National Renewable Energy Laboratory
*Innovation for Our Energy Future*

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

# Intermediate Ethanol Fuel Blends Research at DOE and National Labs

**Presented by:**
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**Fuels Performance Group**
**NREL**

MIT-NESCAUM Symposium
MIT Endicott House
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DOE Contacts:
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Biomass - Joan Glickman, Shabnam Fardanesh

# Agenda

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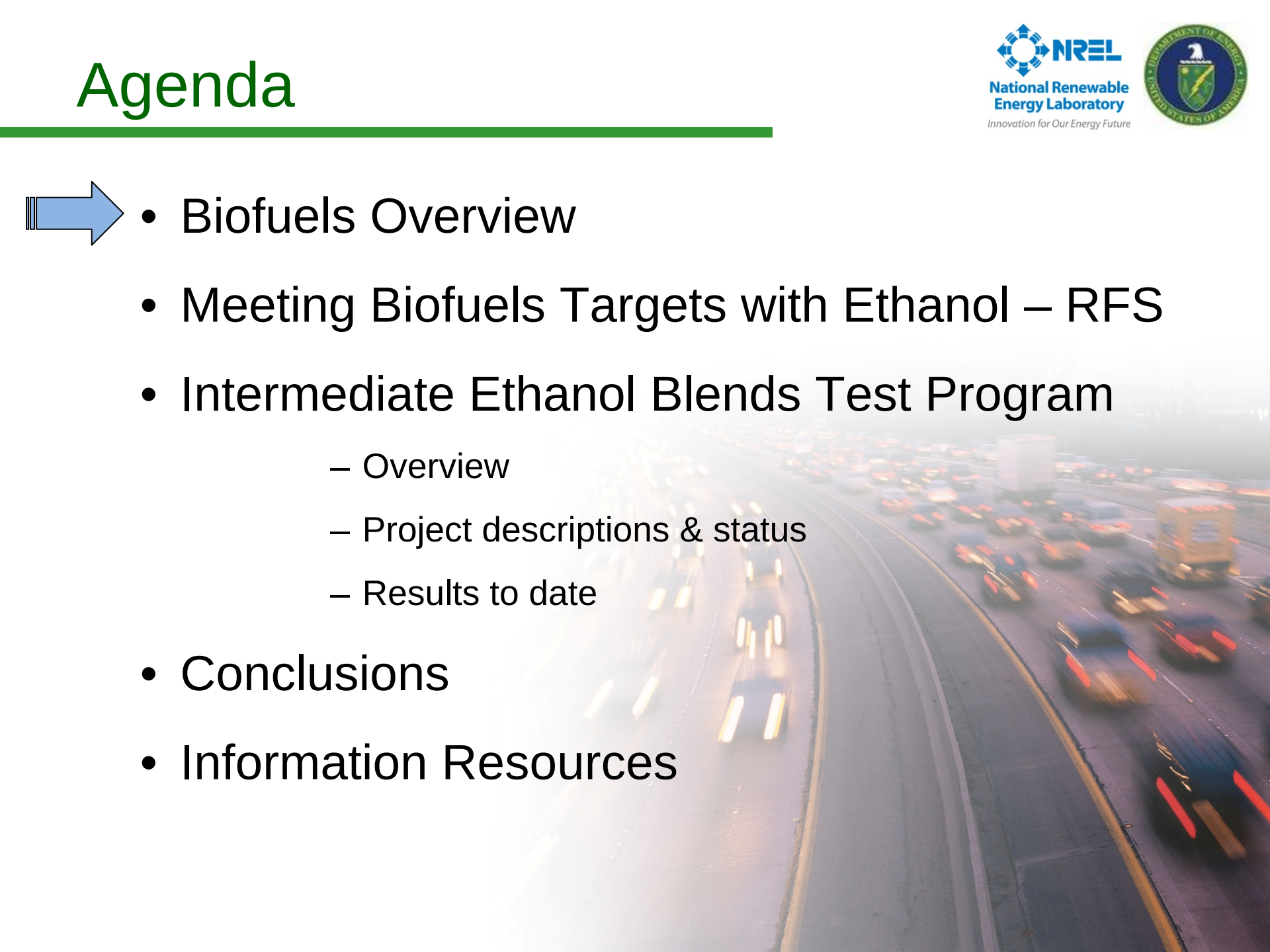
- Biofuels Overview
- Meeting Biofuels Targets with Ethanol – RFS
- Intermediate Ethanol Blends Test Program
  - Overview
  - Project descriptions & status
  - Results to date
- Conclusions
- Information Resources



# U.S. Biofuels Current Status

**U.S. Consumption**
**Gasoline: 140 bgy**
**Diesel: 60 bgy**

## Biodiesel [1]

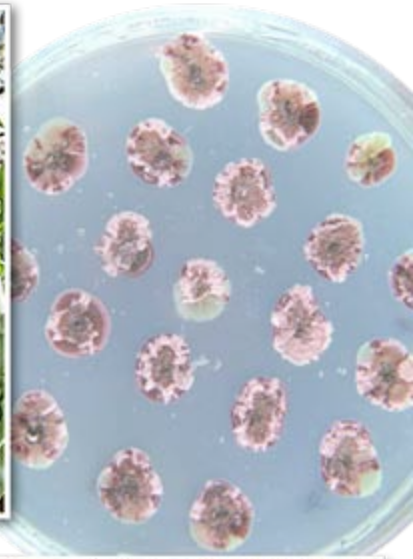
- 176 commercial plants
- 2.6 bgy capacity (2009)
- 0.7 bg produced (2008)

## Corn Ethanol [2]

- 178 commercial plants
- 11.4 bgy capacity (+ 2.1 bgy planned) (2009)
- 9.2 bg produced (2008)

## Cellulosic Ethanol [3]

- 13 demo plants DOE-funded
- ~.250 bgy capacity projected
- More plants projects to be awarded




**~1,900 E85 stations**

**bg = billion gallons; bgy = billion gallons per year**

Sources: 1- National Biodiesel Board, 2- Renewable Fuels Association, 3- DOE Biomass Program

# U.S. Biofuels Goals

**U.S. Consumption**
Gasoline: 140 bgy
Diesel: 60 bgy

## Cellulosic Ethanol

- Cost Competitive with gas by 2012
- Both biochemical and thermochemical conversion pathways
- Current estimate: $2.40/gallon

## Renewable Fuel Standard

- 36 bgy of renewable fuels by 2022
- Caps corn ethanol at 15 bgy
- Advanced biofuels at 21 bgy

