AVIATION BIOFUELS

Life Cycle Perspective

UTIAS Colloquium on Sustainable Aviation 2013

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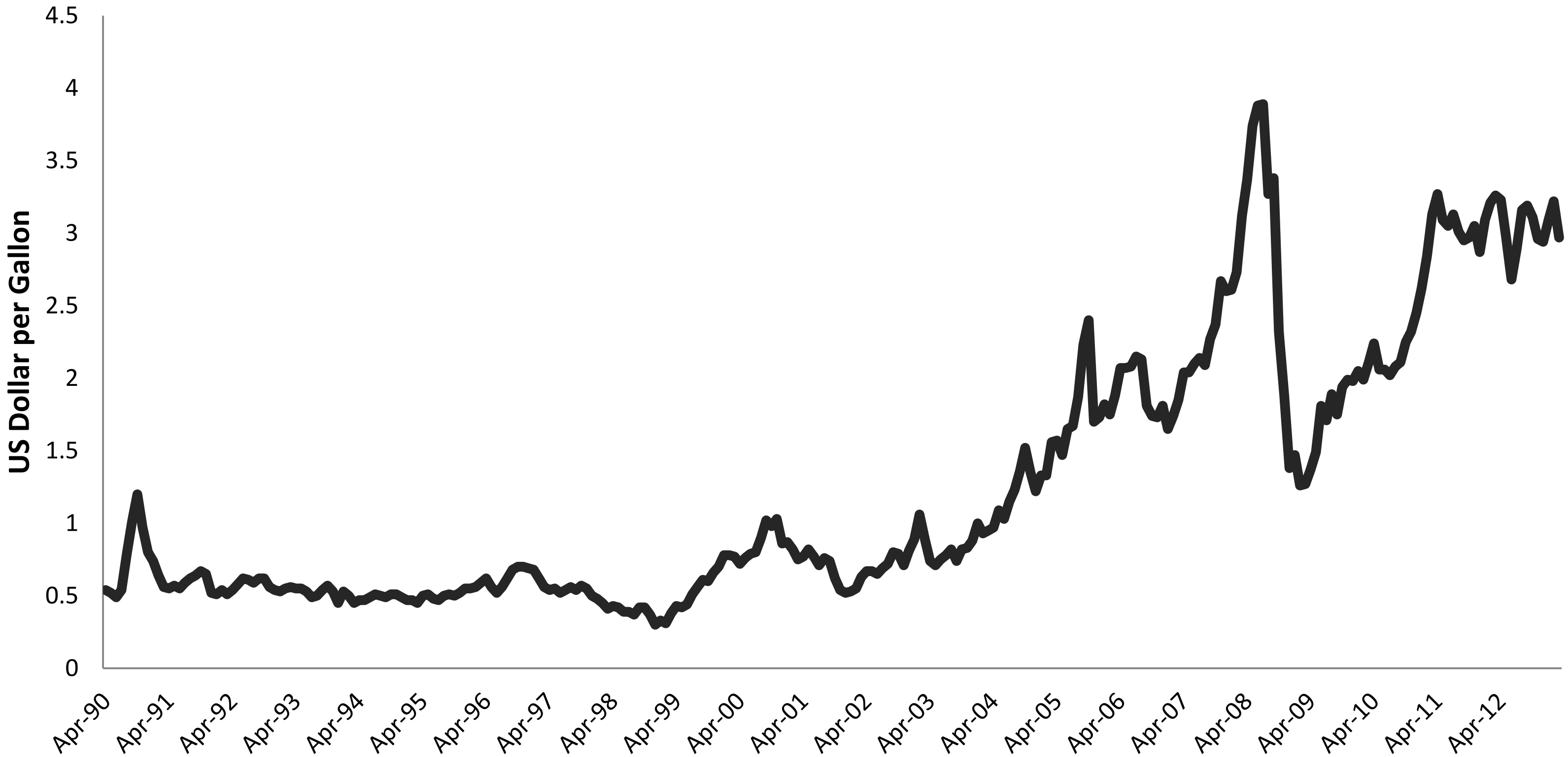
GLOBAL ISSUES – AVIATION INDUSTRY

