


UC DAVIS SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

# Low Carbon Fuel Standard (LCFS) Status Review+

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STEPS Spring Symposium


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ITS UCDAVIS INSTITUTE of TRANSPORTATION STUDIES

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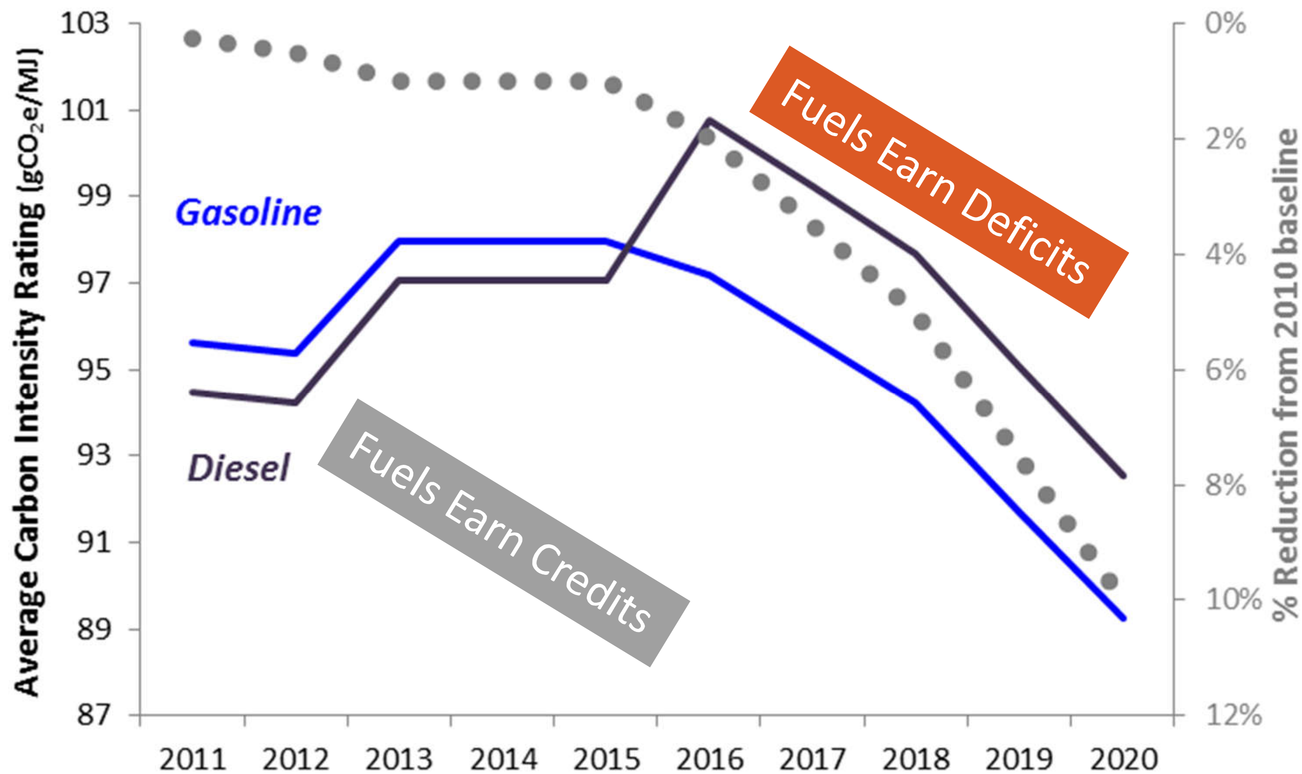
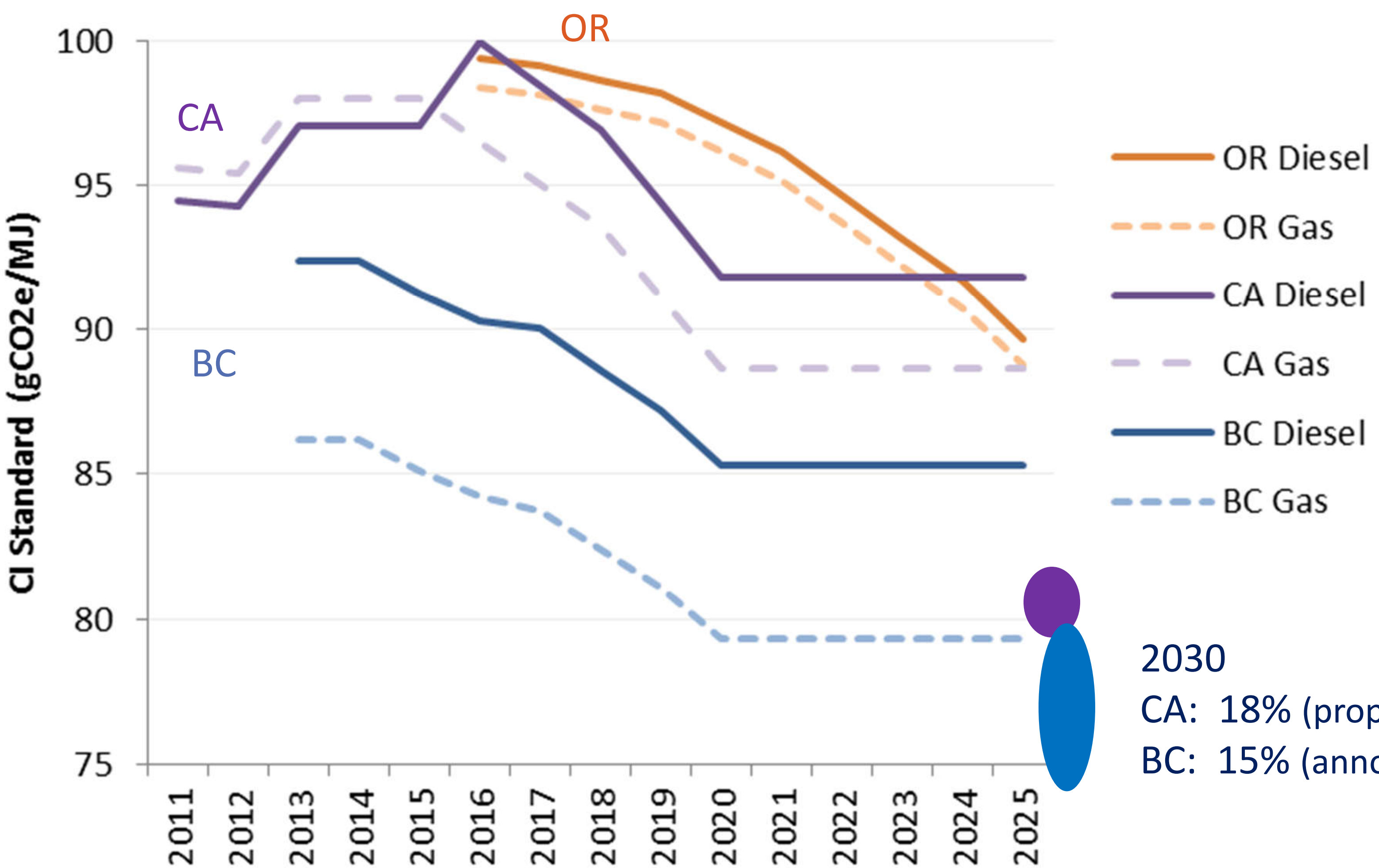
# California's LCFS: Rated Carbon Intensity (CI) Must Drop 10% in 10 Years (2010-2020 via annual standard)