## Ethanol 30x30 Goal

- Internal DOE goal
- Equates to ~ 60 bgy
- Replaces 30% of current gasoline usage by 2030

bg = billion gallons; bgy = billion gallons per year

# Biofuels Sustainability

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**Food vs. Fuel Debate**

**Indirect Land Use Change (iLUC)**

**Sustainability Analysis/Life Cycle Assessment**

# Generation 1 & 2 Biofuels

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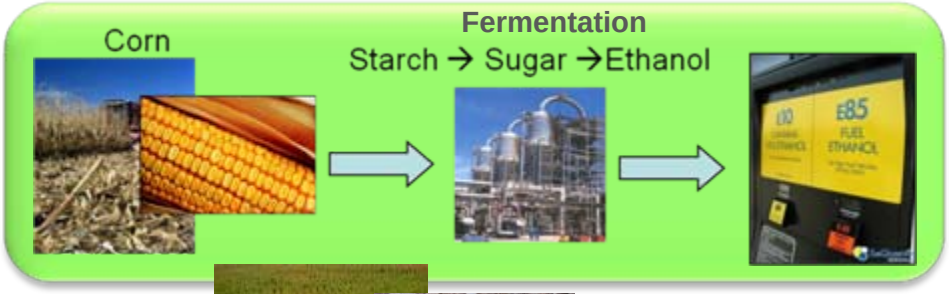
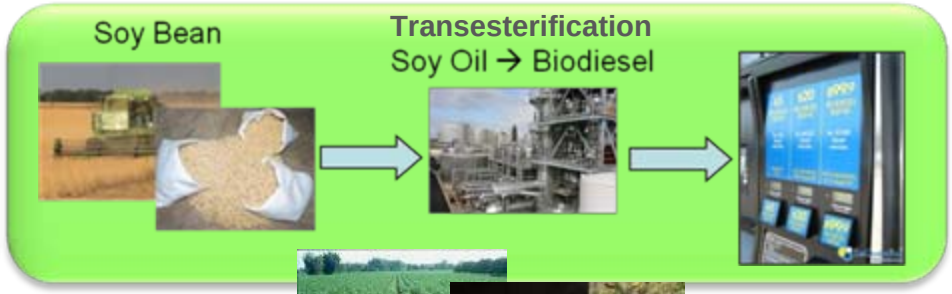
- **1st Gen** -- from sugar/starch crops, plant oils, or animal fats



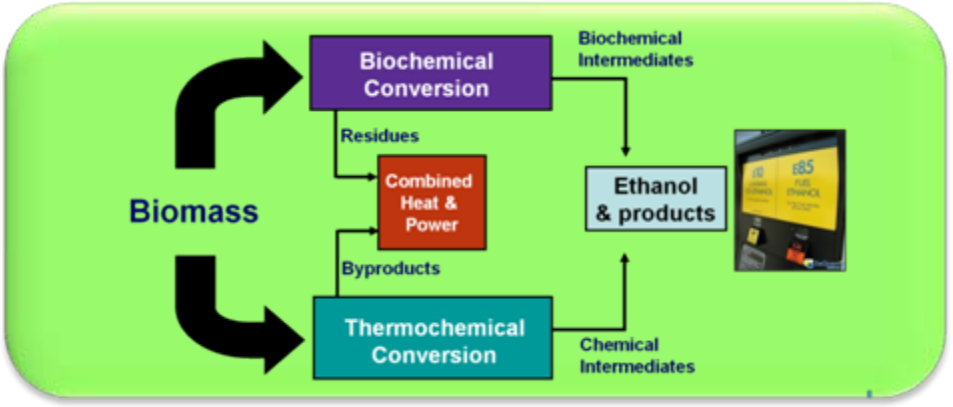



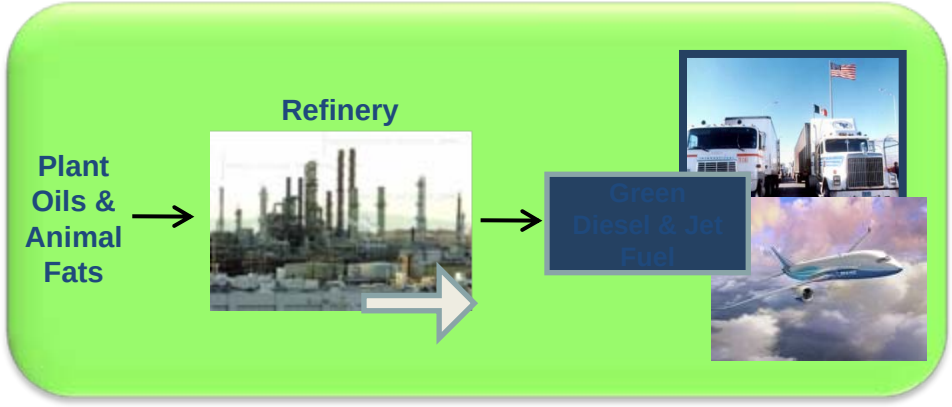

**Cassava**

1.5th Gen

**Jatropha**

- **2nd Gen –** cellulosic ethanol, green diesel



# Why Follow-On Generations ?

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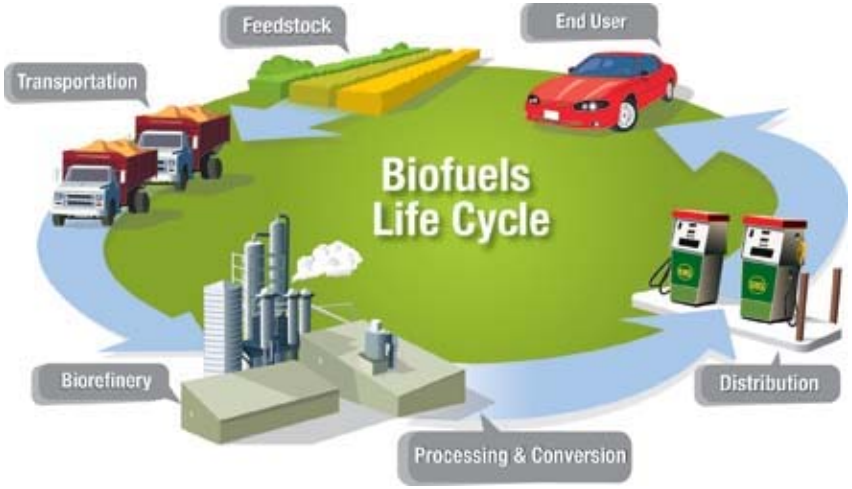
## 3rd & 4th Generations

