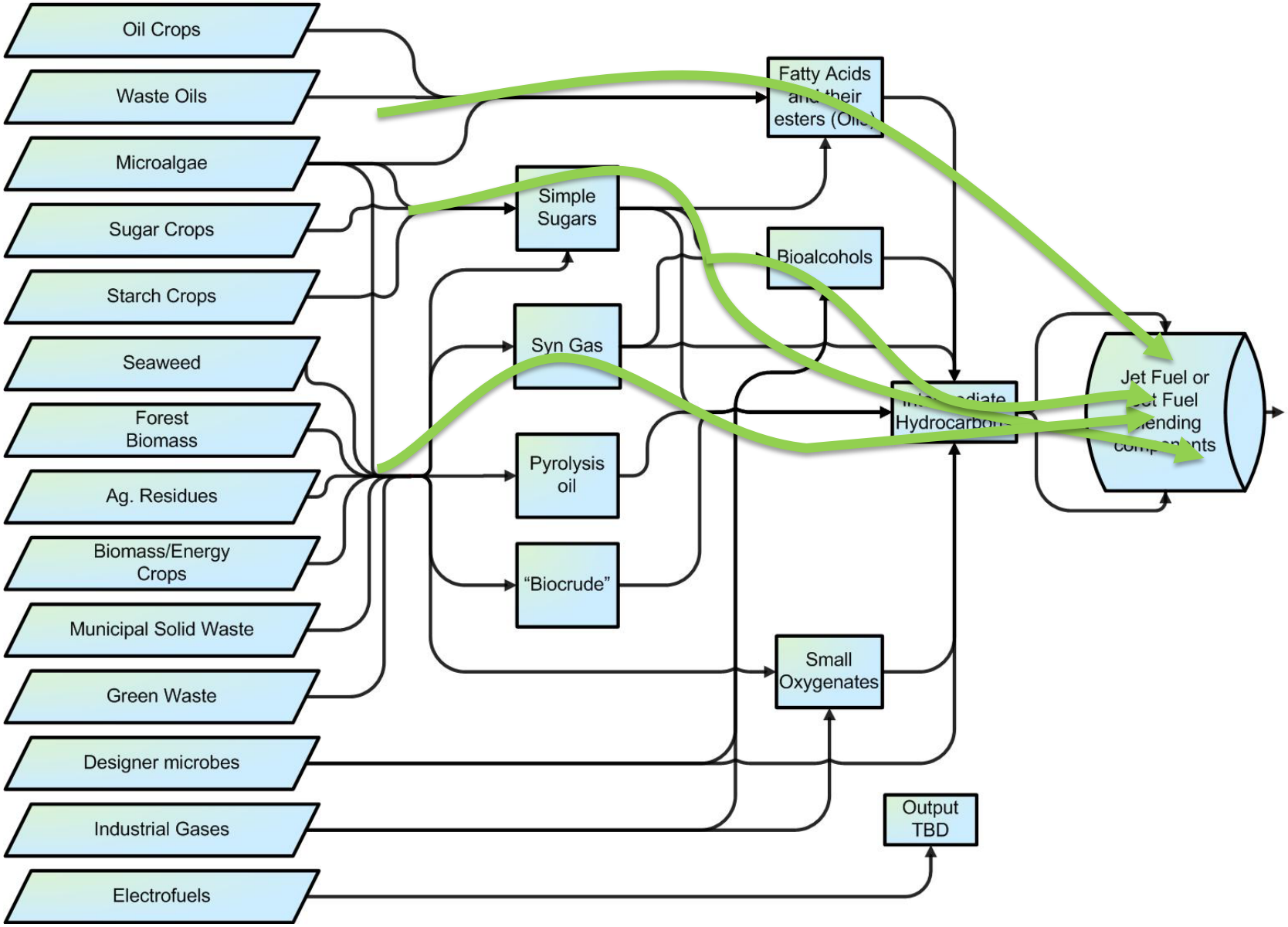
Emissions costs

Biofuel technology costs

Green diesel: Aviation biofuel breakthrough

- Used today in ground transportation
- 1.2+ billion gallons production capacity in US, Europe, Brazil, Asia
- Chemically similar to “HEFA” biofuel approved in 2011
- Price approaches Jet A, including government incentives
- Boeing tested 15% green diesel blend with ecoDemonstrator 787
- Reduces CO_2 by 50-90%, according to Neste Oil

The Technology Landscape… wide open!