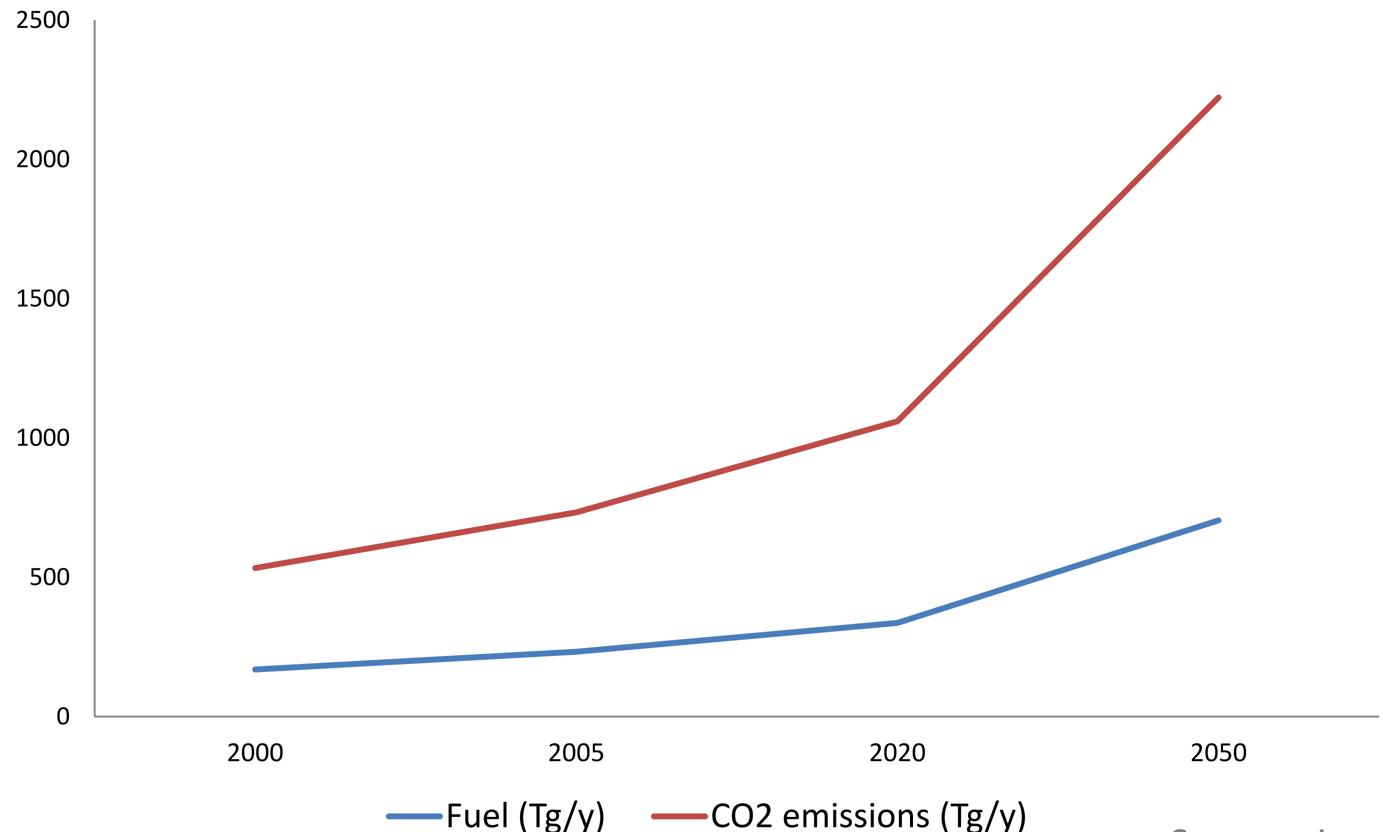
RISING FUEL PRICES



Source: EIA, 2013

GLOBAL CLIMATE CHANGE

AVIATION CONTRIBUTES 2-3% OF GREENHOUSE GAS EMISSIONS

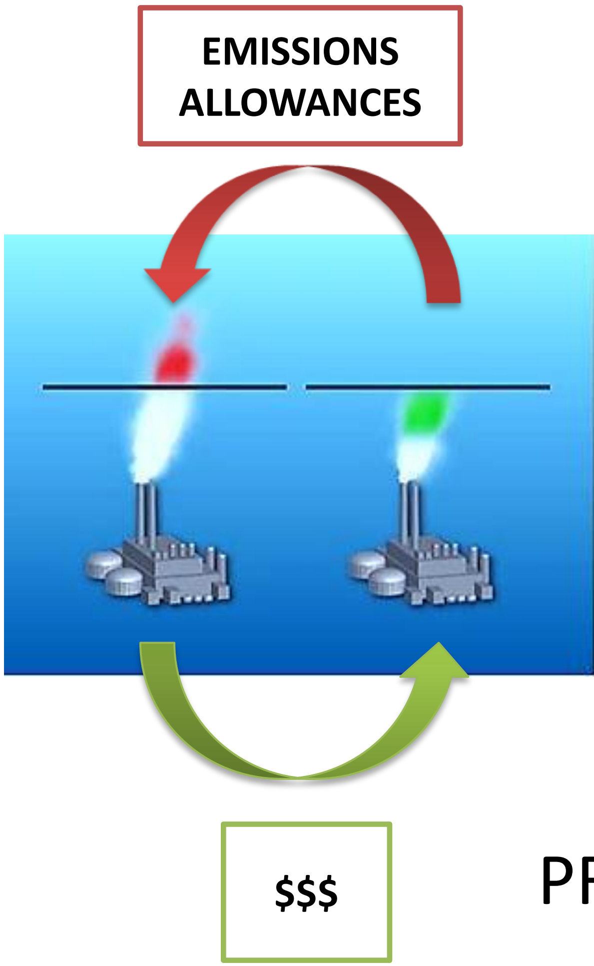


Source: Lee, 2009

WORLD FUEL CONSUMPTION

- Jet fuel
  - 1.5-1.7 billion barrels of Jet A-1/yr (~250 billion L)
- Motor gasoline
  - 7.3 billion barrels

AVIATION BIOFUELS & POLICY

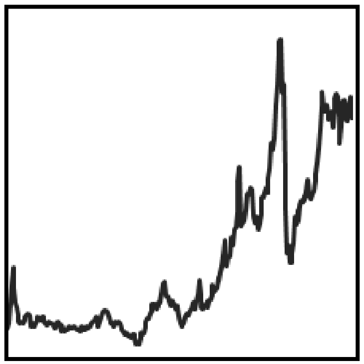


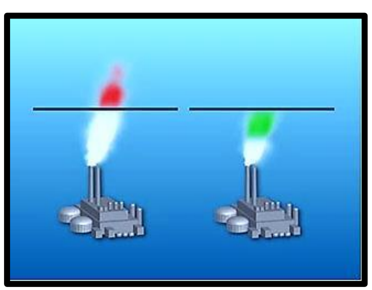
- EU Emissions Trading Scheme (ETS)
  - Emission allowances allocated to industrial operators
  - Allowances can be traded among operators exceeding or under allocated emissions
  - All flights in/out of the EU included as of 2012