- **Higher energy density**
- **Gasoline/diesel-like molecules**
- **Suitability for wider range of end use**
- **Better temperature and cold start ability**
- **Infrastructure compatibility**



# 3rd Generation (New Feedstocks & Fuels)

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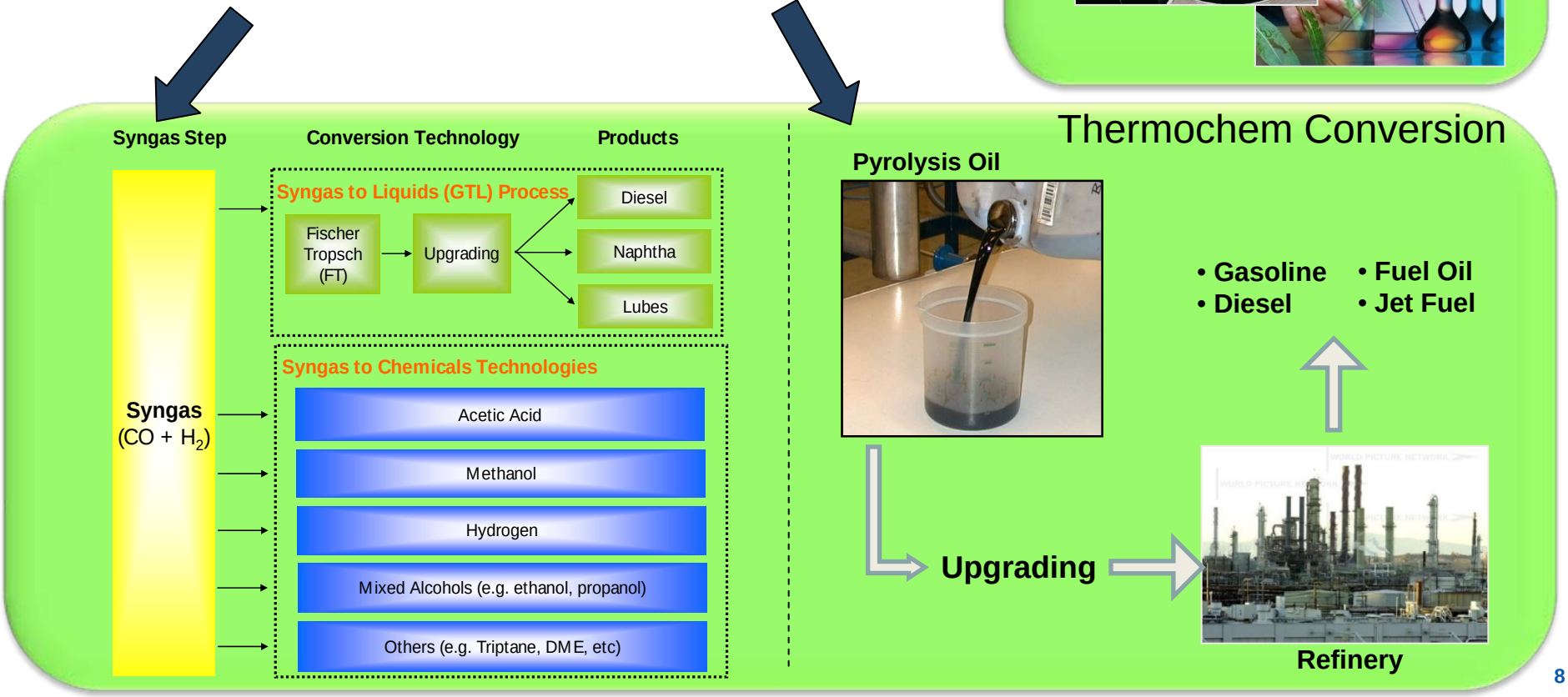
- New energy feedstocks, e.g. algae
- New fuel molecules via thermochemical conversion

# Comparing Potential Oil Yields

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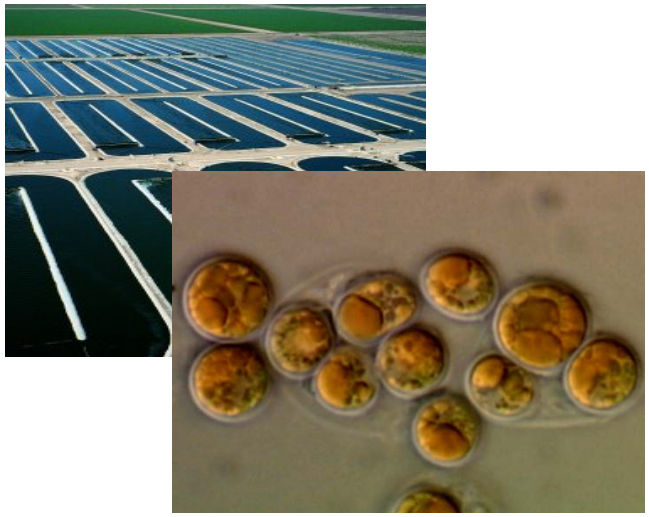
| Crop | Oil Yield Gallons/Acre |
|---|---|
| Corn | 18 |
| Cotton | 35 |
| Soybean | 48 |
| Mustard seed | 61 |
| Sunflower | 102 |
| Rapeseed | 127 |
| Jatropha | 202 |
| Oil palm | 635 |
| Algae | 1,200 – 10,000 |