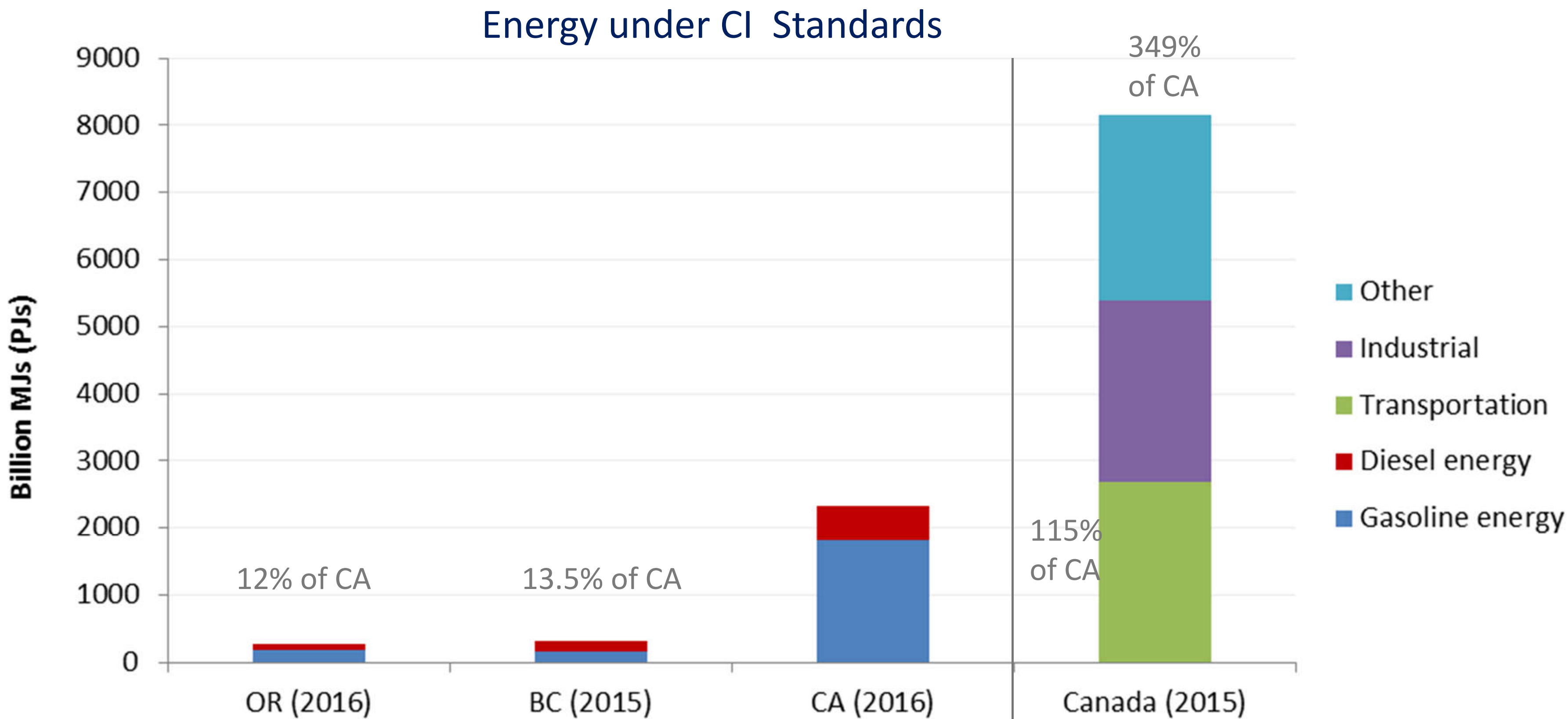

- "Lifecycle" CI rated on a continuous scale
- Market mechanism (fungible, bankable, tradable compliance credits)
- Technology forcing (via stringency), technology neutral (for alternative fuels)

# West Coast Jurisdiction CI Standards to 2025




2030
CA: 18% (proposed)
BC: 15% (announced)

# Beyond California… "LCFS" Energy (at a glance)




*Clean Fuels Program* (OR)
- 10%, 2015-2025
- Broader $C?

*RLCF* (BC)
- 10%, 2010-2020
- Broader $C tax

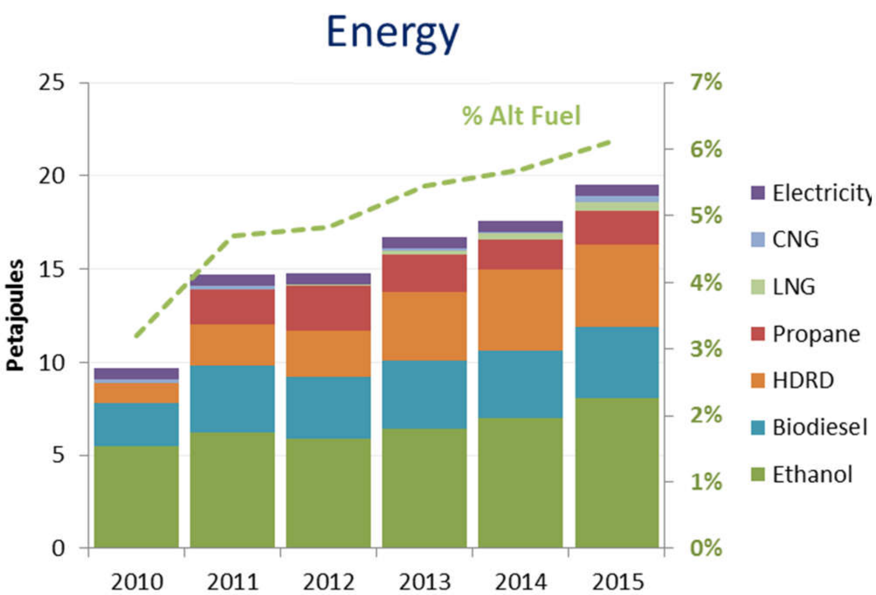
*LCFS* (CA)
- 10%, 2010-2020
- Broader $C (cap-&-trade)

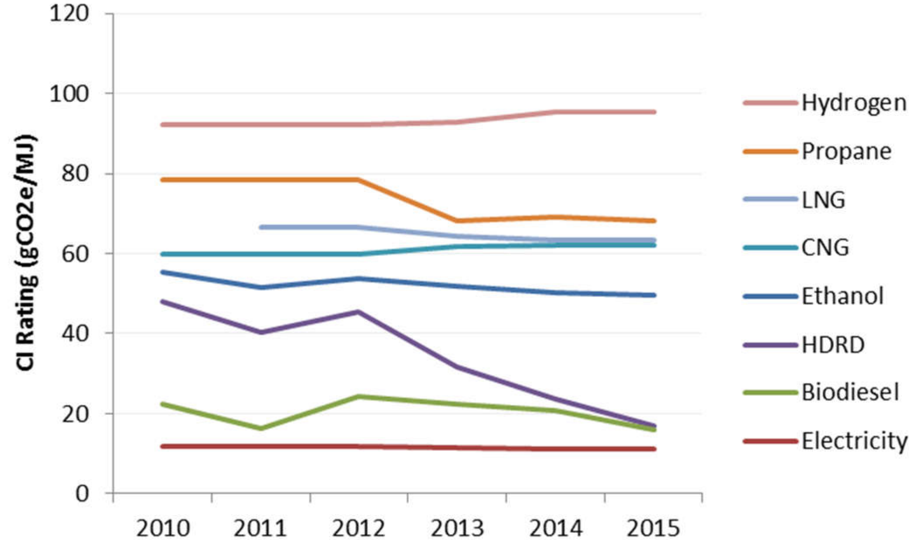
*Clean Fuel Standard in 2019* (Canada)
- 30 MT reductions, 2030
- Regulation in development
- Moving beyond transport(?)
- Broader $C ($10-$50/tonne, 2018-2022)

