BIOFUELS AND ALTERNATIVE ENERGY FOR TRANSPORTATION

Presented to the

Washington State Transportation Commission

September 23, 2014

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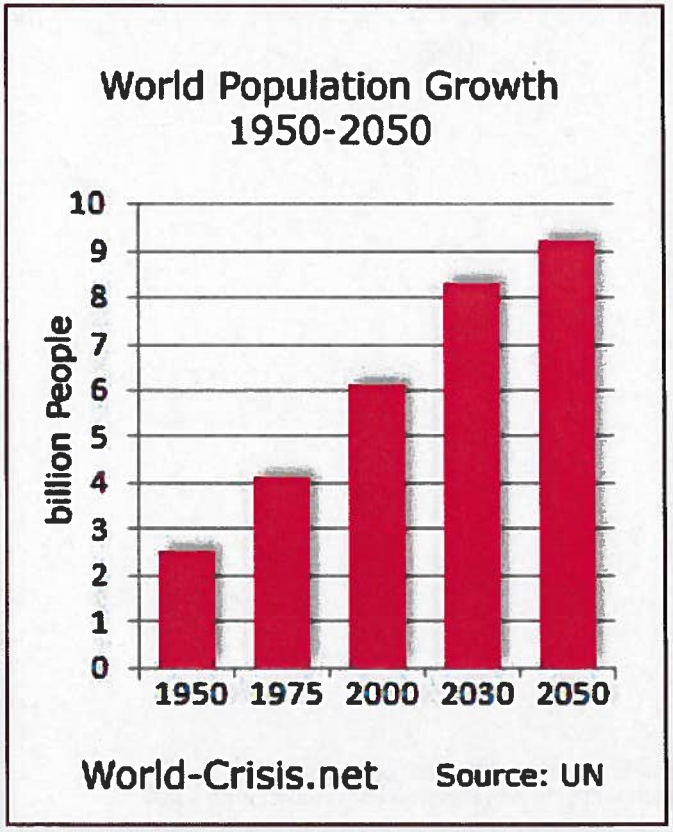
Associate Vice-President for Alternative Energy