Today's Technology Estimate

Optimistic Future Technology

# 4th Generation (Systems Biology Advances)

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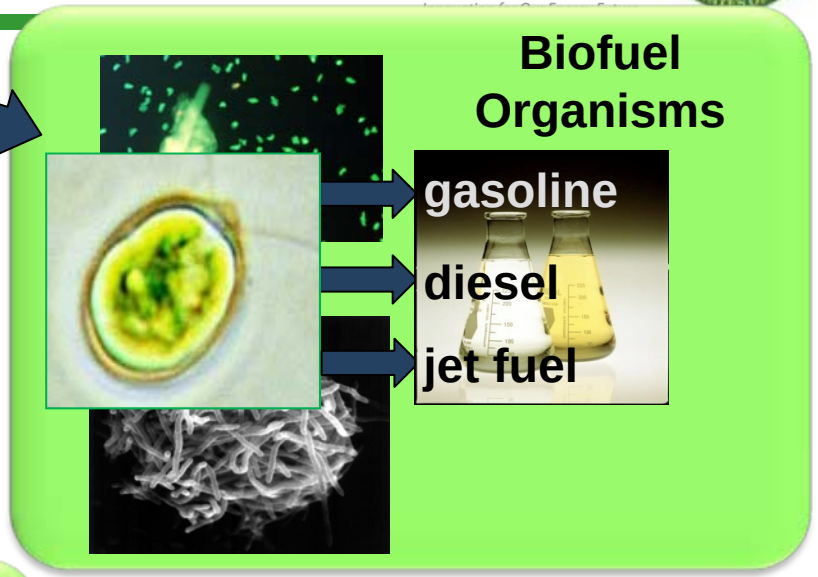
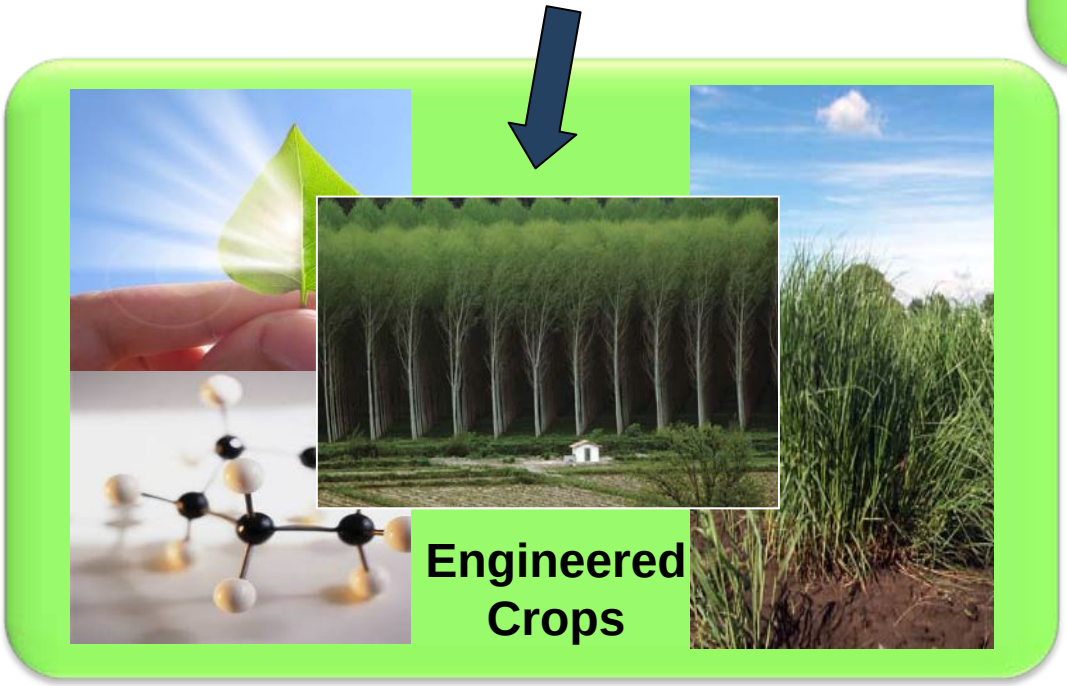
- Higher energy density molecules, directly from organisms
- Crops engineered for self lignocellulosic destruction




# Status of Next Generation Technologies


Deploy


R&D + Demo



R&D

## 2nd Generation

- **Numerous DOE-funded demo projects**
- **Significant industry activity**

## 3rd and 4th Generations

- **DOE to initiate several major programs this year:**
  - **Advanced Biofuels Center(s)**
  - **Algal Biofuels Center(s)**
- **Industry, Academia, and Laboratory involvement in many technologies**

# DOE Biofuels Funding

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U.S. Department of Energy
Energy Efficiency and Renewable Energy

| FY08 Budget | FY09 Budget | ARRA Biofuels Funding | FY10 Request |
|---|---|---|---|
| $200M | $217M | $800M | $235M |

$ 45M -- Feedstock Infrastructure
$ 65M -- Research & Development
$ 690M -- Demonstration Projects

**Office of Science**

- ~ $100M/year for basic research
- Including three "Bioenergy Research Centers"