Sources: OR DEQ, BC Energy/Mines, CA ARB, Statcan

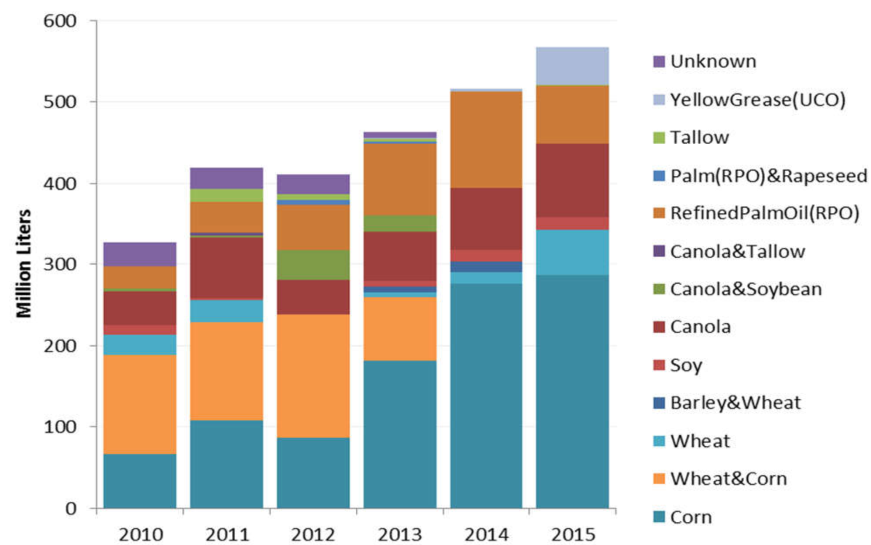
…+Ontario, Alberta

# BC Renewable and Low Carbon Fuel Requirement (at a glance)




Feedstock Biofuel Volumes ➔




- $171/MT (17 trades, 2016)
- 3.5% CI reduction, 2016

Source: BC Energy/Mines

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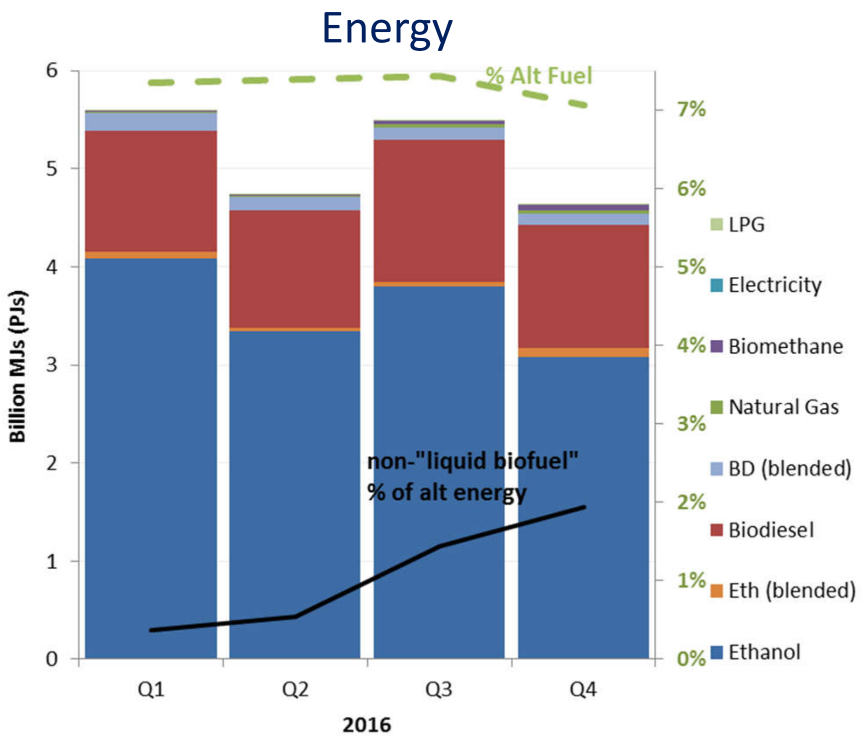
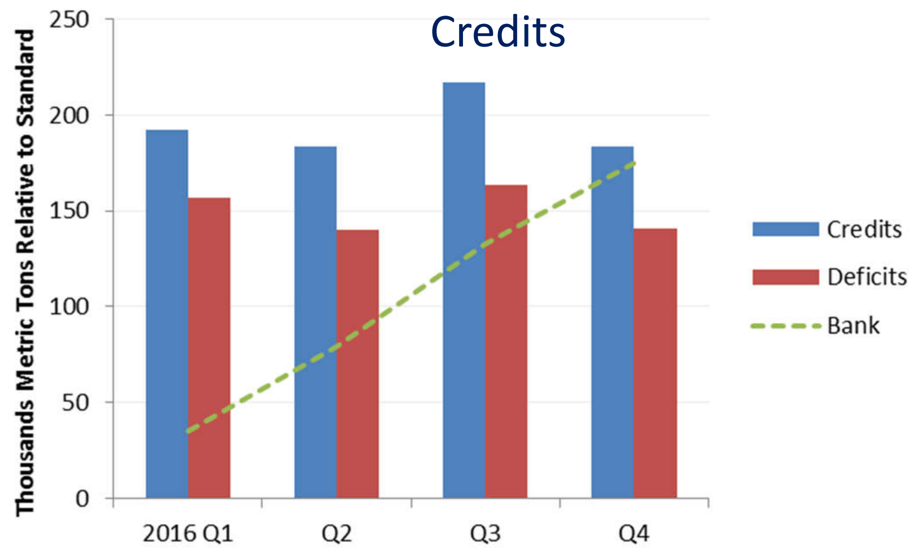
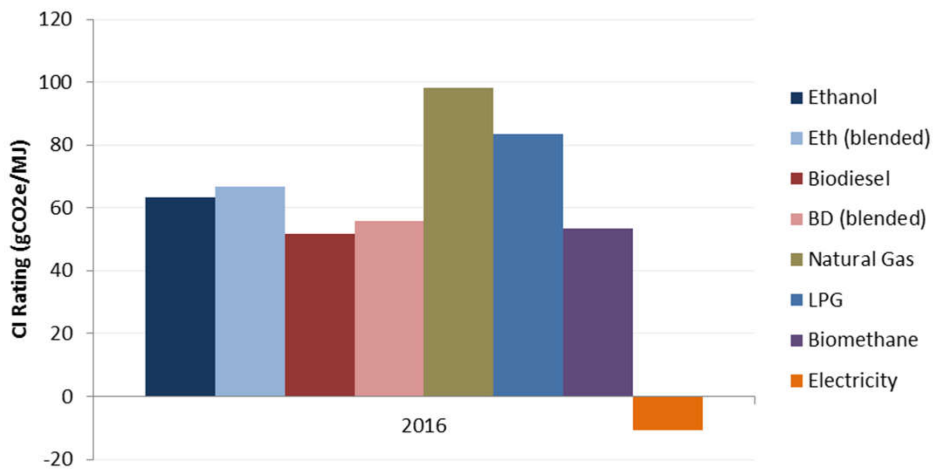
# Oregon Clean Fuels Program (CFP) at a Glance




CI Ratings of Fuel Used




- $45/MT*, 6 trades
- 0.25% CI reductions , 2016
- Cost containment under discussion

Sources: OR DEQ, *PFL market report

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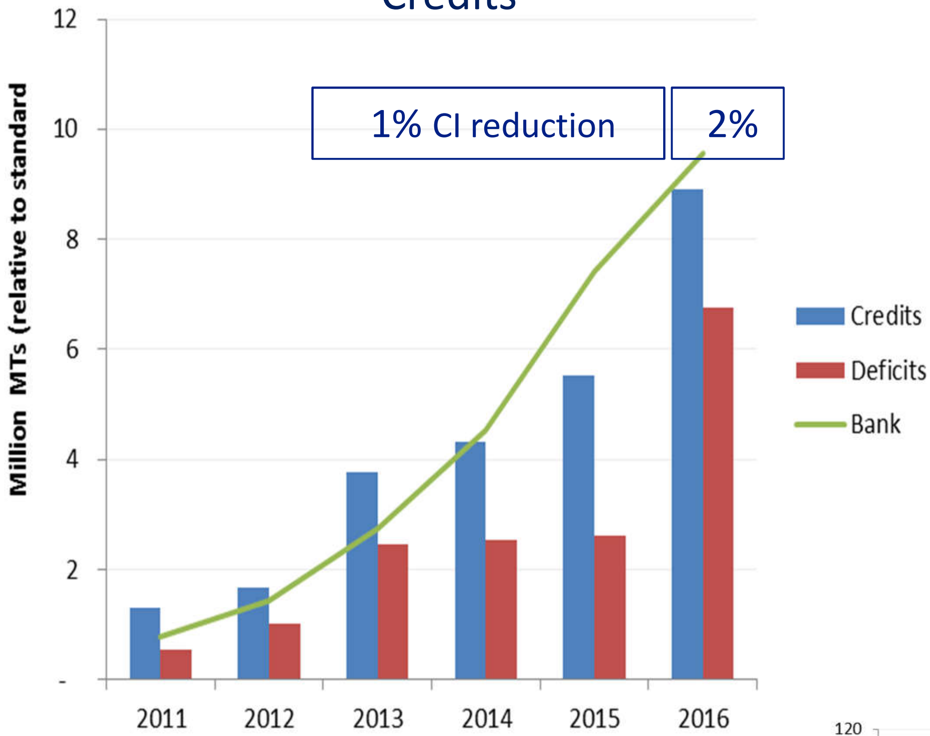
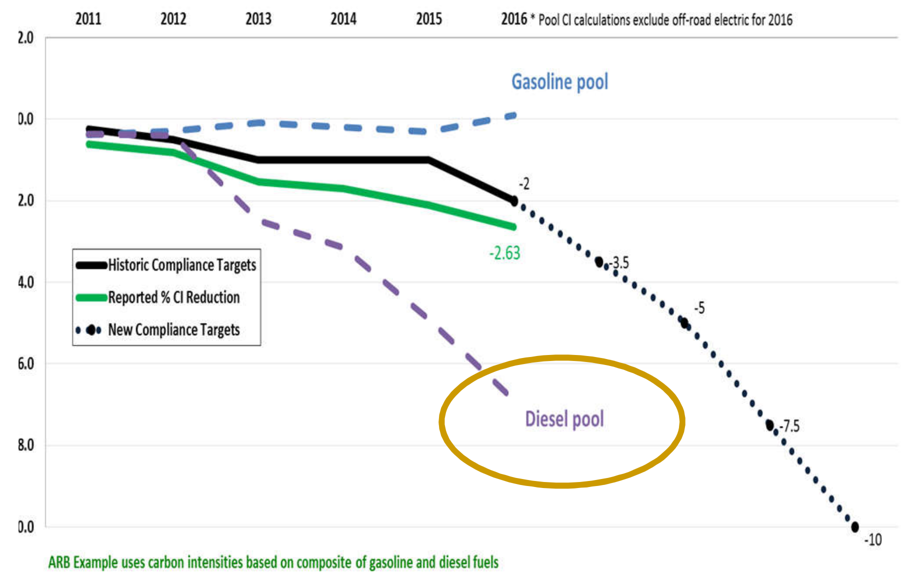
# CA: Growing credit bank driven by diesel pool