PROJECTED COST TO AIRLINES

€ 3.0-4.7 BILLION BY 2015

SOLUTIONS





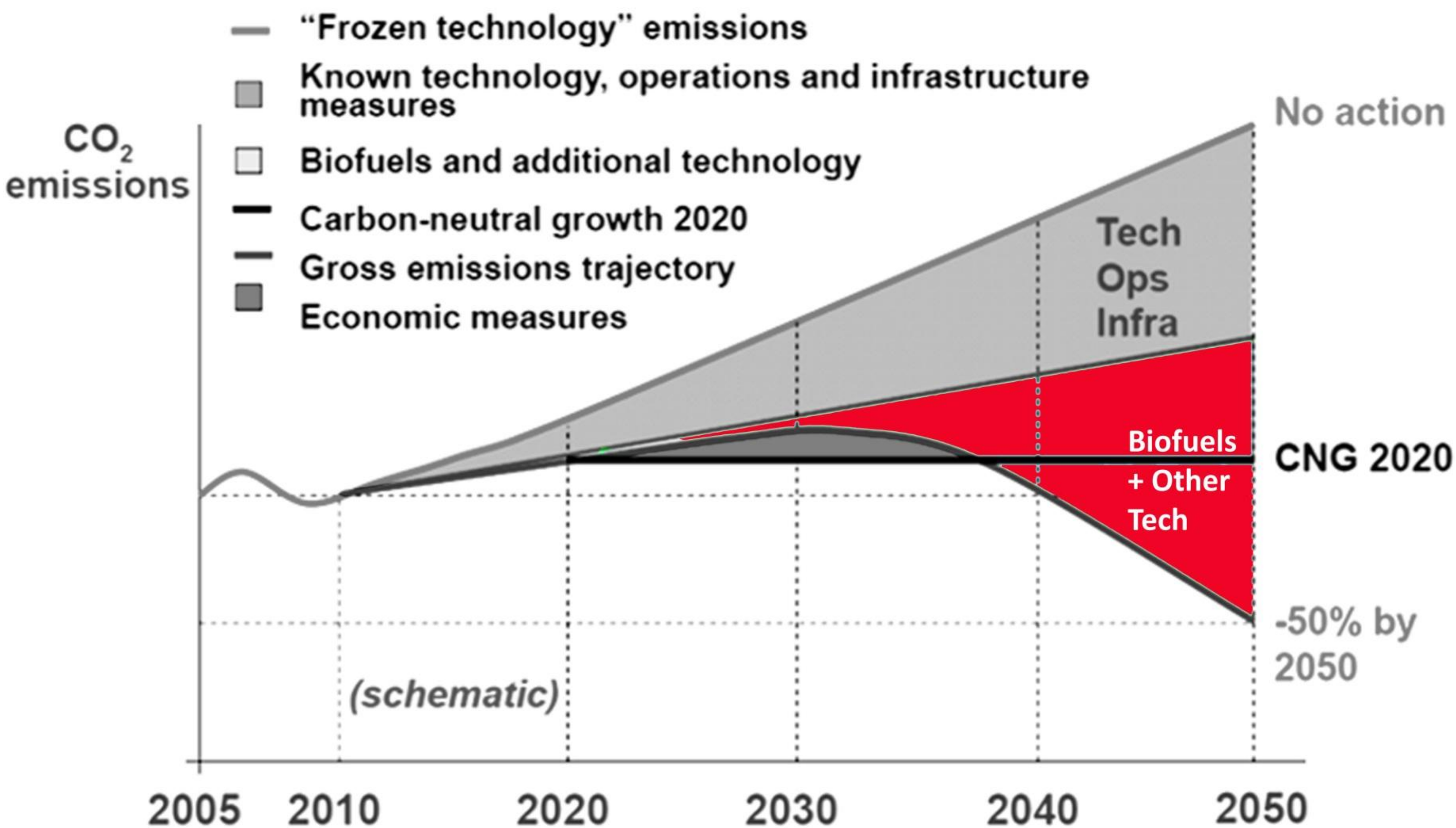
Reduce Fuel Consumption

- Improved Aircraft Design
- Improved Operations

With Projected Air Traffic Increase:

- Need much greater reduction in carbon footprint to meet targets and reduce costs

SOLUTIONS



(IATA, 2009)

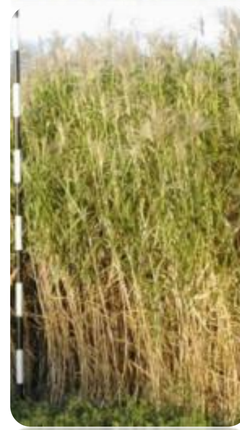
AVIATION BIOFUELS

ALGAE
- High oil yield per unit area
- Rapid growth
- Does not require arable land
- Cost-prohibitive

CAMELINA
- Marginal land
- Low agricultural input

JATROPHA
- Tropical or sub-tropical climate required
- Under development

SALICORNIA
- No impact on freshwater
- Does not require arable land
- Under development



SWITCHGRASS
- High yield with rapid growth
- High carbon sequestration potential
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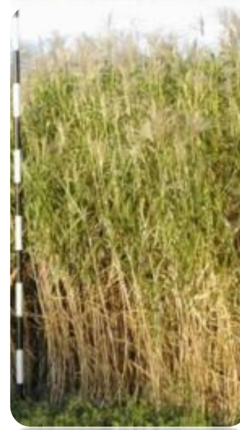

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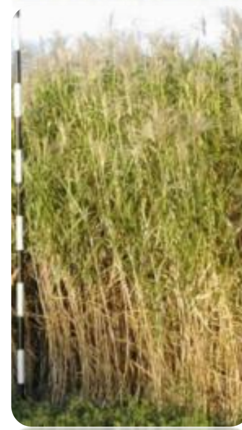

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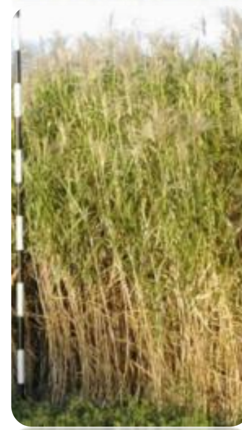

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AVIATION BIOFUELS

OIL FEEDSTOCK

Oil Extraction
Hydrotreatment
Hydrocracking
Separation

Hydroprocessed Esters and Fatty Acids (HEFA) PATHWAY

LIGNOCELLULOSIC FEEDSTOCK

Gasification
Fischer-Tropsch Synthesis
Hydrocracking
Separation

FT PATHWAY

BIO- SYNTHETIC PARAFFINIC KEROSENE (Bio-SPK)

AVIATION BIOFUELS PROPERTIES

- ASTM Standard

		Jet A	FT-SPK	HEFA-SPK
ASTM STANDARD		D1655	D7566	
Acidity, total mg KOH/g	max	0.1	0.015	0.015
Aromatics, vol%	max	25	0.5 (mass%)	0.5 (mass%)
Carbon & Hydrogen, mass%	min		99.5	99.5
Flash point, ^{o}C	min	38	38	38
Density at 15 ^{o}C, kg/m^3	min	775-840	730-770	730-770
Freezing point. ^{o}C	max	-40	-40	-40
Heat content, MJ/kg		42.8		
Water content, mg/kg	max		75	75