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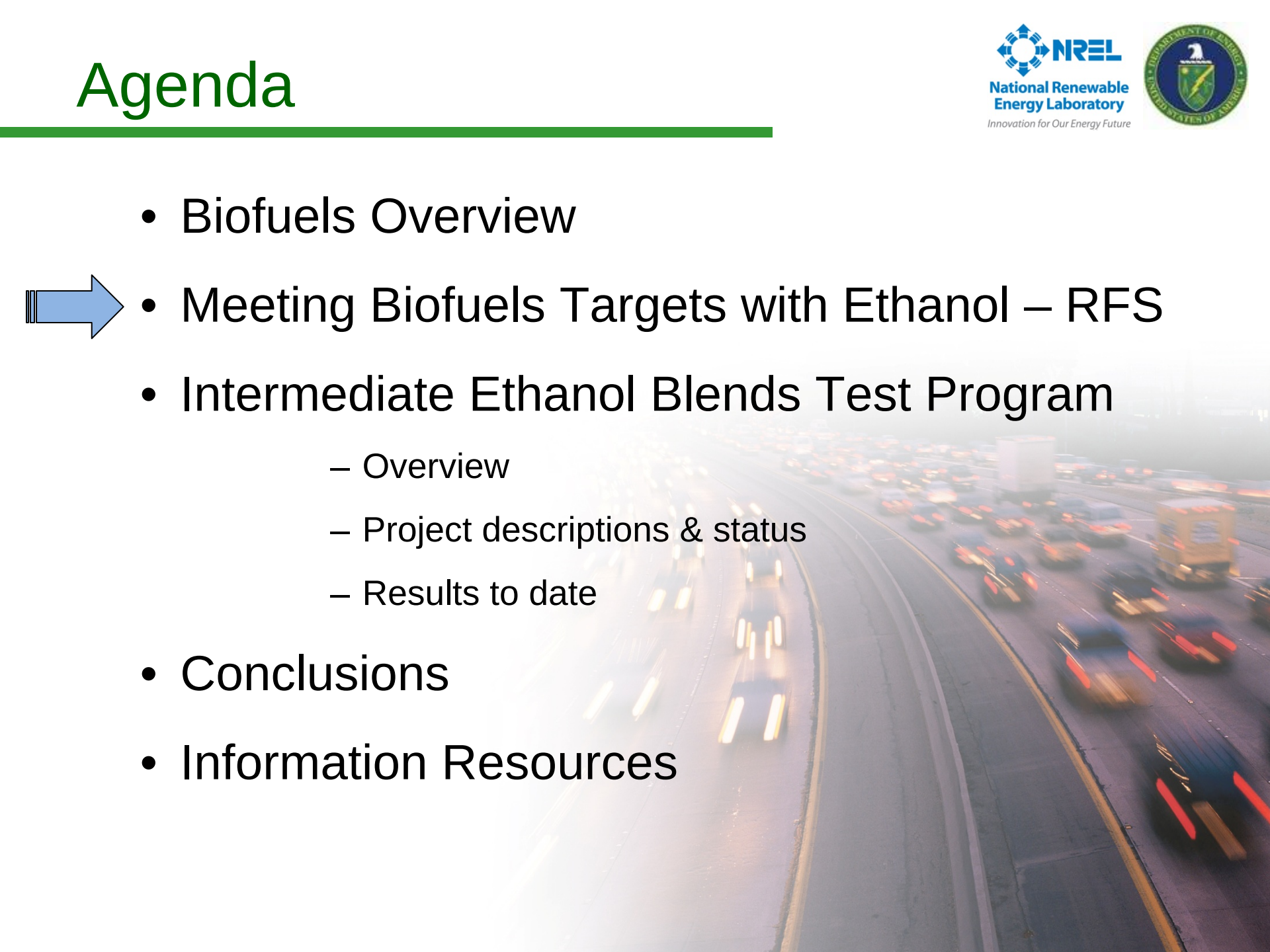
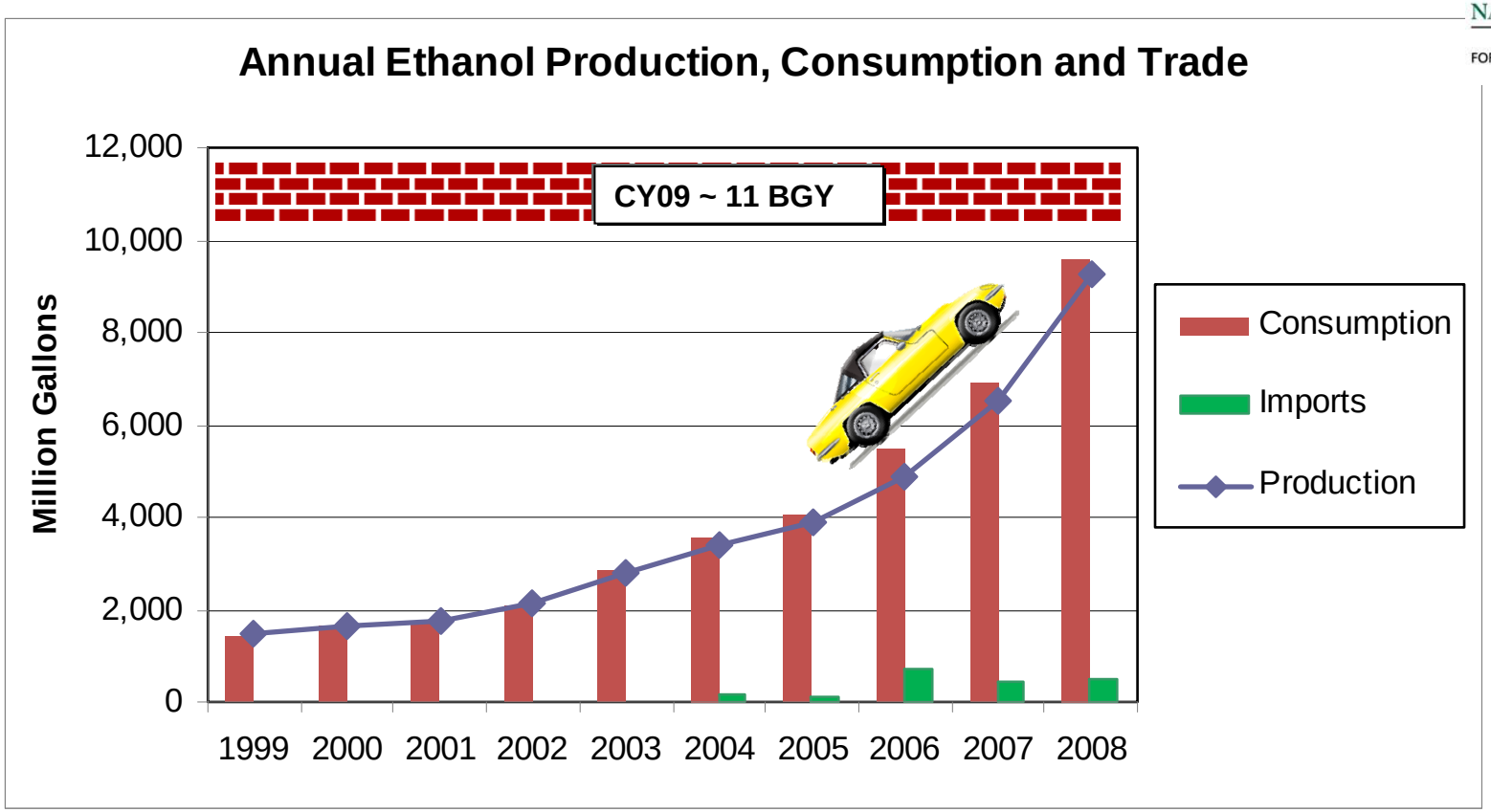


# E10 Blend Wall Problem




- DOE strategy for expanding ethanol use – breaking the blend wall.
  - **Near Term - Evaluate feasibility of using mid-level ethanol blends (e.g., E15, E20) in conventional vehicles (non-flex fuel vehicles).**
  - Long Term - Expand E85 by targeting specific regions/cities.