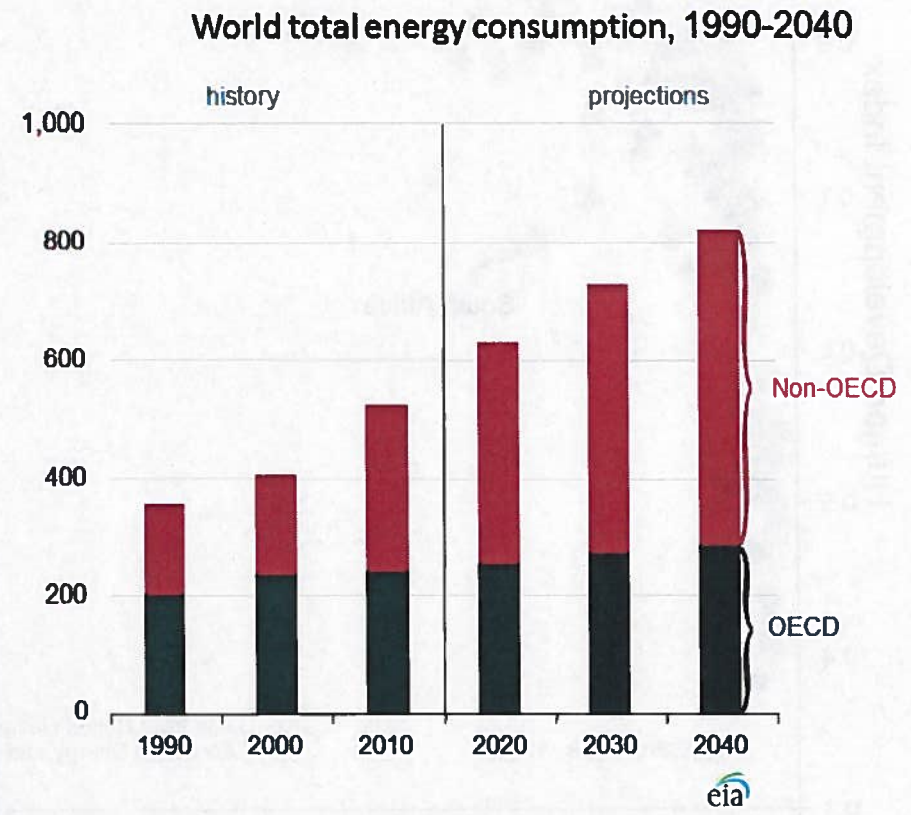
Washington State University

Overview

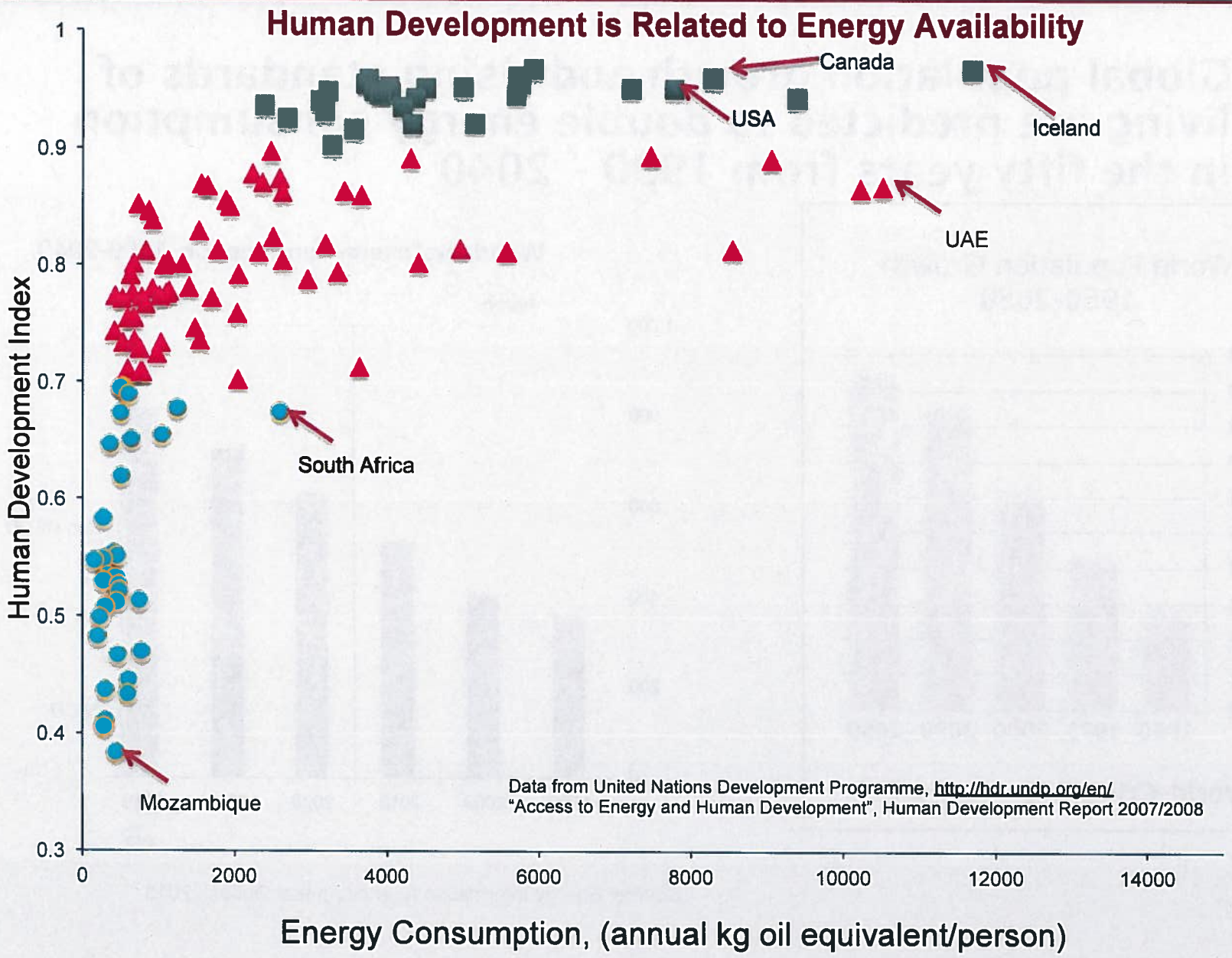
- Background
  - Global Energy Growth
  - Domestic Energy Resources
  - Implications for Transportation in Washington
- Alternative Jet Fuel from Biomass
  - Northwest Advanced Renewables Alliance
  - FAA Center of Excellence for Alternative Jet Fuels and Environment
- Biodiesel – reality in Washington State
- Liquefied Natural Gas – potential for Washington State

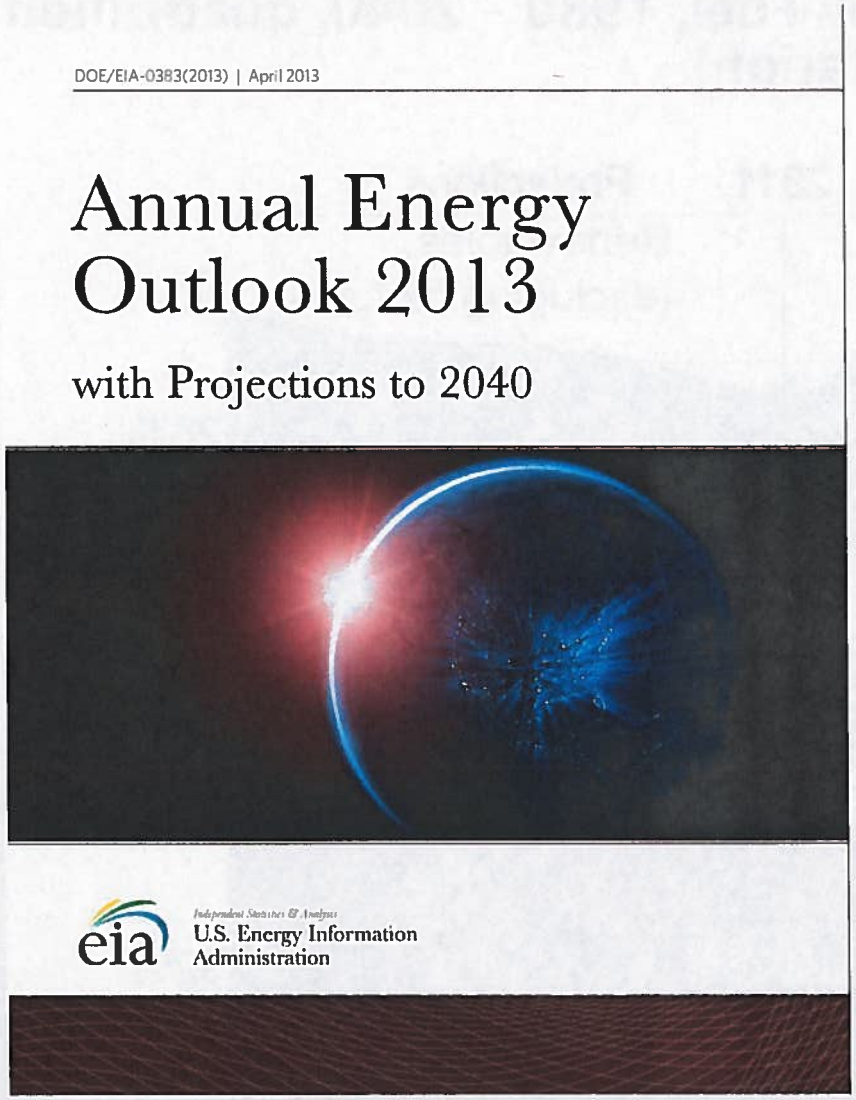
Global population growth and rising standards of living are predicted to double energy consumption in the fifty years from 1990 – 2040