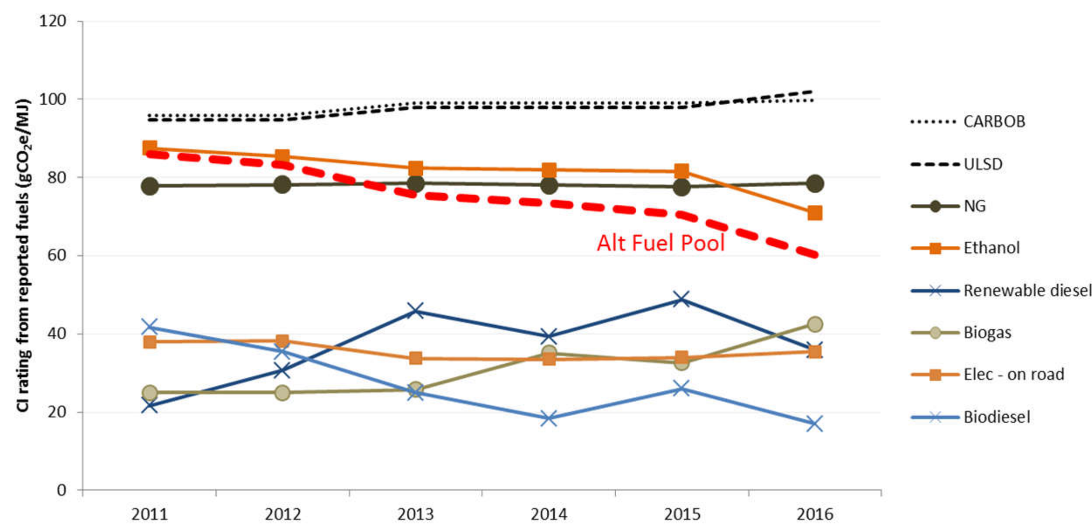
## Credits




## Program CI trends



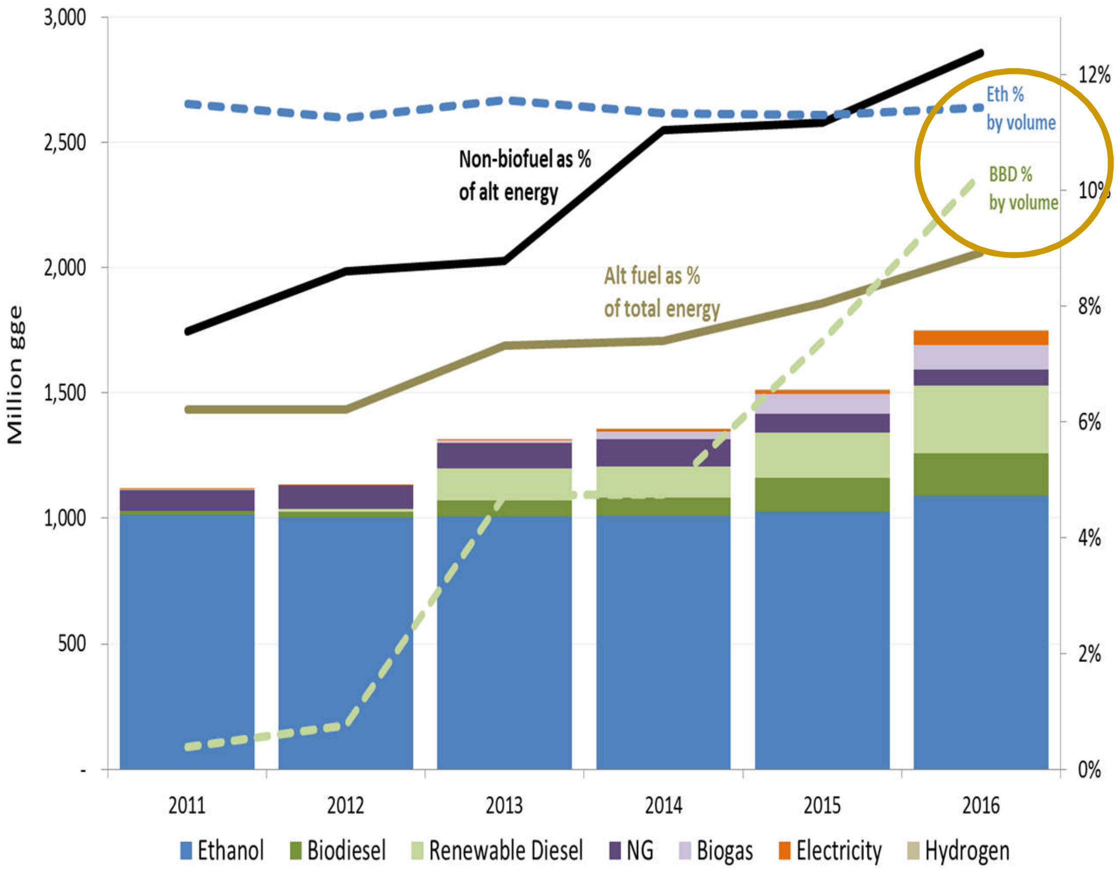

## Fuel CI rating trends

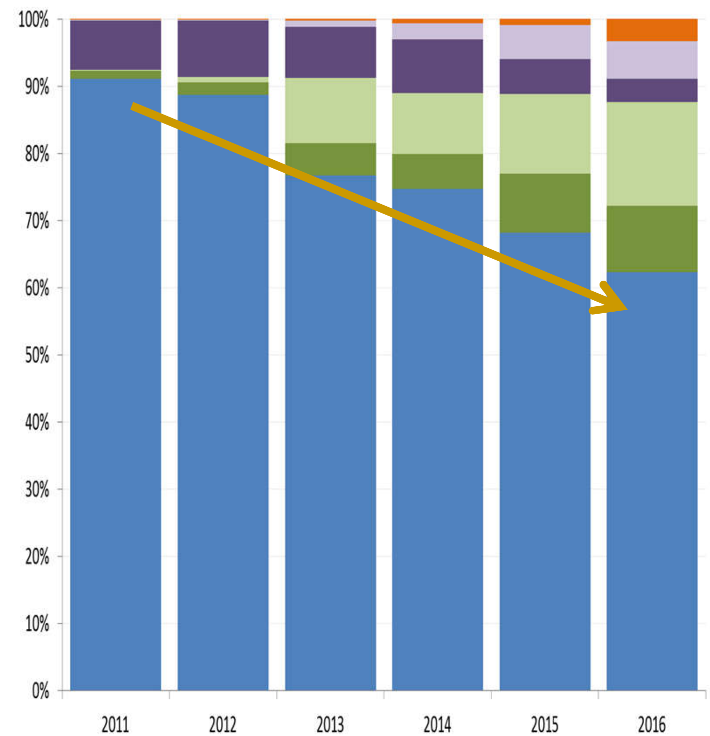



- ~70$/MT ($71-$90, ARB)
- Diesel pool freeze
    - by court ruling
    - pending ARB NOx envt'l impact analysis
- Verification/Monitoring
- Jet Fuel

Source: Adapted from ARB LCFS Data Dashboard

# Alternative Fuel Energy Increased 57% from 2011-2016




- % Alt energy in diesel pool growing (~2.5% to ~13%)
  - 14% with new off-road electric
- Steady (~7.3%) for gasoline pool