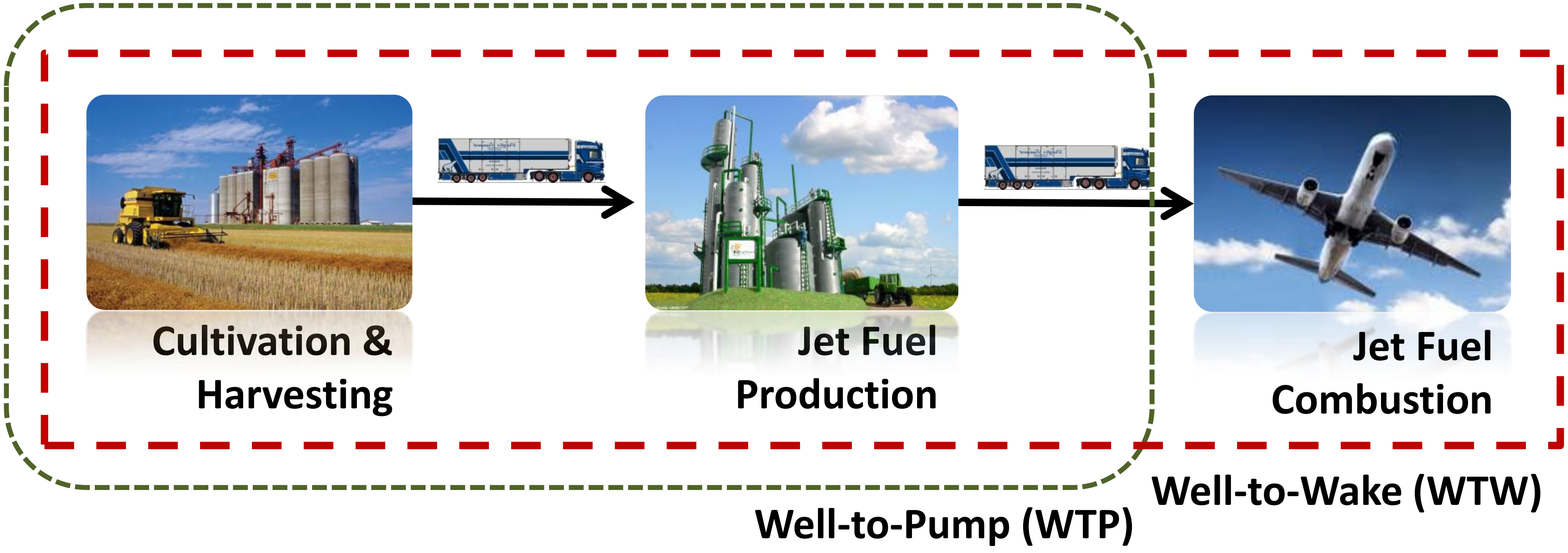
50-50% blend approved

QUANTIFYING EMISSIONS REDUCTIONS

- Requires standardized metric
  - Life cycle assessment (LCA)
    - Cradle-to-grave assessment of environmental impacts
    - Standardized framework (ISO 14040 & ISO 14044)
      - Goal & Scope
      - Inventory Analysis
      - Impact Assessment
      - Interpretation

LCA – System Boundary

- For aviation biofuels:



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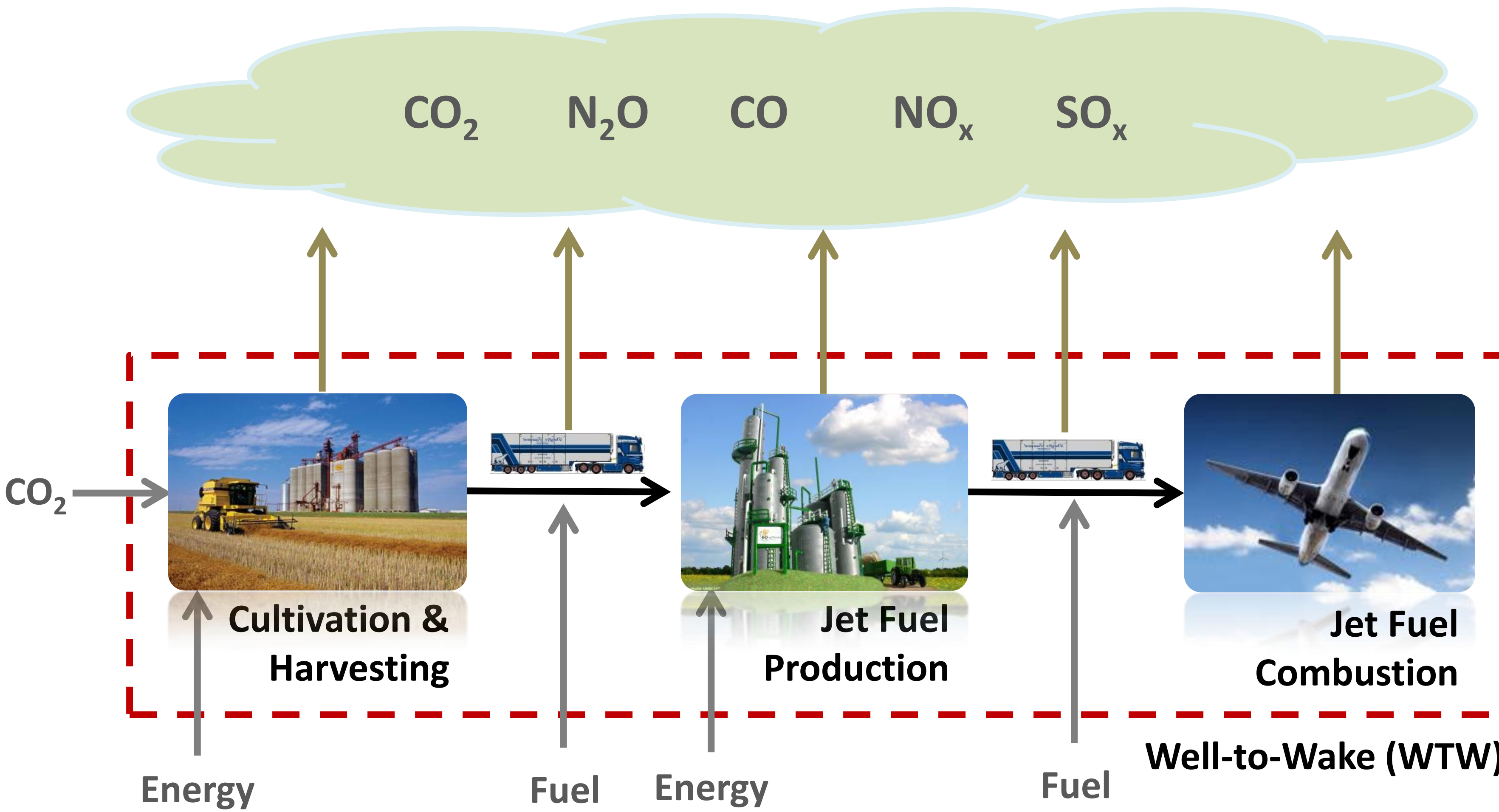


LCA – Inventory & Interpretation

- LCA tools
  - Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET)
  - GHGenius
  - SimaPro
- Inventory Analysis
  - Compilation of emissions data
  - Normalization of data to relate goal and scope

LCA – Inventory & Interpretation

- Impact Assessment
  - Environmental impact categories:
    - e.g. Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Human Toxicity Potential (HTP)
- Classification of Emissions
  - e.g. assigning CO_2, CH_4 and N_2O emissions to GWP