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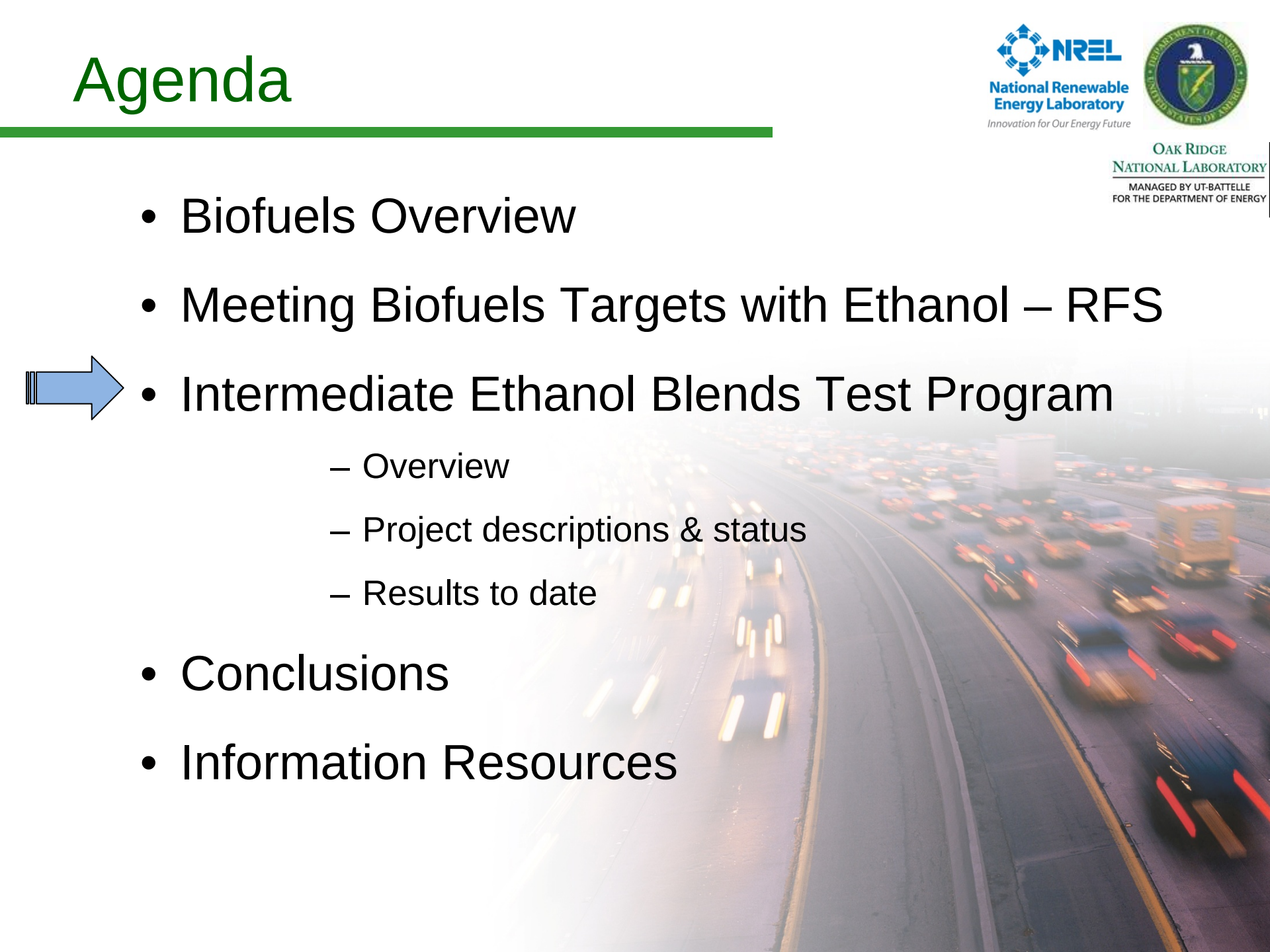

# Waiver Request Background

Clean Air Act § 211(f) gives EPA authority to declare fuels "substantially similar" to gasoline

- "contribute[s] to the failure of" emissions control systems ⇒ no waiver
- EPA has indicated that they interpret "contribute to" quite broadly – *e.g.,* fuel-pump failure might qualify

Intermediate Ethanol Blends Testing – data for EPA / waiver

- Non-FFVs (>97% population)
- DOE Test program:
  - Emissions
  - Driveability / Operability
  - Materials Compatibility
  - Emission Control System Durability (Full Useful Life)

# Completed Testing

## DOE Intermediate Ethanol Blends Test Program

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## Vehicles

Emissions

- 16 vehicle pilot study (including catalyst temperature) – Report (Feb. 2009)
- Evaporative Emissions (with CRC and EPA) (8 vehicles) – Report (2Q 2009)

Cold Start and Driveability

- Sub-50°F testing completed (with CRC, 6 vehicles) – Report (Nov. 2008)

## Small Non-Road Engines

Emissions

- 6 engine pilot study (including exhaust temperature) – Report (Feb. 2009)

Full Useful Life Emissions and Durability

- 17 / 22 engines to full life – Report (Feb. 2009)

# Results: Vehicles

## DOE Intermediate Ethanol Blends Test Program

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### Emissions / Temperature

- Regulated tailpipe emissions with E15 and E20 were similar to levels with E0 when averaged across multiple newer ‘clean’ vehicles in pilot study.
- Change in catalyst temperatures may affect durability – results not clear yet.

### Driveability

- No driveability issues found with either E15 or E20
- No malfunction indicator lights or filter plugging
- Informal observations only

### Fuel Economy

- Fuel economy on volumetric basis decreased for E10, E15, E20
- Closely tracked fuel energy content

### Emissions Durability???

# Results: Small Engines

## DOE Intermediate Ethanol Blends Test Program

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### Emissions/Temperature

- With increasing ethanol content:
  - Regulated emissions – combined HC+NOx – decreased in most cases
  - Engine and exhaust temperatures increased


### Durability

- Commercial engines – no particular sensitivity observed
- Smaller, residential engines – not clear

### Safety

- Potential issue – spontaneous clutch engagement (Correctable with carburetor adjustment)

# FY2009/FY2010 Vehicle Testing

## DOE Intermediate Ethanol Blends Test Program

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### Tailpipe Emissions (with EPA)

- Phase 1 and 2 completed
- Phase 3 underway; results expected Feb. 2010

### Full Useful Life Emissions Study (with CRC and EPA)

- Testing underway
- Results expected 2010
- Interim results Summer 2009 and beyond

### Evaporative Emissions (with CRC and EPA)

- Project in initial stages
- CRC Report expected in 2010

### Fuel System Materials Compatibility (with CRC)

- Testing underway
- Results expected by October 2009

### "Cold Start" and Driveability (with CRC)

- Testing at high ambient temperature
- Tentative start and completion Summer 2010