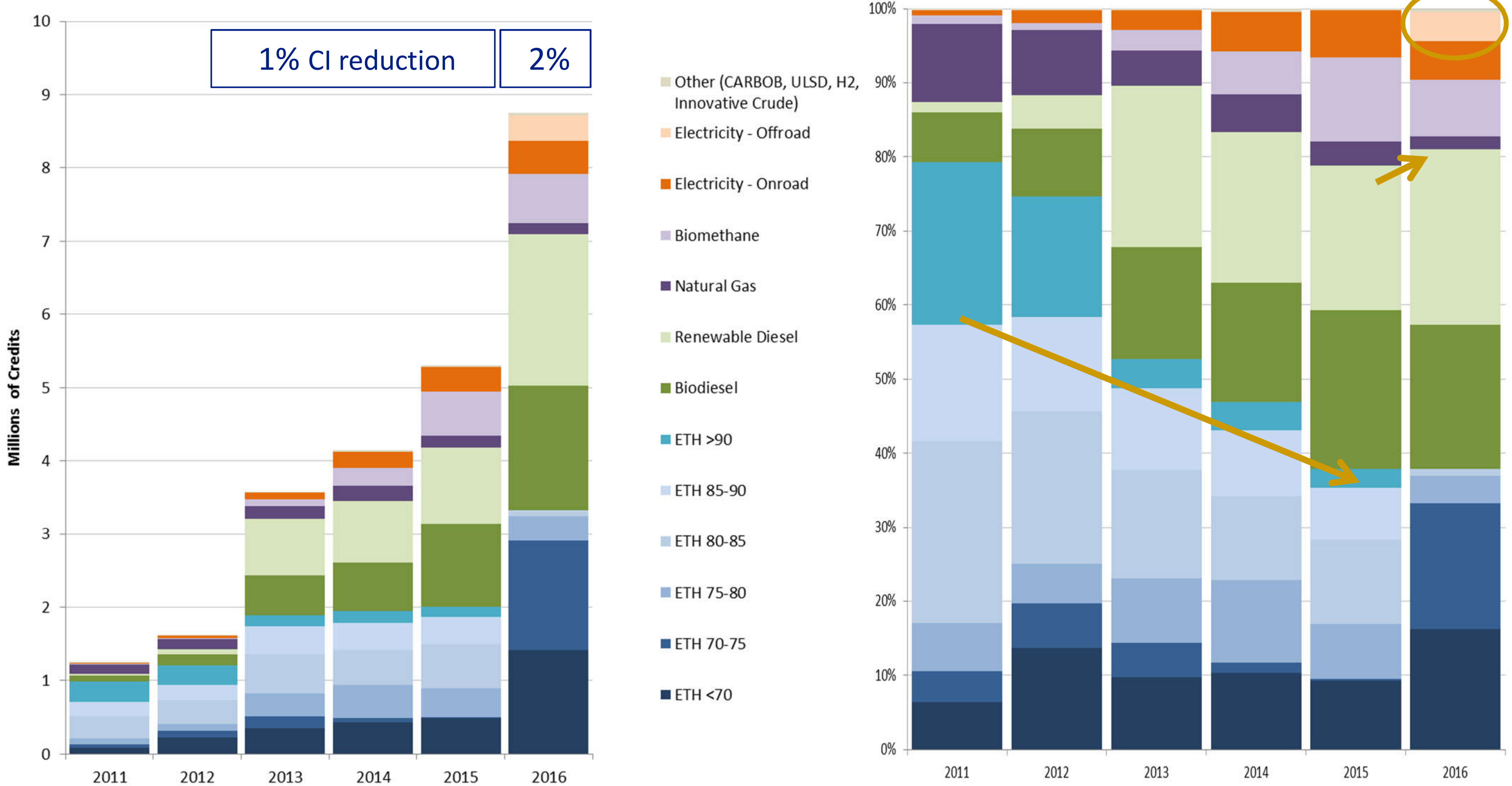
- Ethanol dominant but declining
- RD growing faster than biodiesel
- Biogas faster than fossil NG

Source: ARB data

# 2011-2015 – Credit Generation Diversifies from Ethanol
# 2016 – More Credits, Biofuel Contribution Grows

MTs below annual CI standard

%




Source: ARB Data

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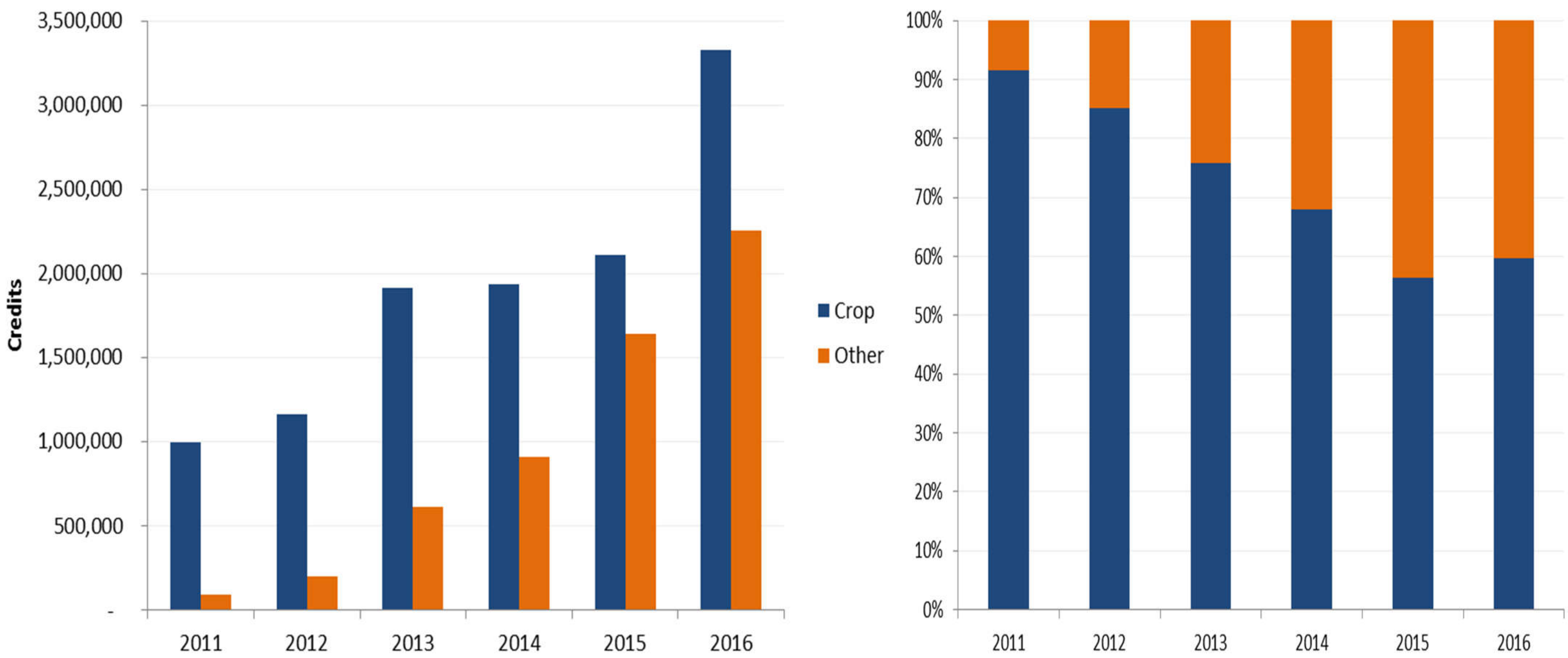
Model updates (lower CI ratings, esp. biofuels)
Widened scope (off-road electric)

# Biofuel Credits – Trend Away from Crops 'Resets' in 2016




Source: ARB data

- Modeling update (lower iLUC estimates)
- Non-crop fuel – indirect impacts?