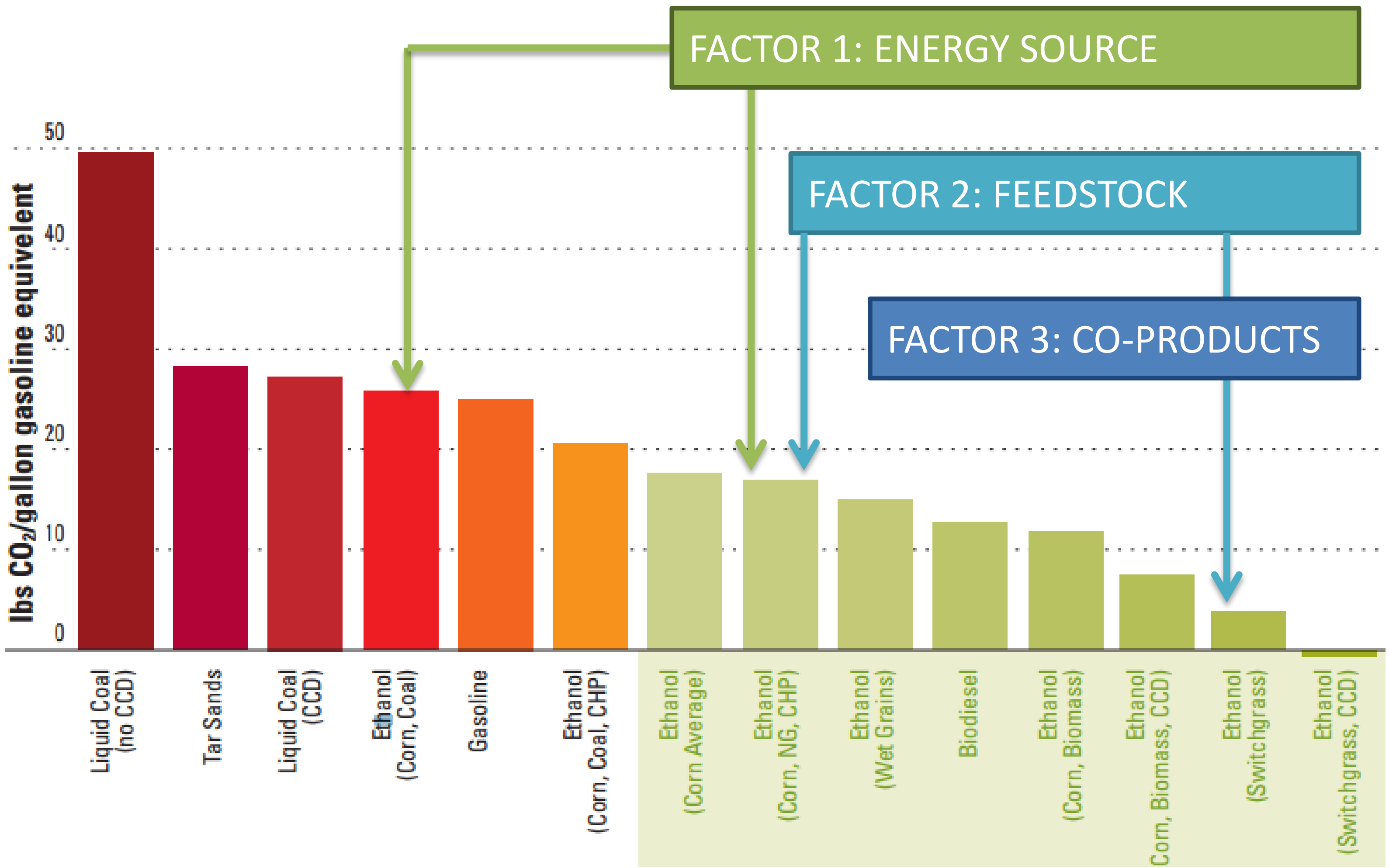
LCA – Inventory & Interpretation

- Normalization to allow comparison
  - Expressing potential impacts to allow comparison

e.g. comparing GWP of CO_2 and CH_4

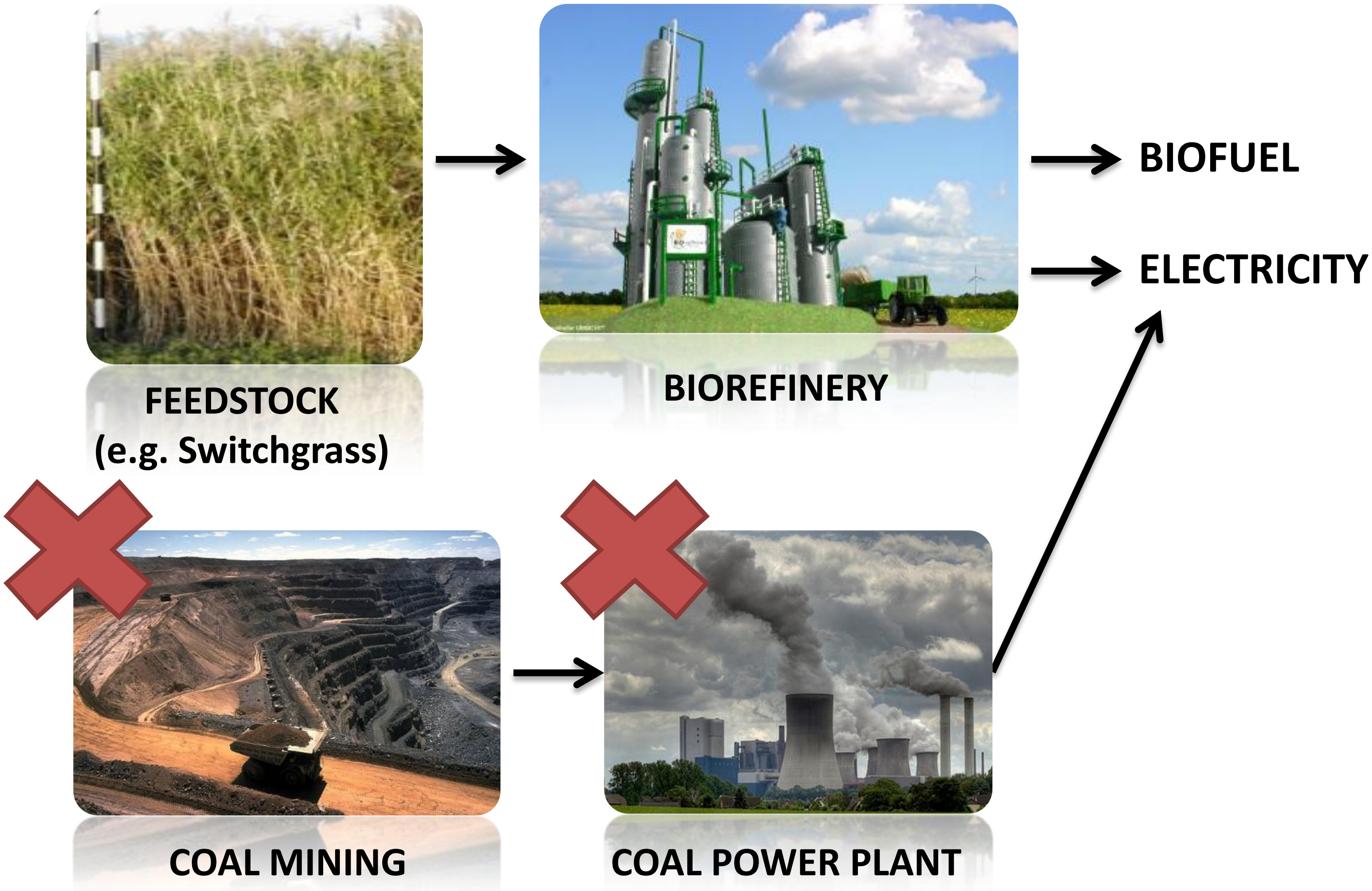
- Weighting of impacts
  - Determining crucial potential impacts
- Evaluation and documentation
  - Verification of result accuracy and proper documentation