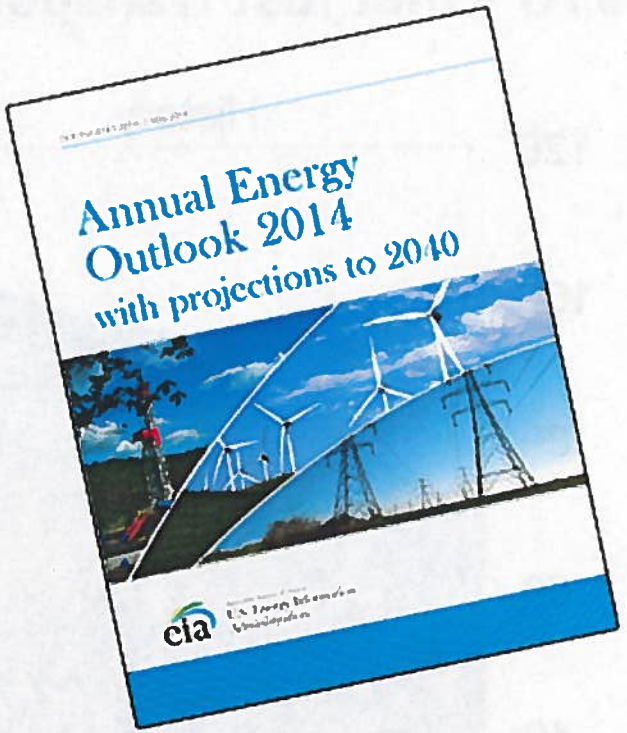


Source: Energy Information Agency Annual Outlook 2013


Human Development is Related to Energy Availability
Canada
USA
Iceland
UAE
South Africa
Mozambique
Human Development Index
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
2000
4000
6000
8000
10000
12000
14000
Energy Consumption, (annual kg oil equivalent/person)
Data from United Nations Development Programme, http://hdr.undp.org/en/
"Access to Energy and Human Development", Human Development Report 2007/2008