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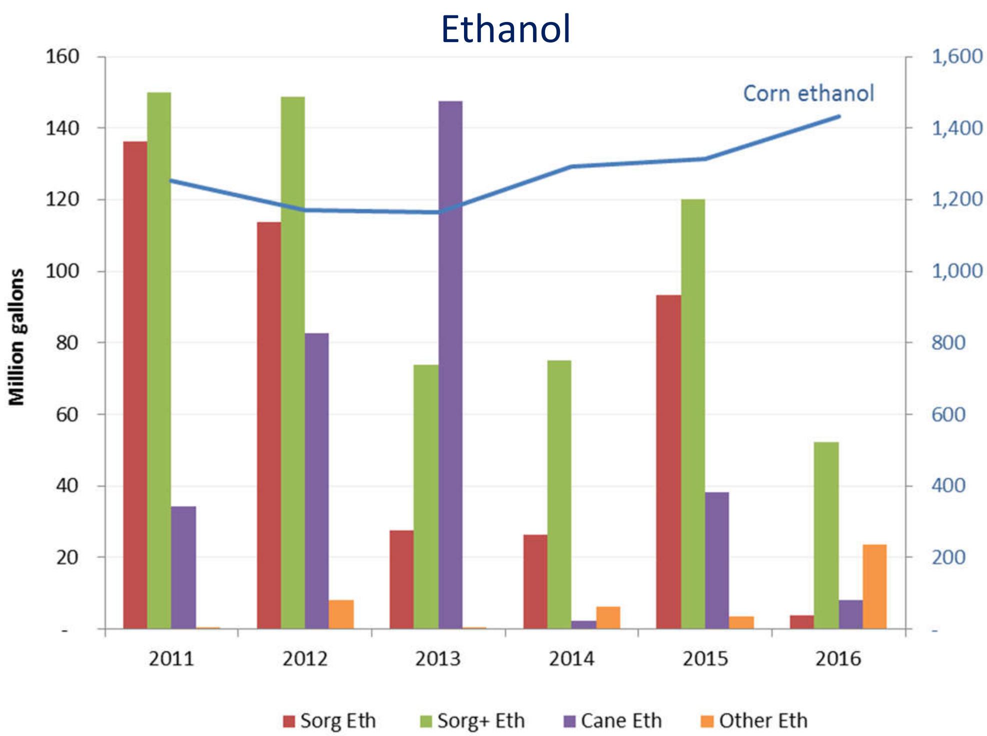
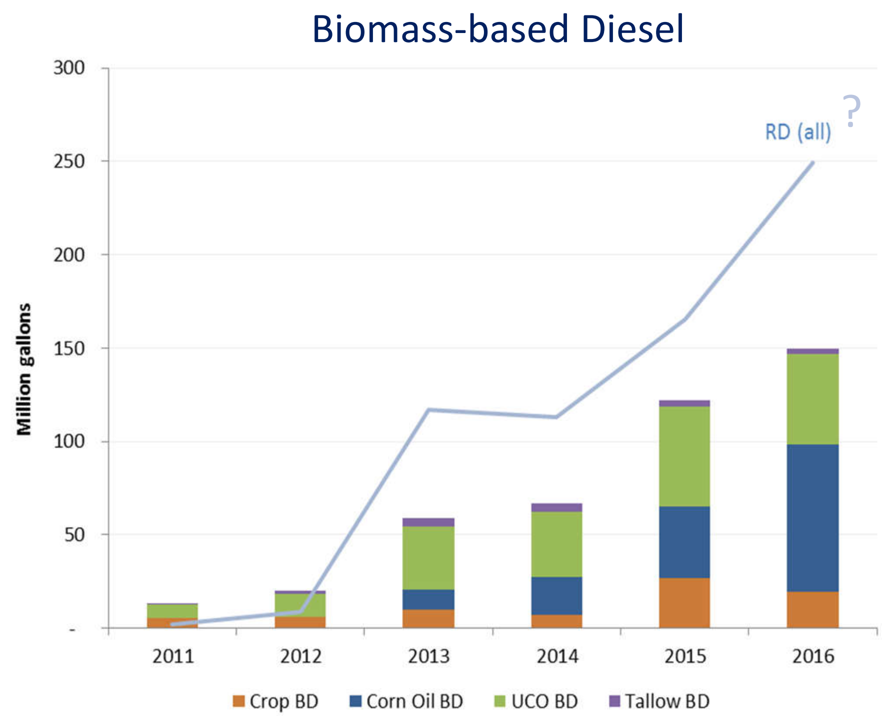
# Corn dominates ethanol volumes
(order of magnitude)

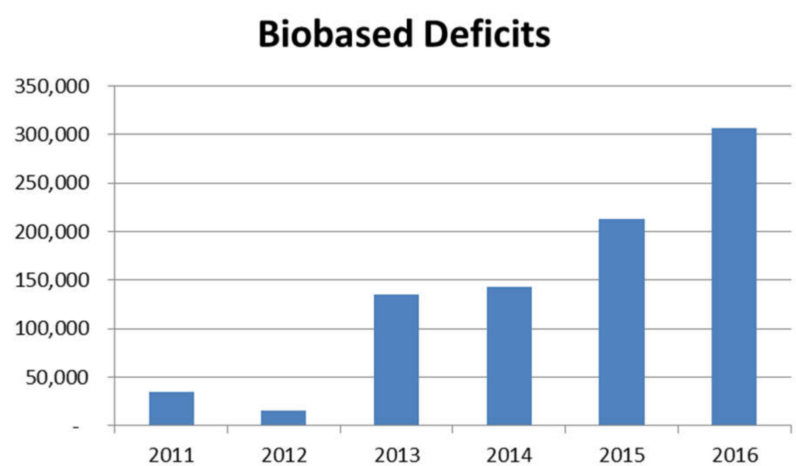
# Corn oil now dominant in BD ("legacy CI artefact?)




Source: ARB data

RD deficits – palm?

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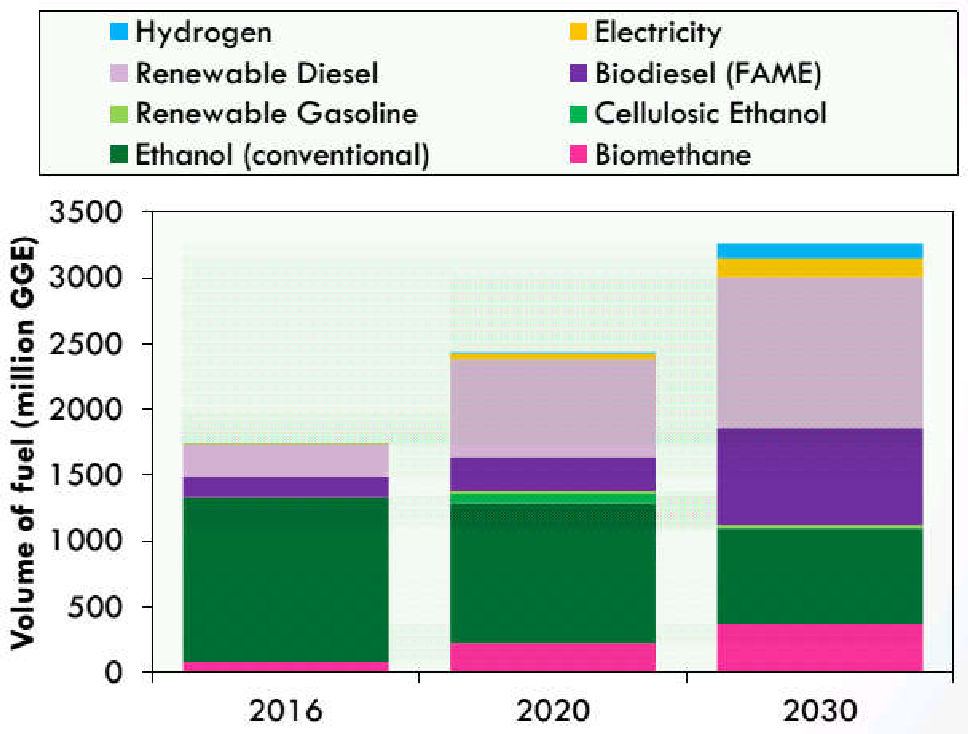
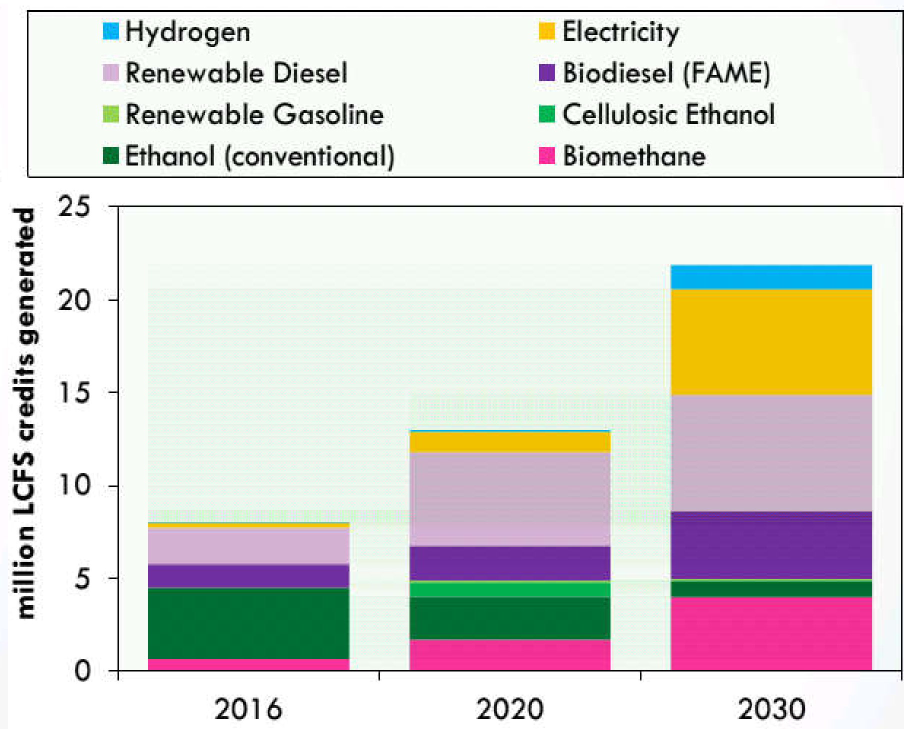
# ARB Modeling for Scoping Plan Proposal : 18% by 2030