LCA – RESULTS FOR BIOFUELS VARY



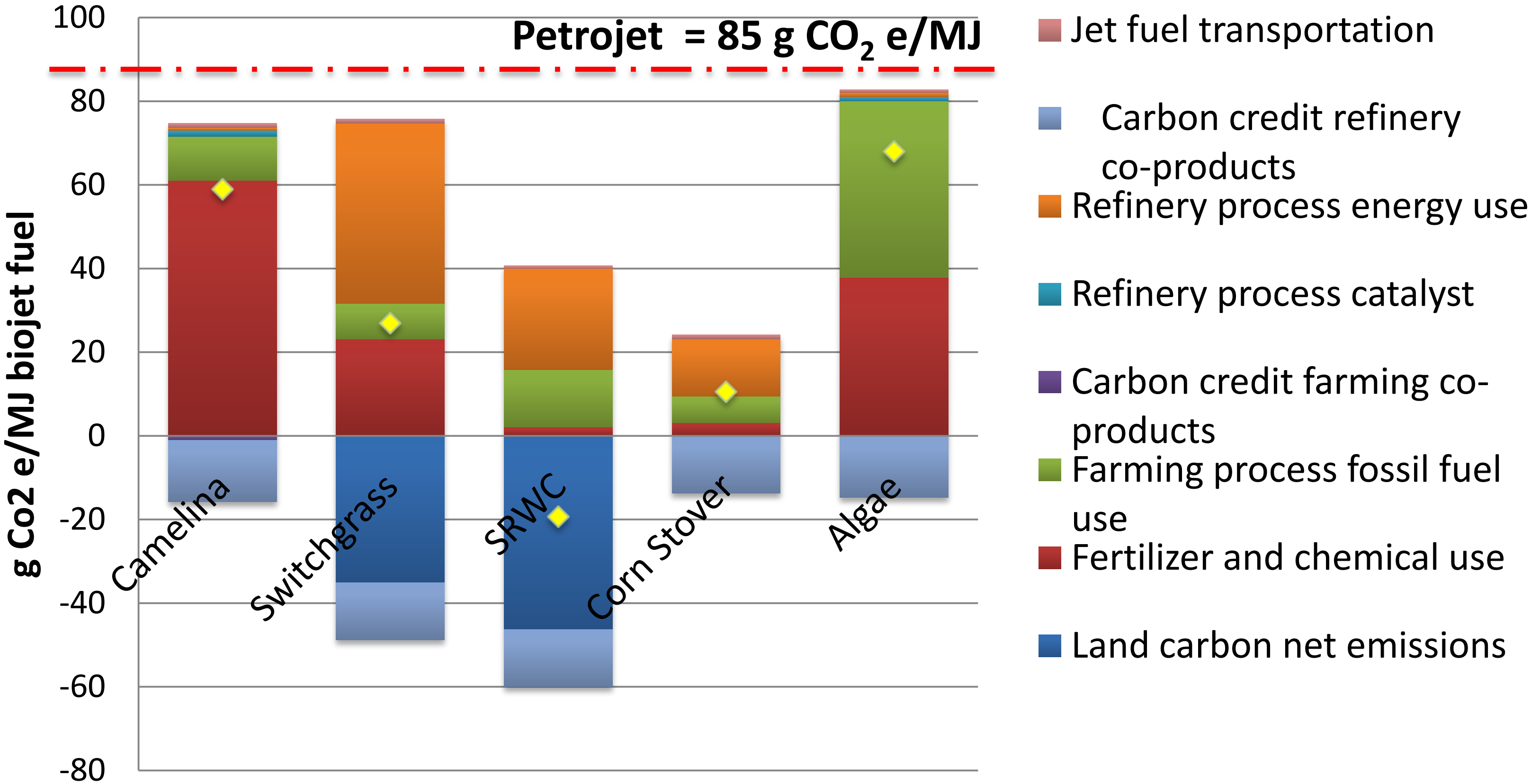
Source: NRDC, 2007

LCA – CO-PRODUCTS



LIFE CYCLE ASSESSMENT

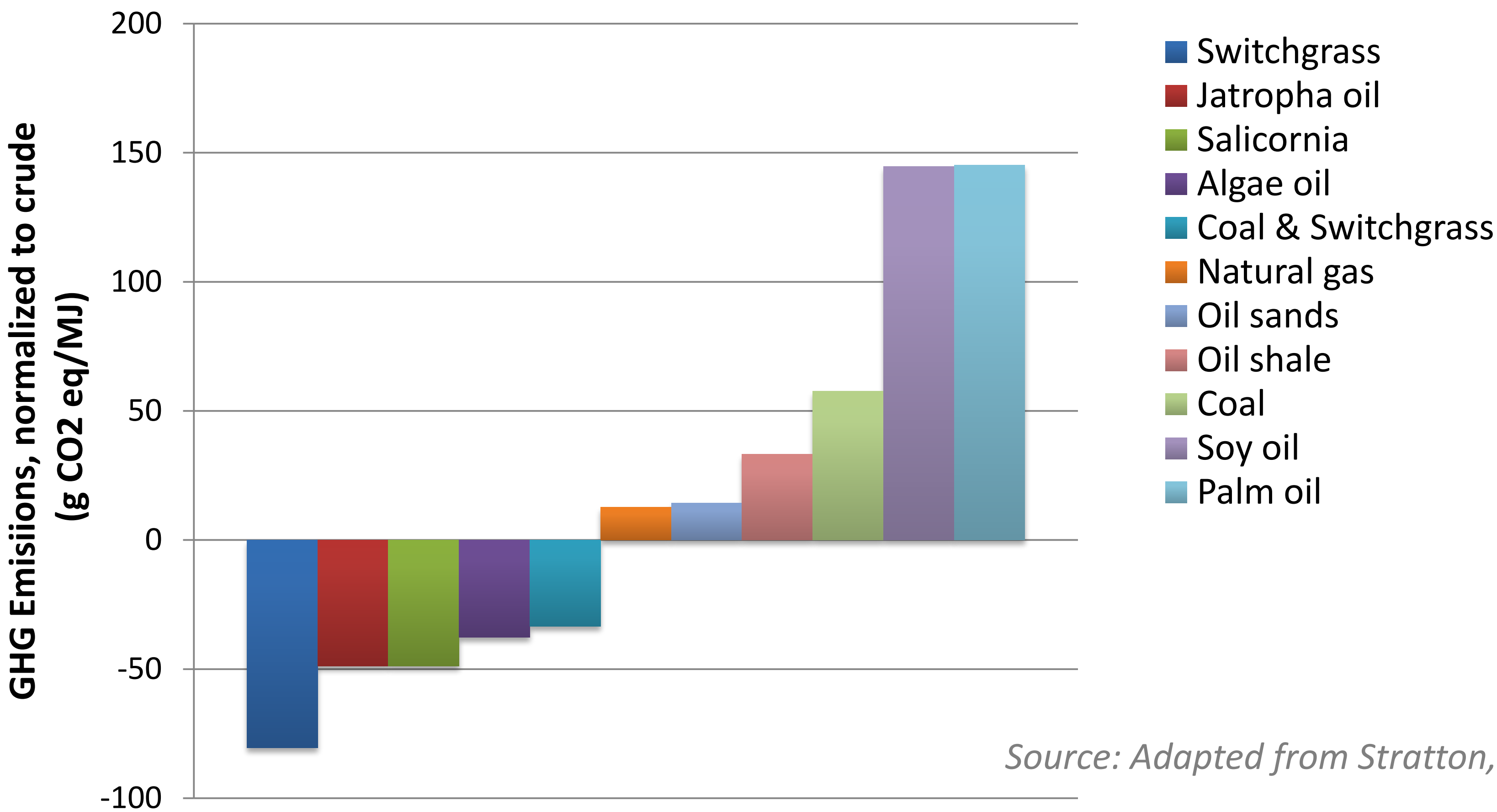
Case study 1 – LCA for US biojet production