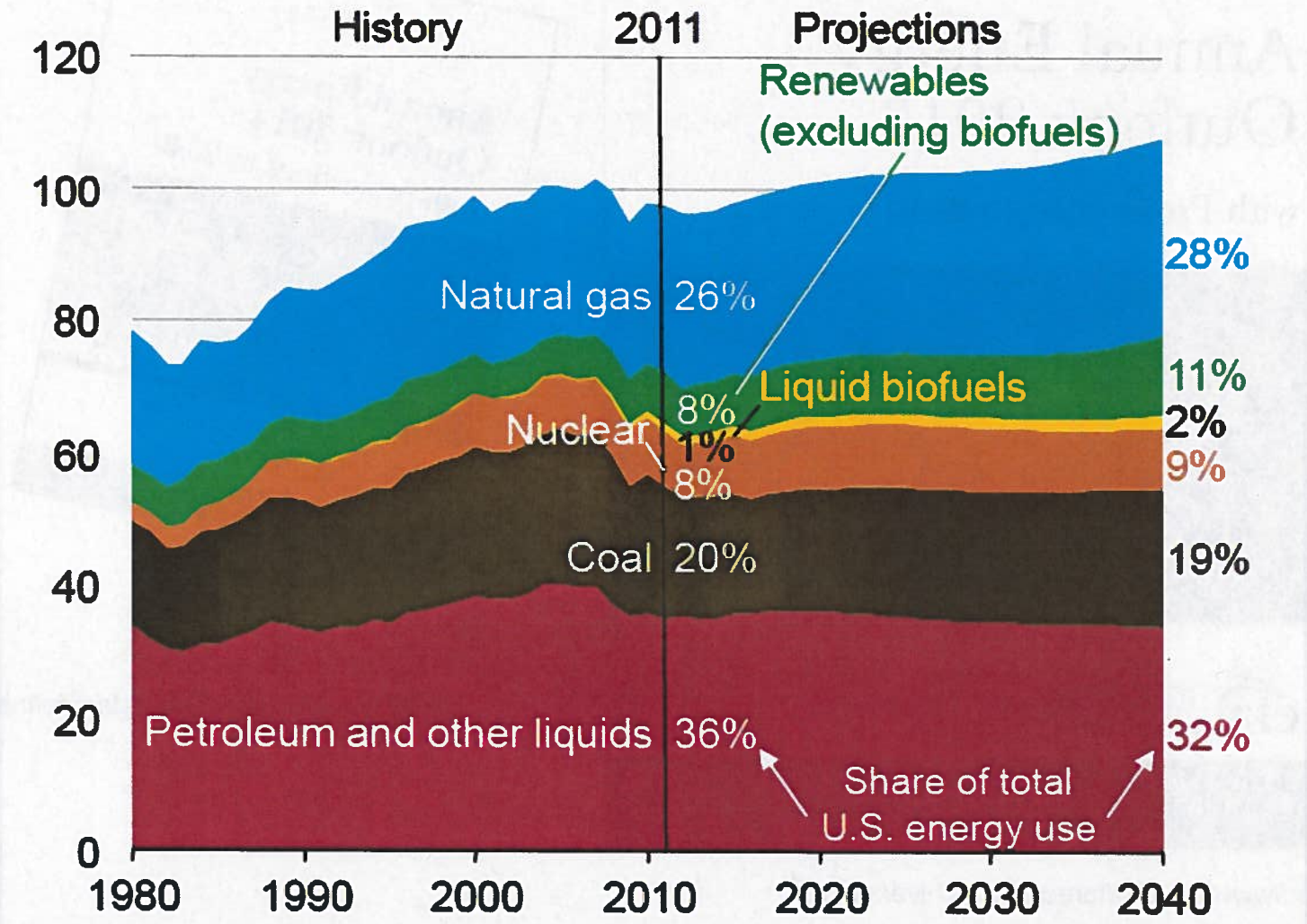


http://www.eia.gov/forecasts/archive/aeo13/



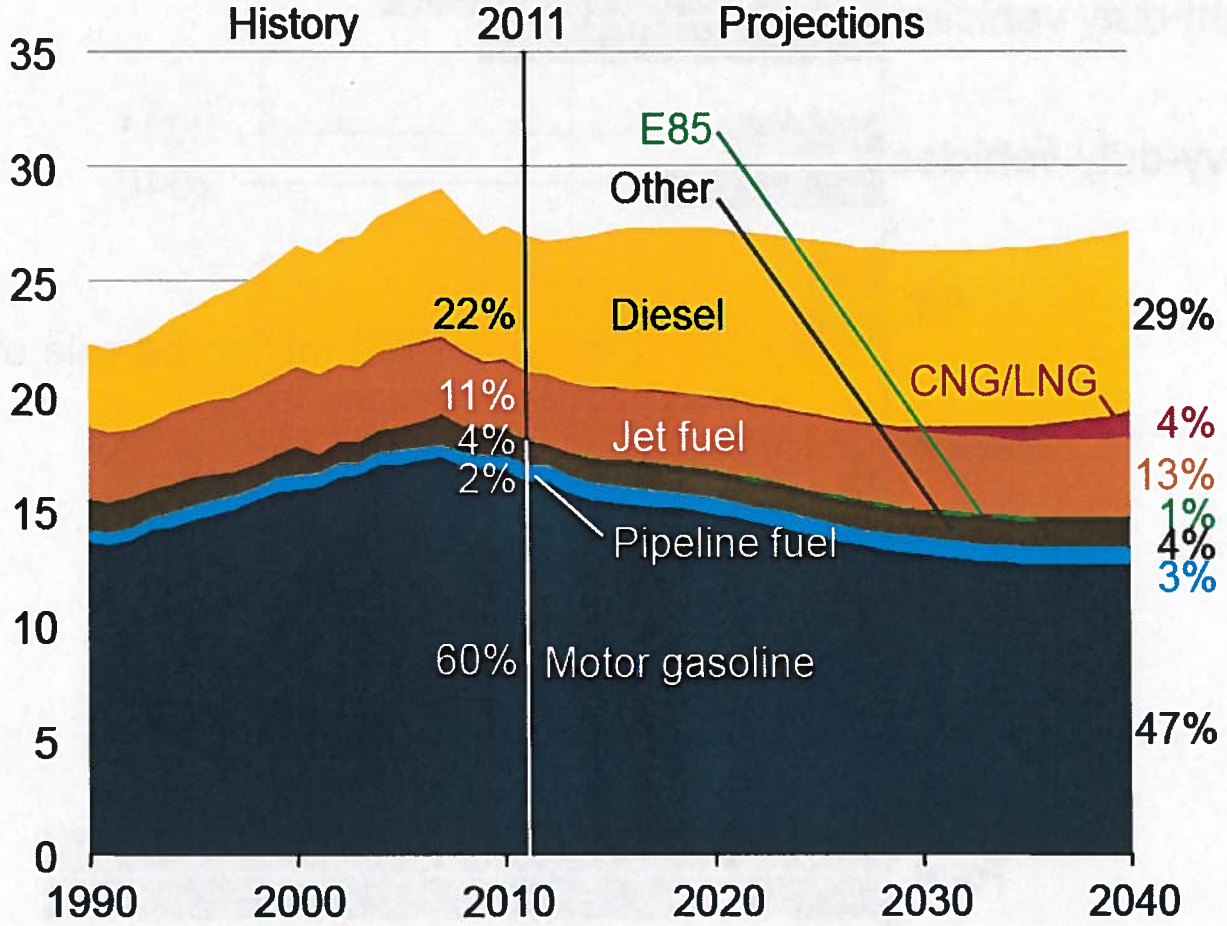
http://www.eia.gov/forecasts/aeo/index.cfm

US Primary Energy Use by Fuel, 1980 – 2040, quadrillion BTU – (not just transportation)