Volumes




Credits




- Least-cost-optimization
- ..within scenario modeling constraints (E3)

- Credits rely on technologies in use
  - Electricity, RD biggest contributors
  - Biogas, BD next
  - Little ethanol
- Competing demand not modeled (yet)

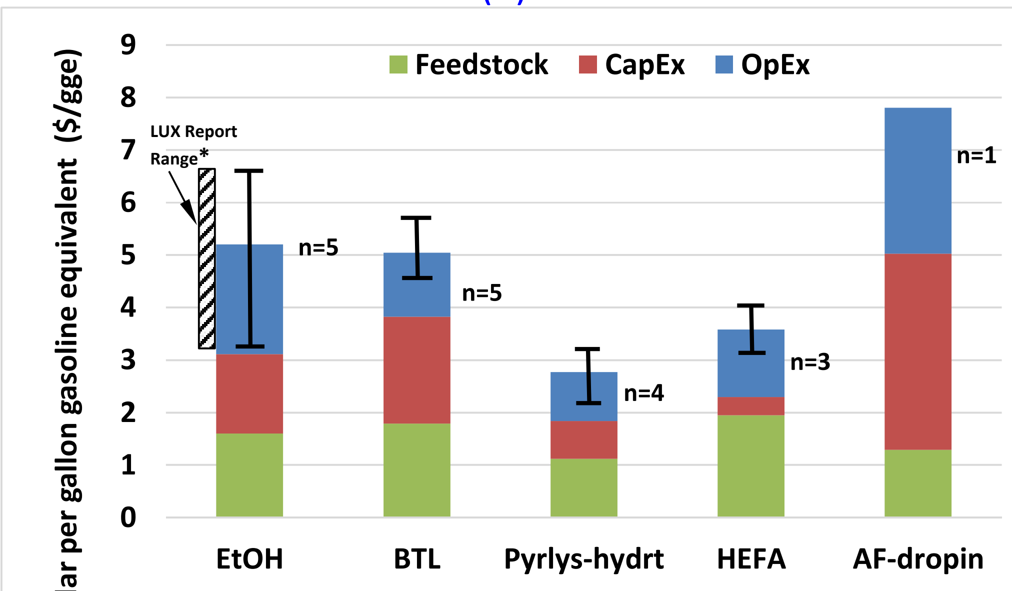
Source: ARB presentation, 3/17/17 workshop

# Looking ahead

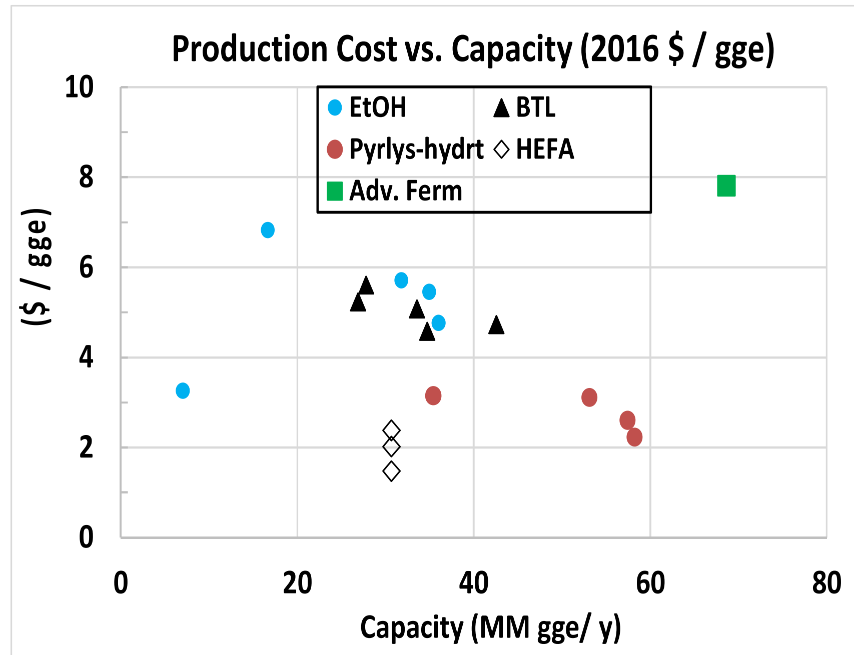
- Where will fuels flow?
  - market signal for more low-C rated fuel volumes, ambitious targets
  - potentially increased competition for low-C rated fuels
  - program (and credit price) differences might mitigate ( 'glidepath' for some mid-range CI fuels?)
- Cost Containment
  - all jurisdictions have in some form or are considering
- Ex post GHG, environmental impact assessment
  - CI ratings (different across programs, change over time within programs)
  - Compare to baseline-year CI, current CI of reference fuels, or "BAU"?
    - baseline CI updates?
  - Emissions impacts outside CI ratings system (e.g., rebound effects or fuel pool switching)
  - Accounting for uncertainty (CIs, drivetrain efficiency ratings (EERs))?

# Biofuel Cost Project* Fuel Cost Estimates from Literature – Pyrolysis, HEFA Generally Lower

Average, range (high - low), and number of studies (n)




**Key:**
**EtOH** = Cellulosic Ethanol
**BTL**=Biomass to Liquid Hydrocarbons (gasification - Fischer Tropsch)
**Pyrlys-hydrt** = Pyrolysis-to-biocrude then hydrotreatment.
**HEFA** = hydrogenated esters and fatty esters.
**AF-dropin** =Advanced Fermentation- Cellulosic EtOH to liquid hydrocarbons




Capacity is nameplate

- Technology maturity level – early commercial deployment (i.e., some cost reductions could occur with more learning) but beyond “pioneer plant” stage

*Sources: van der Hoeven (2016); Ou et al. (2014); Anex et al. (2010); Zhao et al. (2015); Li et al. (2015); Brown et al. (2013); Pearlson et al.(2013); Seber et al. (2014); Staples et al.(2014), and Tuna & Hulteberg (2014)*

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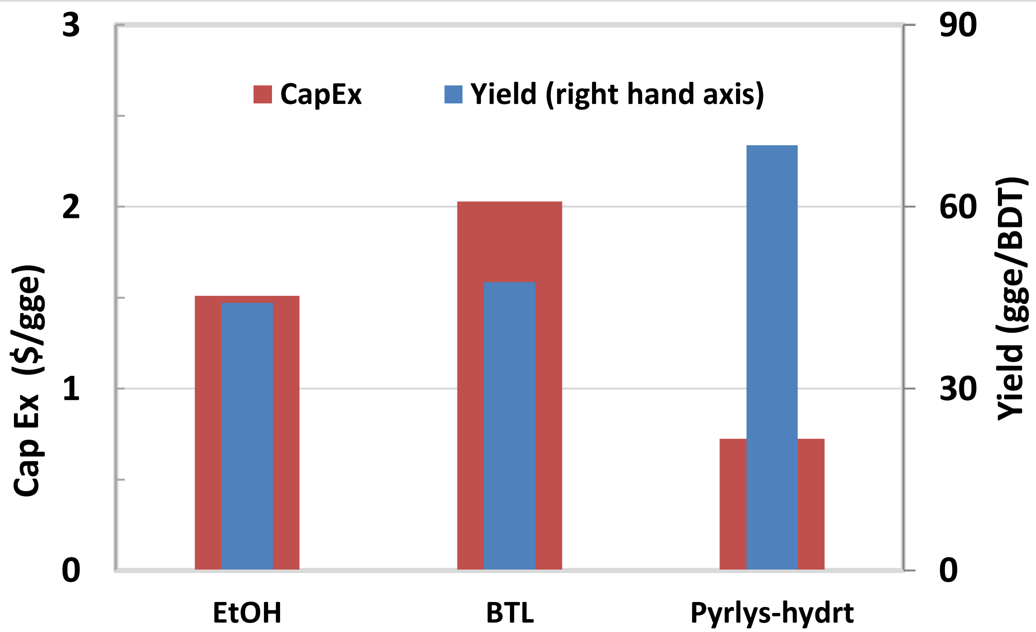
*Rob Williams

# CapEx & Yield – Lignocellulosic Fuels




**Key:**
**EtOH** = Cellulosic Ethanol
**BTL**=Biomass to Liquid Hydrocarbons (gasification - Fischer Tropsch)
**Pyrlys-hydrt** = Pyrolysis-to-biocrude then hydrotreatment.