Source: Adapted from Augusdinata, 2011

LIFE CYCLE ASSESSMENT

Case study 2 – LCA results compared to petroleum jet



Source: Adapted from Stratton, 2010

FUTURE WORK

- Strengthen economic assessments
- Feedstock development
  - e.g. camelina, carinata, algae
  - Understand yields, energy and fertilizer demand…
  - Develop/assess co-products
- Conversion technology evaluation
  - e.g. pyrolysis, HEFA, FT, carbohydrates to alkanes
- Assessment of other metrics
  - e.g. freshwater demand, cost-effectiveness
  - Other emissions

CONCLUSION

- LCA is a tool for quantification of environmental impacts
- Evaluate available options and impact of choice of action
  - for better or for worse
- Identify areas for improvement
- Quantify uncertainty/variability in performance
- Can be coupled with economic evaluation when making decision
- Provide guidance to policymakers and other decision makers

REFERENCES

- EIA, "Monthly US Gulf Coast Kerosene-Type Jet Fuel Spot Price FOB," [online], URL: www.eia.gov [cited 8 may 2013].
- Lee, D. S., Fahey, D. W., Forster, P. M., Newton, P. J., Wit, R. C. N., Ling, L. L, Owen B., Sausen, R., "Aviation and global climate change in the 21st century," Atmospheric Environment, Vol. 43, 22-23, 2009, pp. 3520-3537.
- IATA, "Carbon-Neutral Growth by 2020," Press release [online], No. 26, URL: http://www.iata.org/pressroom/pr/Pages/2009-06-08-03.aspx [cited 2 may 2013].
- Hendricks, R. C., Bushnell, D. M., and Shouse, D. T., "Aviation Fueling: A cleaner, Greener Approach," *International Journal of Rotating Machinery*, Vol. 2011, 2011, pp. 1-13.
- Kinder, J. D., "Evaluation of Bio-Derived Synthetic Paraffinic Kerosenes (Bio-SPKs)", The Boeing Company, UOP, United States Air Force Research Laboratory, Report Version 5.0, May 2010.
- Whitfield, R., "The biojet fuel industry: its rapid emergence, future development, and likely profile," *Journal of Aerospace Engineering*, Vol. 225, No. 6, 2011, pp. 619-630.
- NRDC, "Getting Biofuels Right: Eight Steps for Reaping Real Environmental Benefits from Biofuels" [online], URL: http://www.nrdc.org/air/transportation/biofuels/right.pdf [cited 8 may 2013]
- Agusdinata, D. B., Zhao, F., Ileleji, K., and DeLaurentis, D., "Life Cycle Assessment of Potential Biojet Fuel Production in the United States," *Environmental Science & Technology*, Vol. 45, 2011, pp. 9133-9143.

REFERENCES

- Stratton, R. W., "Life cycle assessment of greenhouse gas emissions and non-CO_2 combustion effects from alternative jet fuels," M.A.Sc. Dissertation, Department of Aeronautics and Astronautics, MIT, Boston, MA, 2010.
- Bespertov, V., Skelly, J., Trifonov, M., Vallee, G., Valois, B., Villaume, F., "The European directive to include aviation in the European CO2 emissions trading scheme, consequences and strategic options for the aviation industry," Research Project, HEC Paris, 2009.
- ASTM Standard D7566-12, "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons," ASTM International, West Conshohocken, PA, 2012, DOI: 10.1520/D7566-12A, www.astm.org.
- US Department of Energy. "US Billion-Ton Update," [online]. URL: http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf [cited May 15 2013].

THANK YOU

QUESTIONS?