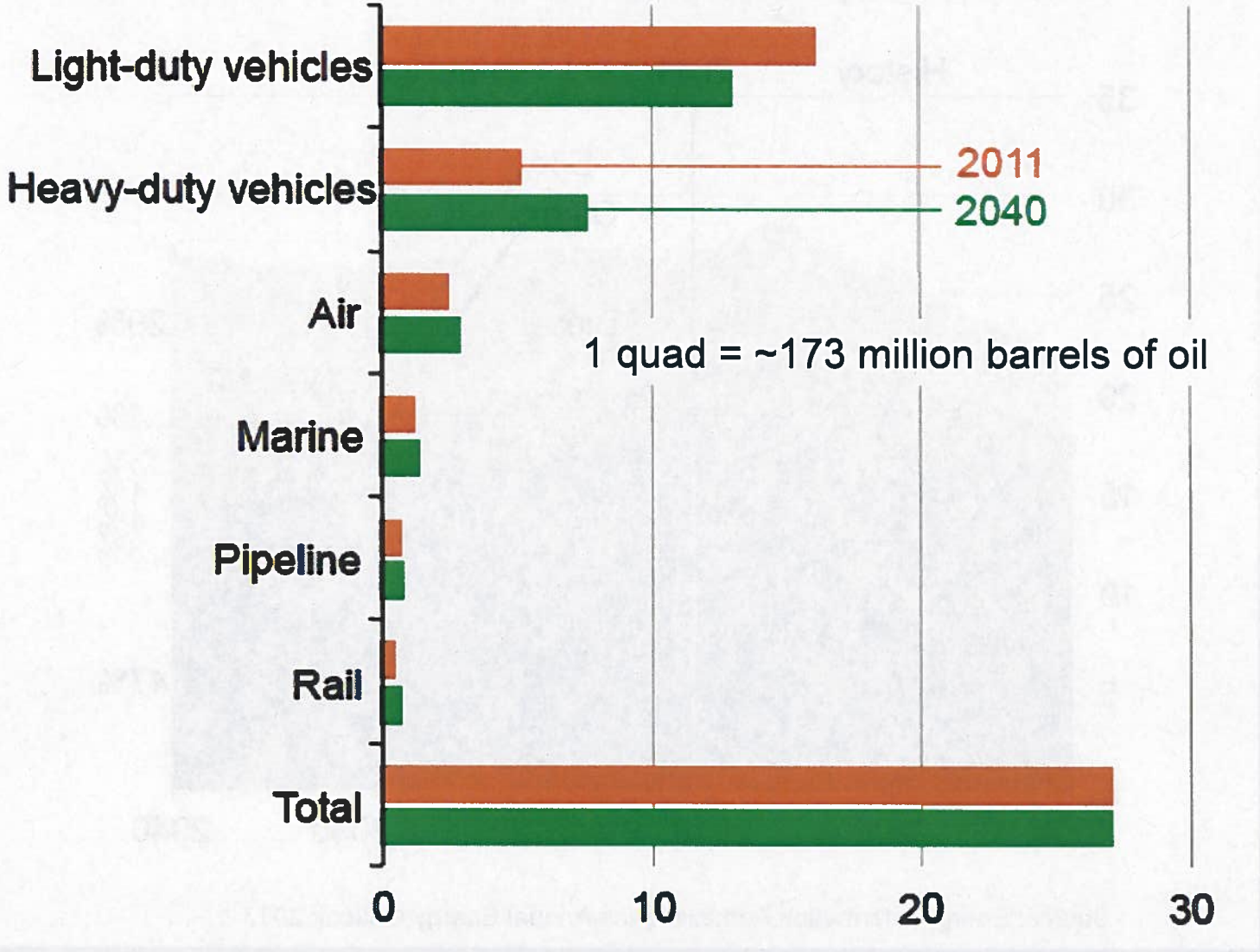
Source: Energy Information Agency Annual Outlook 2013

Transportation Energy Consumption by Fuel 1990-2040(quadrillion BTU)



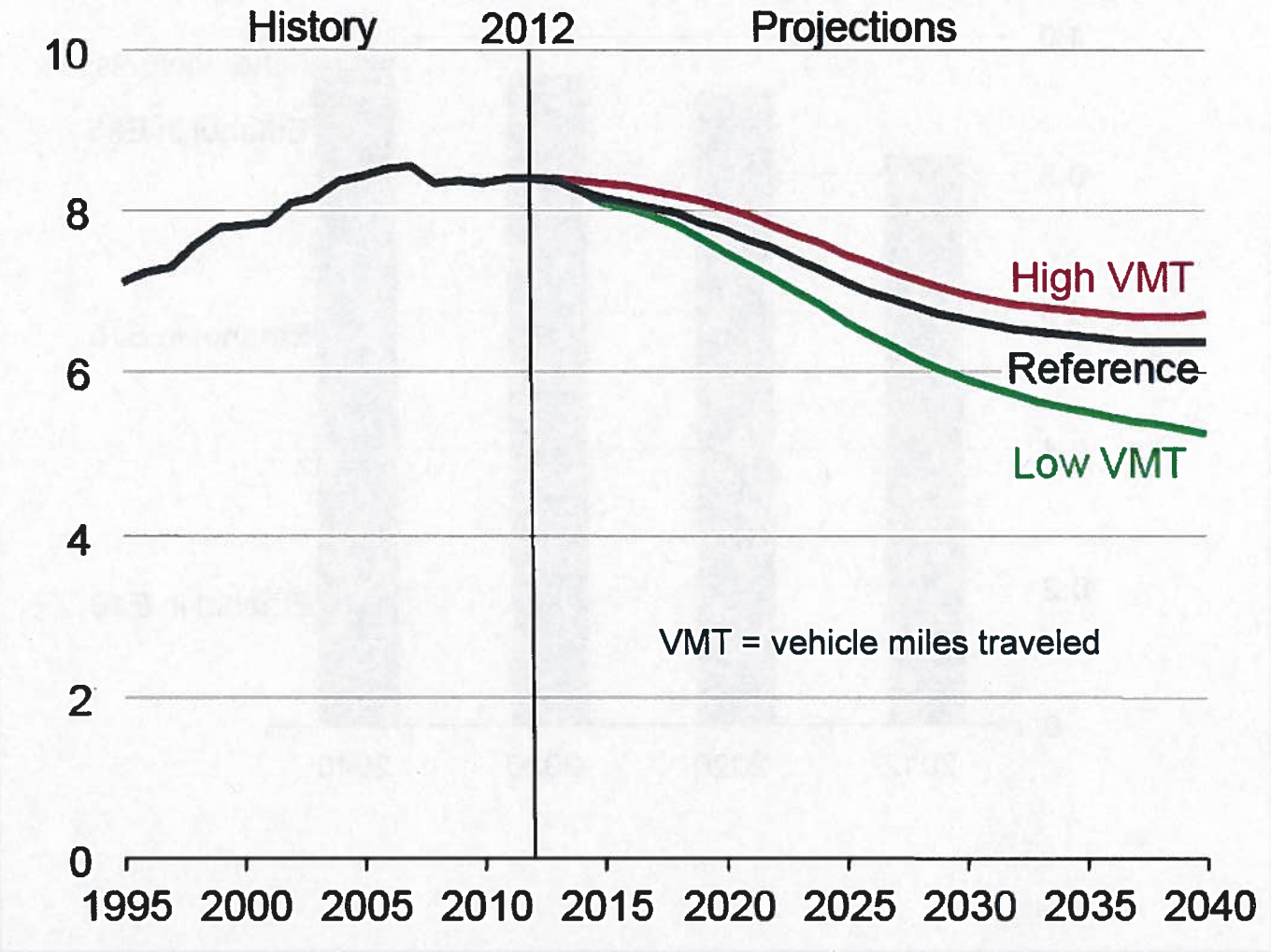
Source: Energy Information Administration Annual Energy Outlook 2013