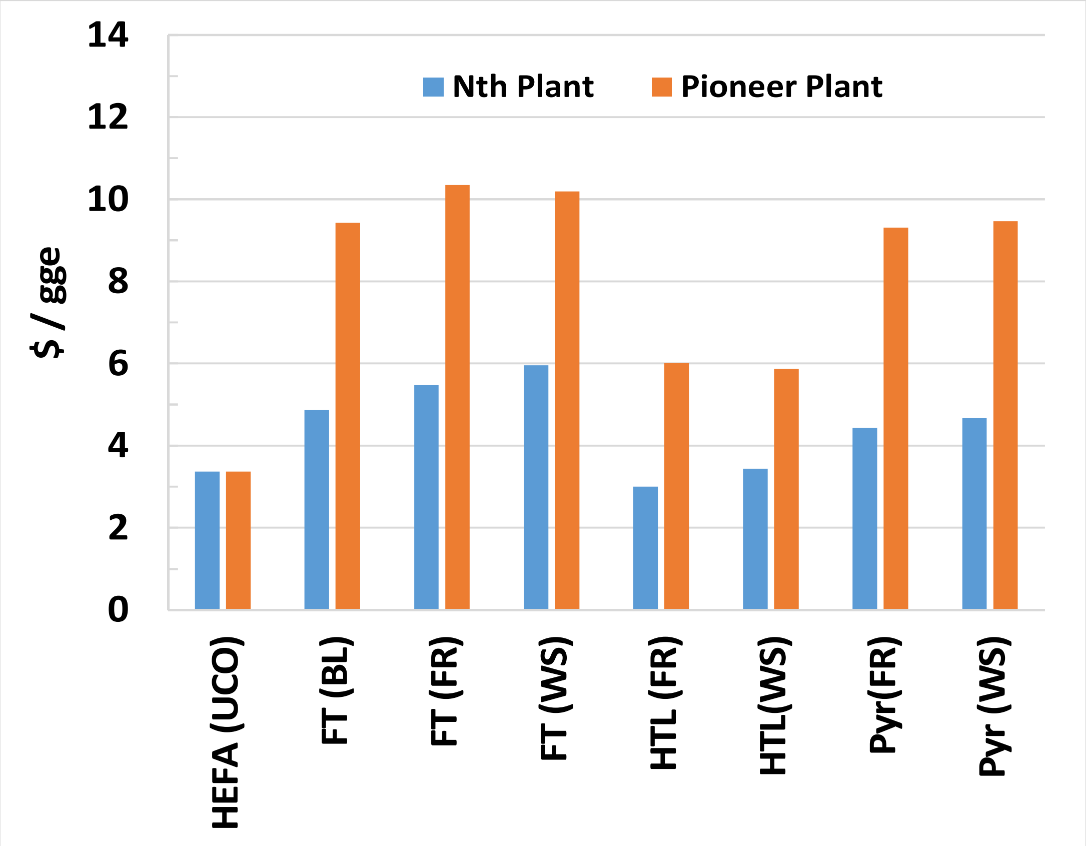
Pyrolysis-hydrotreatment has lower capital cost and higher yield compared to ethanol and BTL (Fischer-Tropsch) pathways.

This largely explains the lower fuel production cost for pyrolysis in the literature.

| Fuel product | n | Averages (2016 $/gge) | | | | Yield ave (gge/BDT) |
|---|---|---|---|---|---|---|
| | | Total Cost | Feedstock | OpEx | CapEx | |
| EtOH | 5 | 5.79 | 1.60 | 2.68 | 1.51 | 44 |
| BTL | 5 | 5.04 | 1.79 | 1.21 | 2.03 | 48 |
| Pyrlys-hydrt | 4 | 2.77 | 1.12 | 0.93 | 0.72 | 70 |

*Sources: van der Hoeven (2016); Ou et al. (2014); Anex et al. (2010); Zhao et al. (2015); Li et al. (2015); Brown et al. (2013); Pearlson et al.(2013); Seber et al. (2014); Staples et al.(2014), and Tuna & Hulteberg (2014)*

# Renewable Jet Fuel Estimated Production Cost or Minimum Fuel Selling Price (MFSP, **2016** $/ gge)*




- Feedstock costs were modified to reflect values in US literature, i.e., $75/BDT for lignocellulosic feedstock and $490/ton for used cooking oil and $0 for black liquor (waste product of pulp process).
- $0.75 per Euro currency conversion as specified in de Jong
- A gallon of jet fuel has energy equivalent of 1.1 gge

**Technologies**

- HEFA = Hydroprocessed Esters & Fatty Acids
- FT = Gasification-to-Fischer Tropsch
- HTL = Hydrothermal Liquefaction
- Pyr= Pyrolysis –biocrude-hydrogenation

**Feedstocks ( )**

- UCO = Used cooking oil
- BL = Black liquor, hog fuel, forestry residues
- FR = Forestry residues
- WS = Wheat straw

<u>Co-production findings</u>
(co-location, retrofits)
MFSP reductions

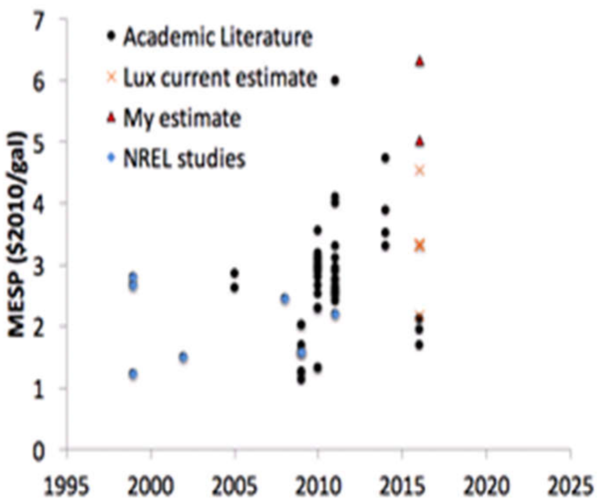
- 5-8% Pioneer
- 4-8% Nth plant
- geography matters

(feedstock prices, wages, discount rates, policy, existing infrastructure)

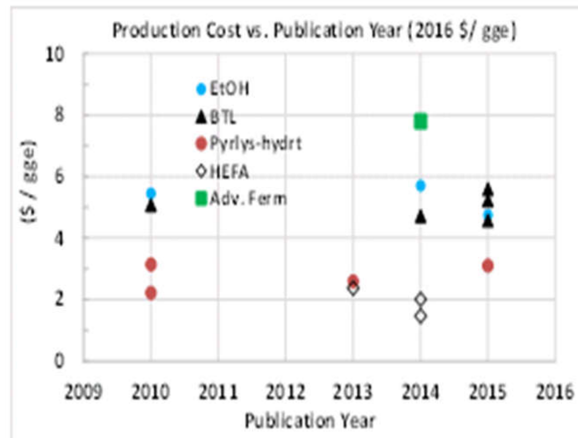
*de Jong, S., R. Hoefnagels, A. Faaij, R. Slade, R. Mawhood and M. Junginger (2015). "The feasibility of short-term production strategies for renewable jet fuels - a comprehensive techno-economic comparison." Biofuels Bioproducts & Biorefining-Biofpr **9**(6): 778-800.

# Looking ahead – understanding cost estimate time trends

Study Cost Estimates Change Over Time: Cellulosic Ethanol (Parker 2016)




Reviewed Literature Study Costs Over Time




Small 'n' per technology...
At nameplate capacity

Nathan Parker. 2016. "Transition cost for cellulosic biofuels: Overcoming the mountain of despair". Iowa NSF EPSCoR Energy Policy Seminar, March 2, 2016. Iowa State University.

Sources: van der Hoeven (2016); Ou et al. (2014); Anex et al. (2010); Zhao et al. (2015); Li et al. (2015); Brown et al. (2013); Pearlson et al.(2013); Sabar et al. (2014); Staples et al.(2014), and Tuna & Hulteberg (2014)

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Thank you!

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