Boeing's Role and Actions

Boeing's Role

Protect our environment

Assure industry growth

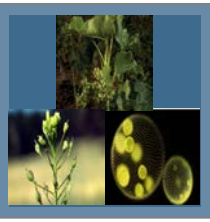
Address customer's top cost

Act as industry catalyst to accelerate commercialization

Core activities

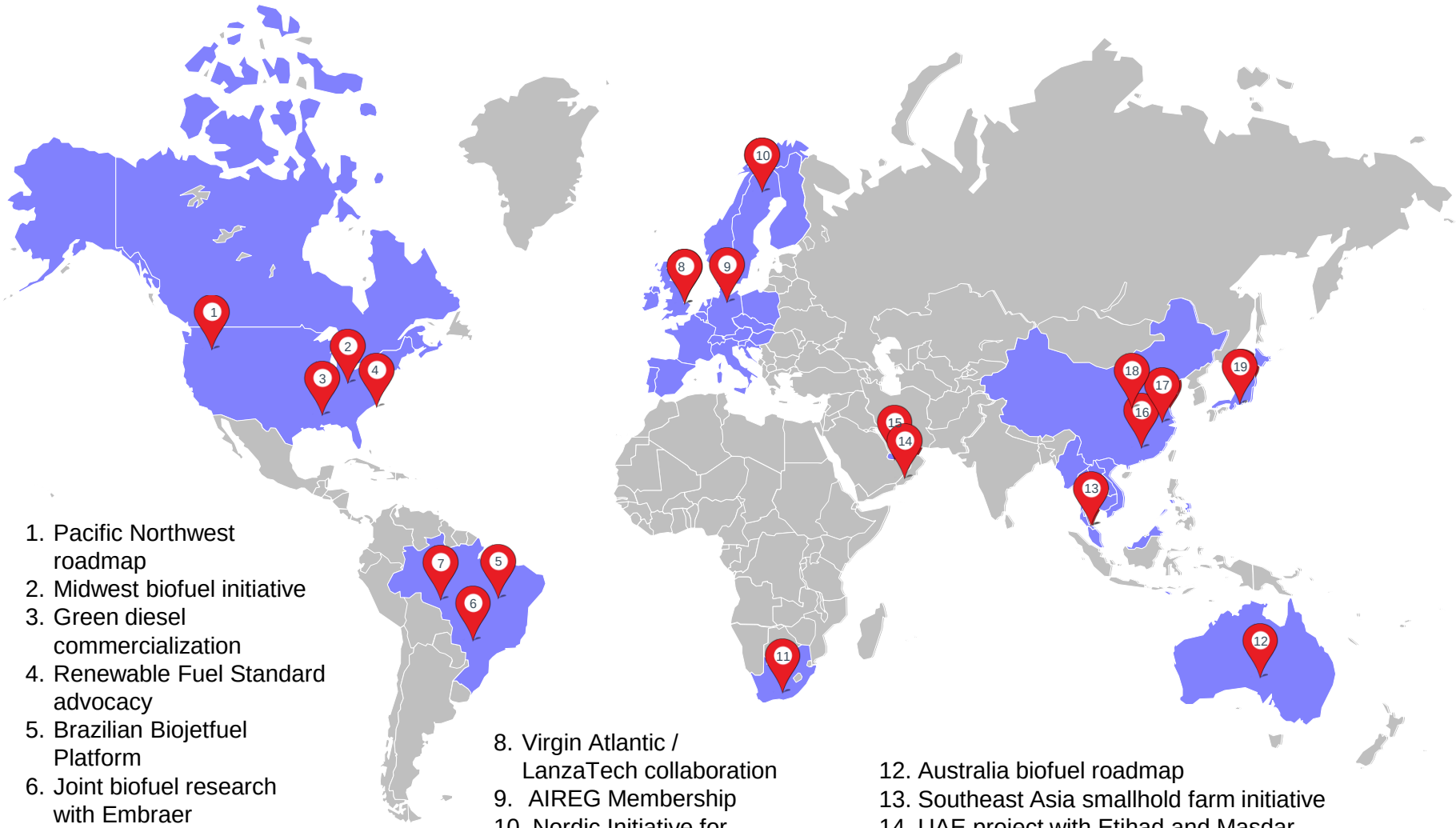
Support and Advocacy

Feedstock and Pathway R&D



Fuels approval

Boeing global biofuel engagements



1. Pacific Northwest roadmap
2. Midwest biofuel initiative
3. Green diesel commercialization
4. Renewable Fuel Standard advocacy
5. Brazilian Biojetfuel Platform
6. Joint biofuel research with Embraer
7. GOL biofuel flights

* Global coordination for Sustainable Aviation Fuel Users Group

8. Virgin Atlantic / LanzaTech collaboration
9. AIREG Membership
10. Nordic Initiative for Sustainable Aviation
11. South African Airways biofuel collaboration

12. Australia biofuel roadmap
13. Southeast Asia smallhold farm initiative
14. UAE project with Etihad and Masdar
15. BIOjet Abu Dhabi with Etihad
16. Biofuel R&D in China
17. “Gutter oil” facility with COMAC
18. Hainan Airlines commercial flight
19. Japan biofuel roadmap

Moving From Dreams to Reality

Aviation Biofuel Progress

- ASTM approval for commercial use
- Organized demand – commercial and defence
- Favorable policy developments
- Commercial flights continue

Next Steps

- Expanded ASTM approval
- Emphasis on policy continuity
- Research – expanded feedstocks/pathways
- Innovation – supply chain and commercial

Boeing is committed to a sustainable future


BOEING