Delivered energy consumption for transportation by mode, 2011 and 2040 (quadrillion Btu)



Source: U.S. Energy Information Administration | Annual Energy Outlook 2014

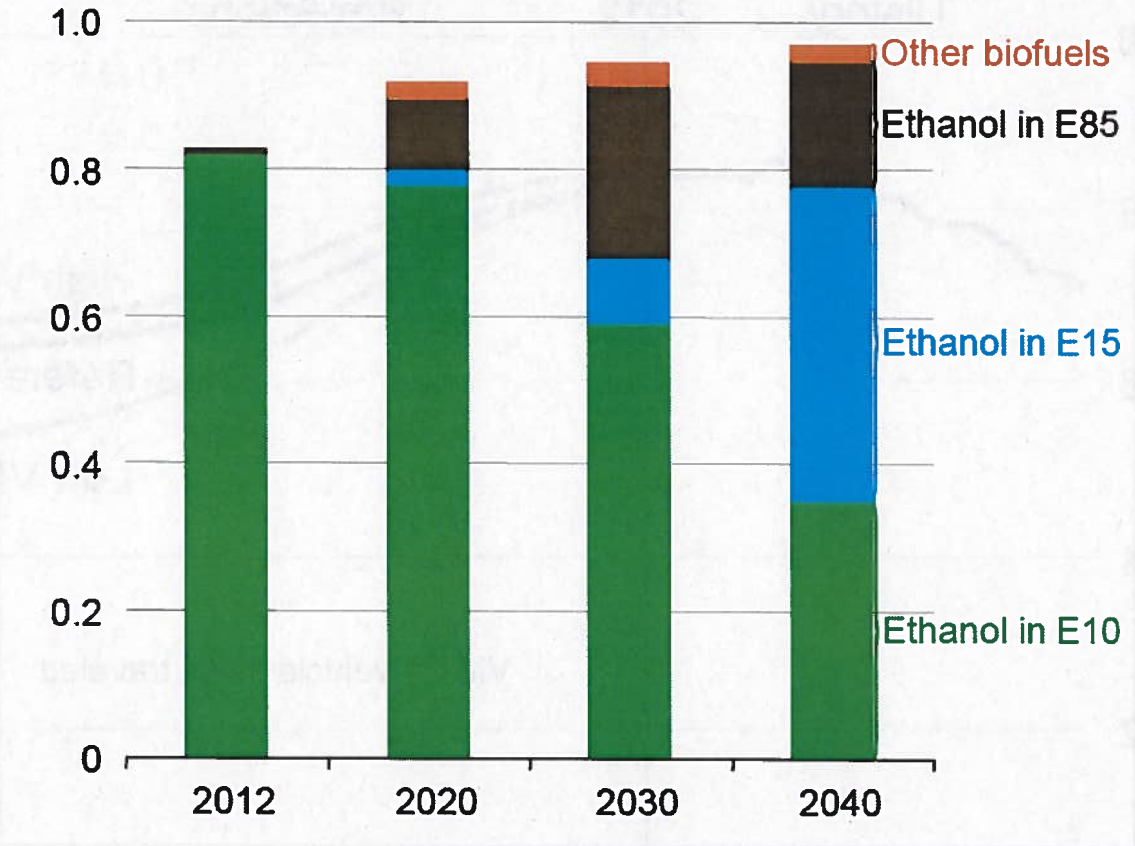
Light Duty Vehicle Energy Usage Projections