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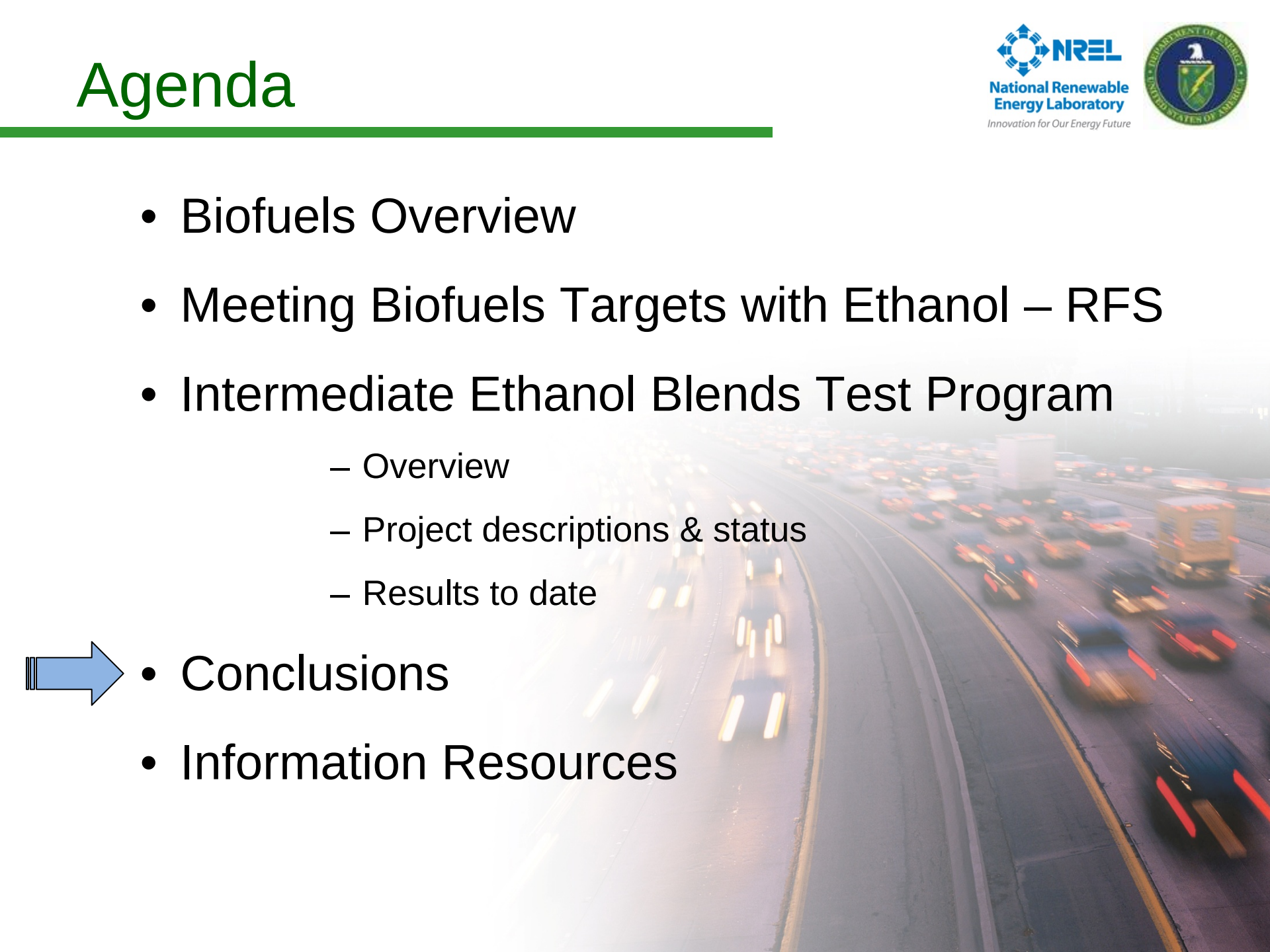
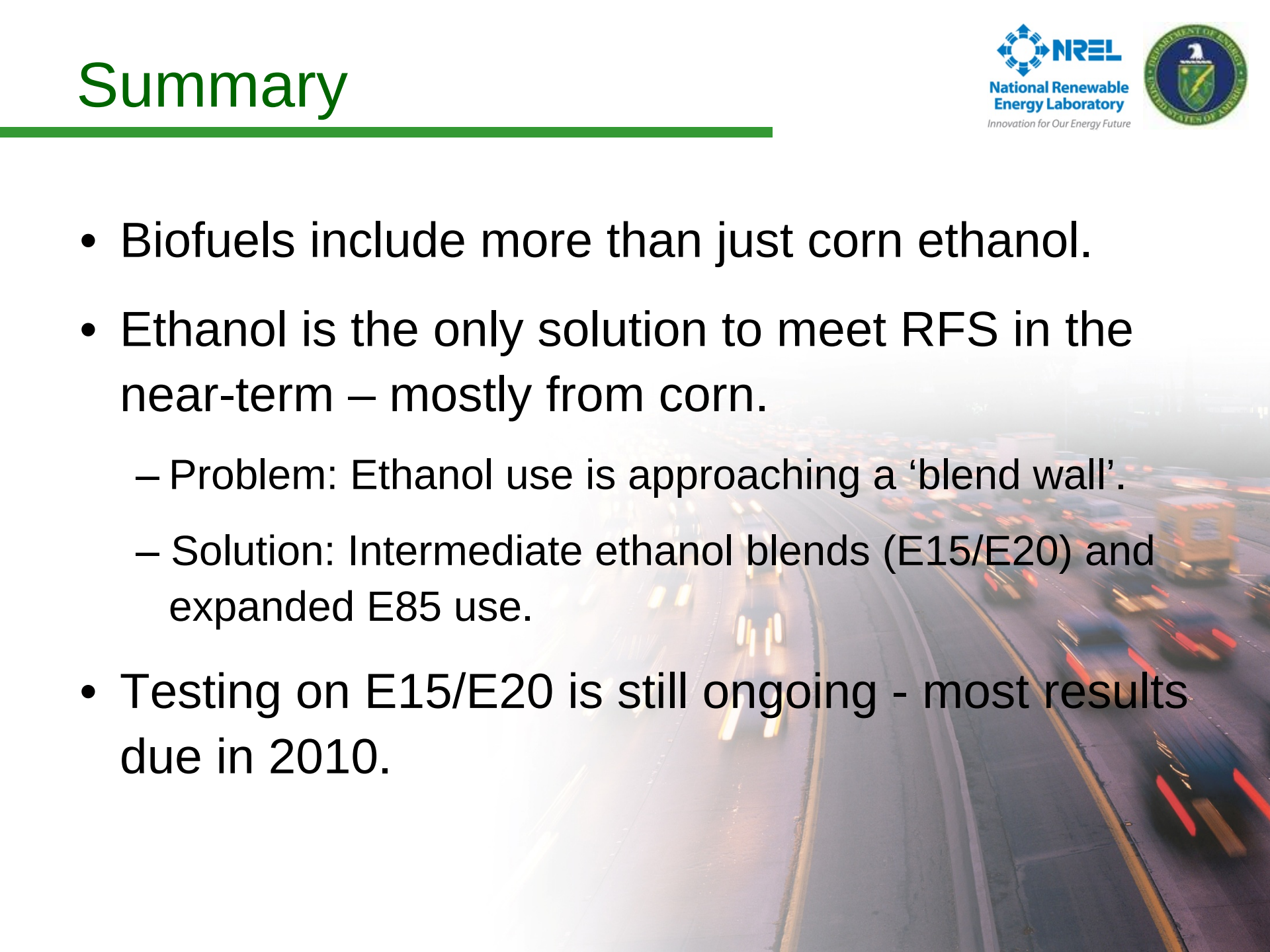