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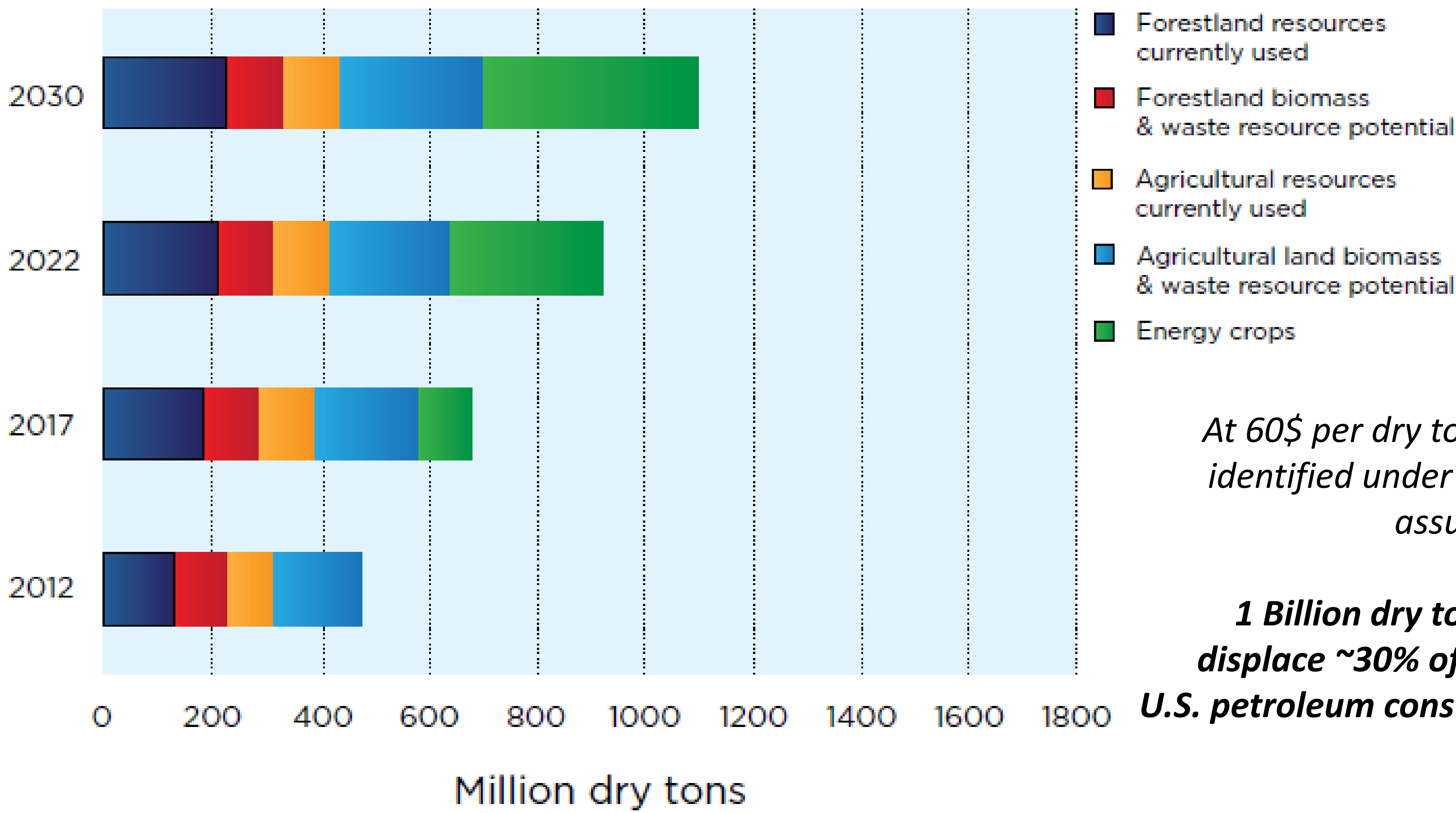
Currently Used & Potential Resources: U.S.

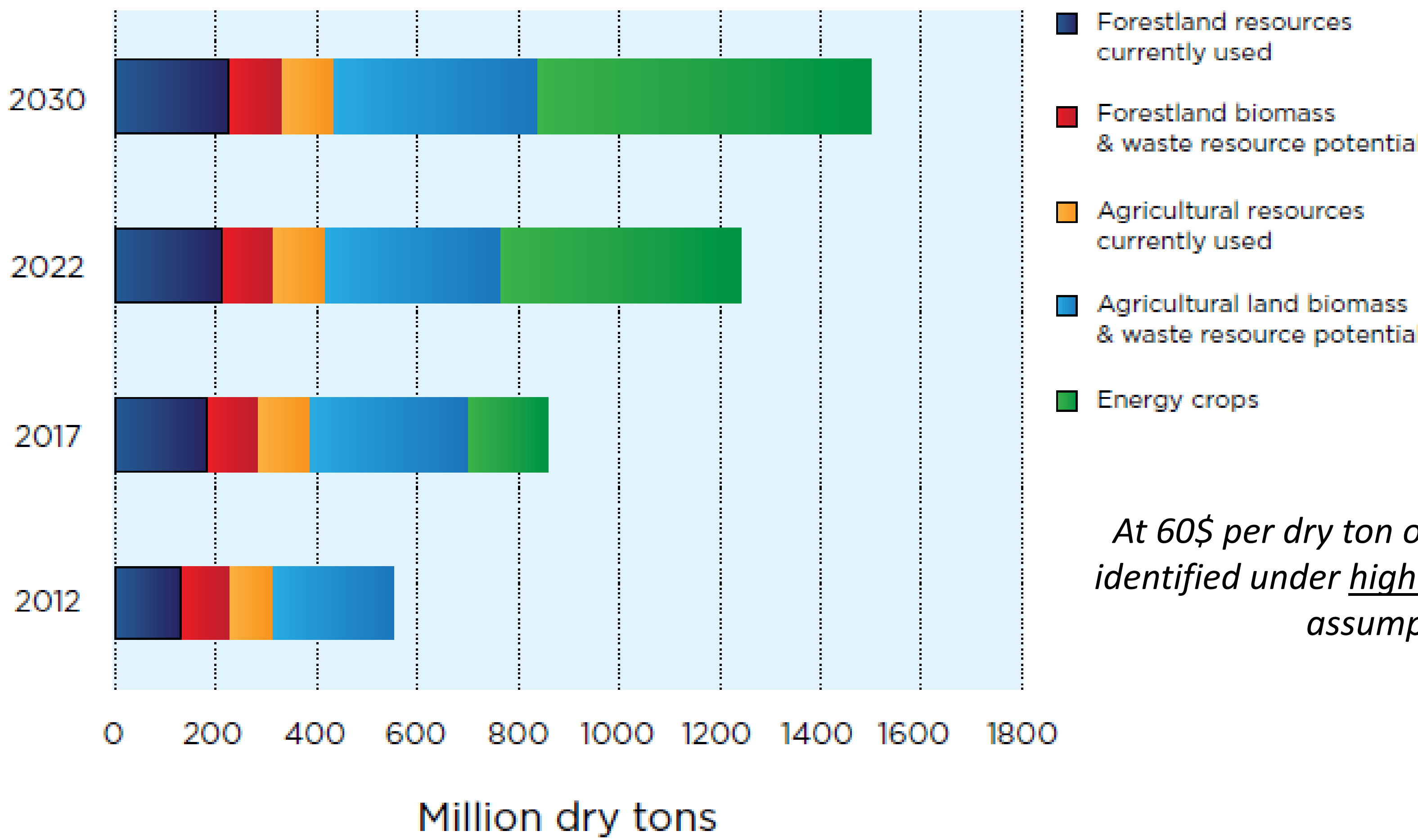


At 60$ per dry ton or less identified under baseline assumptions

1 Billion dry tons/yr to displace ~30% of present U.S. petroleum consumption

Source: US Department of Energy, 2011

Currently Used & Potential Resources: U.S.



At 60$ per dry ton or less identified under <u>high-yield</u> assumptions

Source: US Department of Energy, 2011