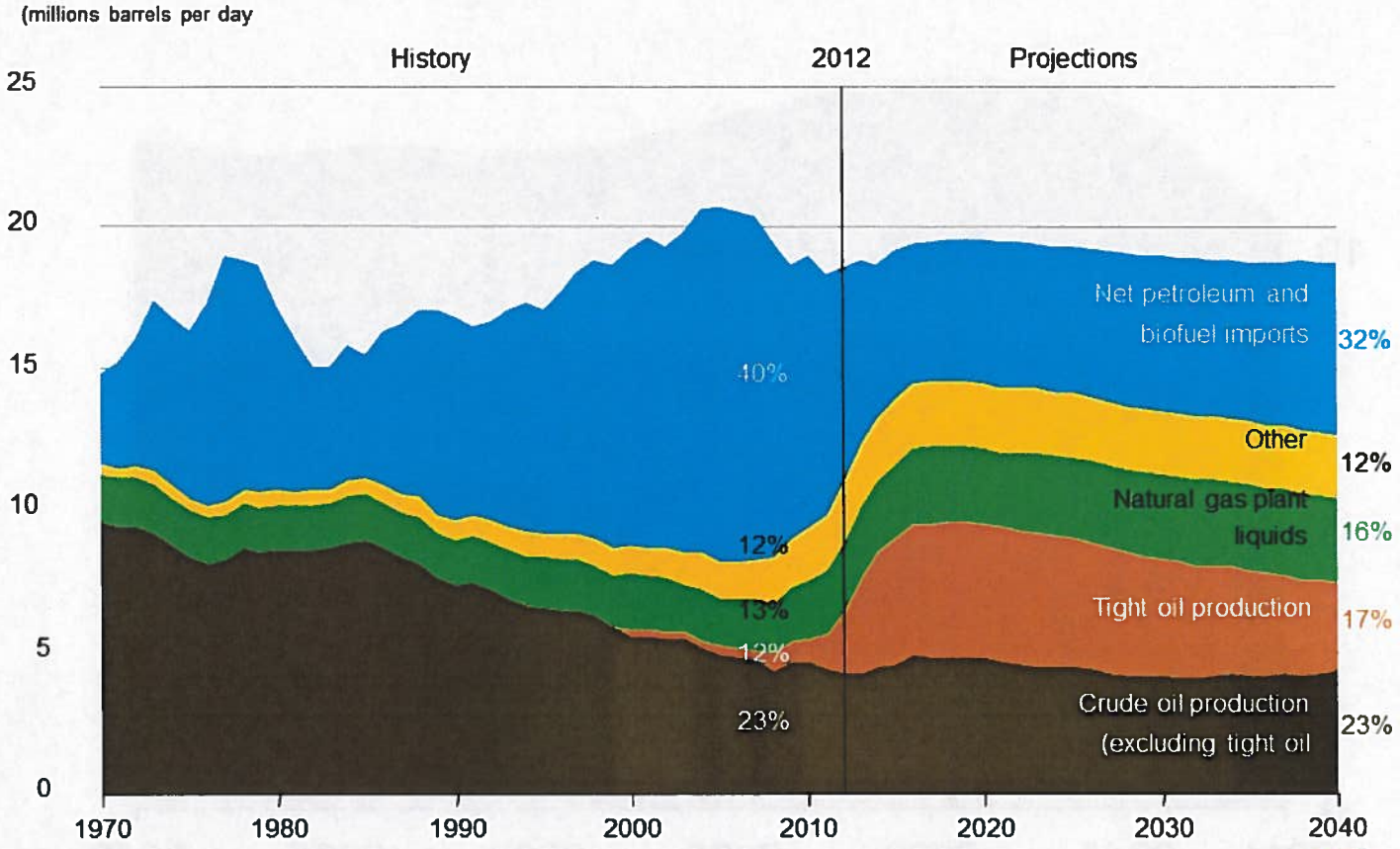
Source: U.S. Energy Information Administration | Annual Energy Outlook 2014

Consumption of Biofuels in Light Vehicles

(million barrels per day)



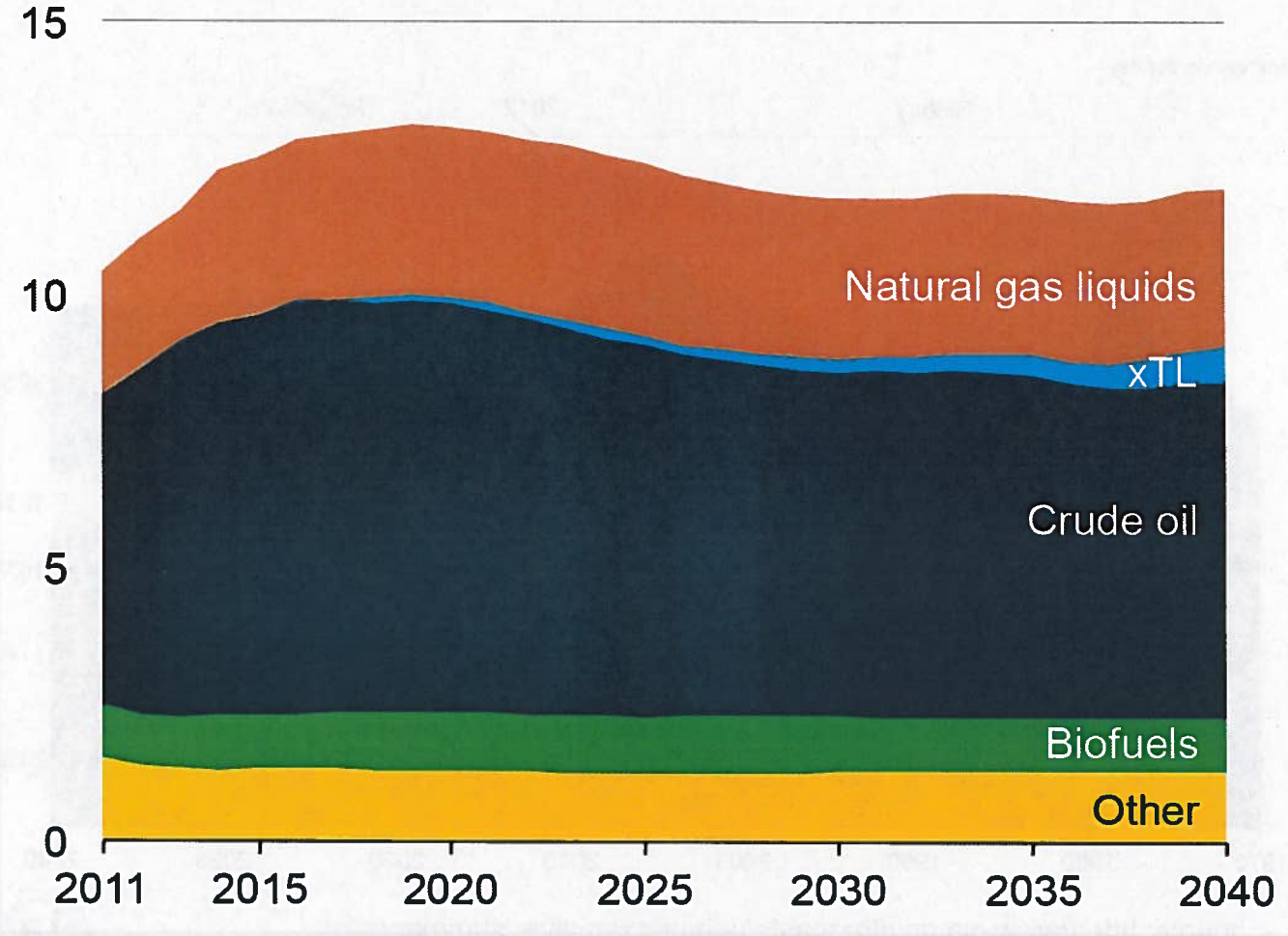
US Petroleum and Other Liquid Fuels by Source, 1970 - 2040