# Summary

- Biofuels include more than just corn ethanol.
- Ethanol is the only solution to meet RFS in the near-term – mostly from corn.
  - Problem: Ethanol use is approaching a ‘blend wall’.
  - Solution: Intermediate ethanol blends (E15/E20) and expanded E85 use.
- Testing on E15/E20 is still ongoing - most results due in 2010.



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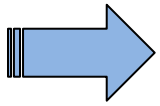


# Information Resources

NREL – http://www.nrel.gov

Oak Ridge National Laboratory – http://ornl.gov

DOE Office of Vehicle Technologies - http://www1.eere.energy.gov/vehiclesandfuels/

DOE Office of Biomass Program - http://www1.eere.energy.gov/biomass/

EERE Info Center - www1.eere.energy.gov/informationcenter

Alternative Fuels Data Center - http://www.eere.energy.gov/afdc/fuels/ethanol.html

Bioenergy Feedstock Information Network - http://bioenergy.ornl.gov/

Biomass R&D Initiative – www.biomass.govtools.us

Grant Solicitations - www.grants.gov

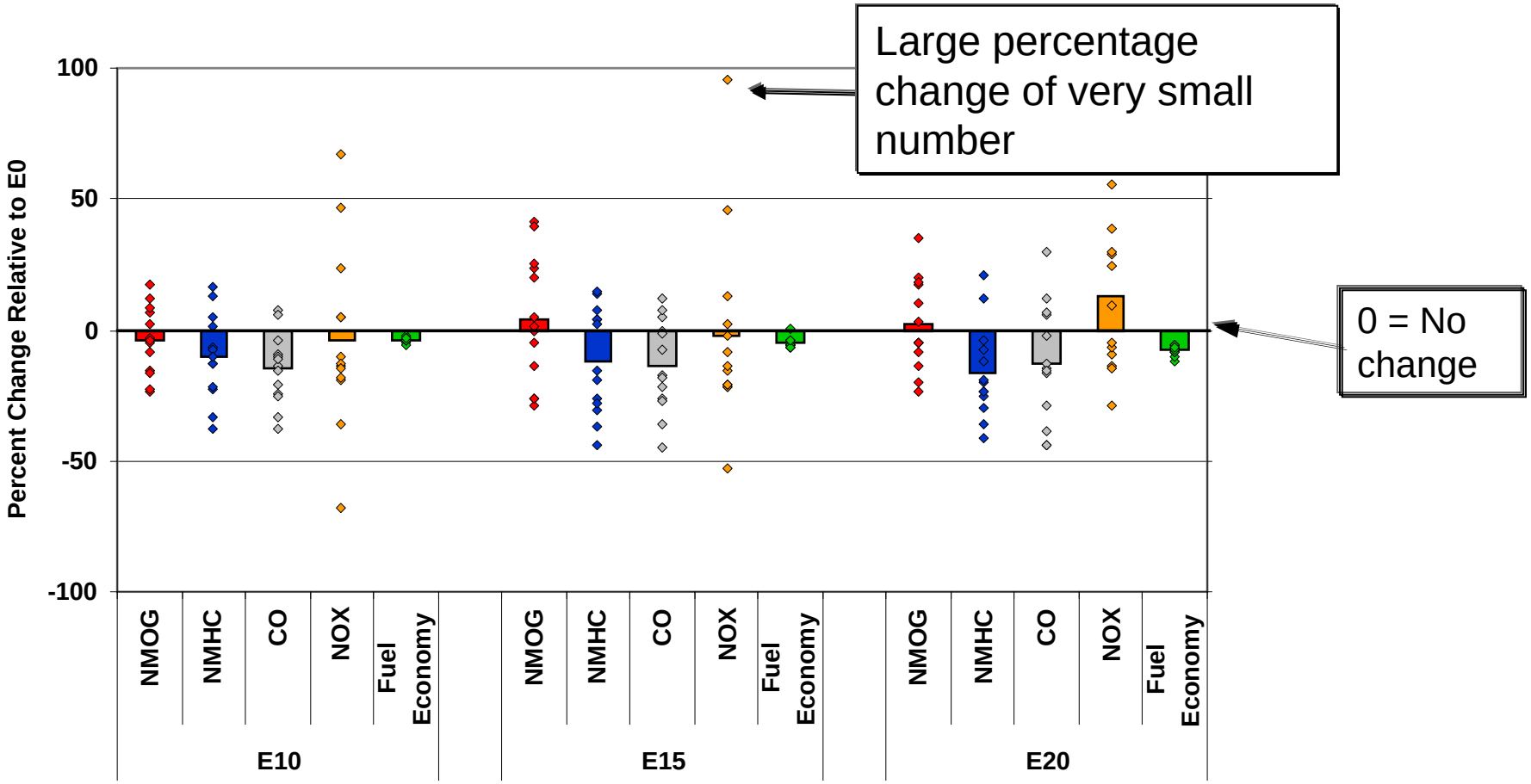
Office of Science - http://www.er.doe.gov/

Intermediate blends Report #1 (updated) - http://feerc.ornl.gov/publications/Int_blends_Rpt1_Updated.pdf

# Backup Slides

# Results: Vehicle Emissions & Fuel Economy

- **Given the scatter in the testing, the average emissions were relatively unchanged from E0.**
- **The reduction in fuel economy due to ethanol was predictable and statistically significant.**



# Results: Vehicle Catalyst Temperatures

- **Approximately half the vehicles had an increase in catalyst temperature at full power. Otherwise, the catalyst temperatures were lower for all vehicles under all other driving conditions.**
- **The effect of higher temperatures at full power is still unclear and being tested by DOE.**