source: http://www.eia.gov/forecasts/aeo/er/executive_summary.cfm

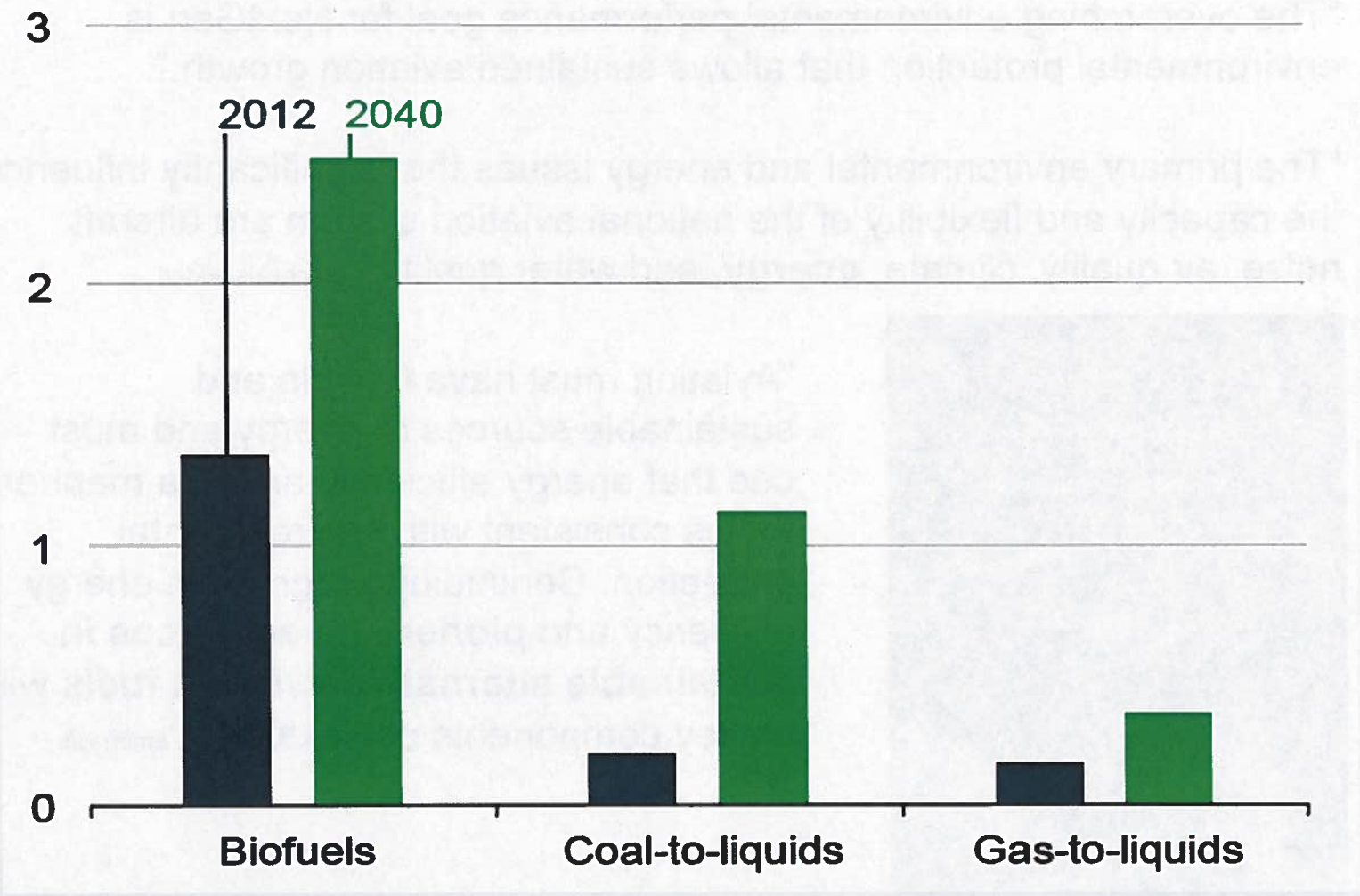
eia

US Production of Petroleum and Other Liquids by Source, 2011-2040 (million barrels per day)



Source: Energy Information Administration Annual Energy Outlook 2013

Growth of Biofuels and Coal-to-Liquid and Gas-to-Liquid Fuels

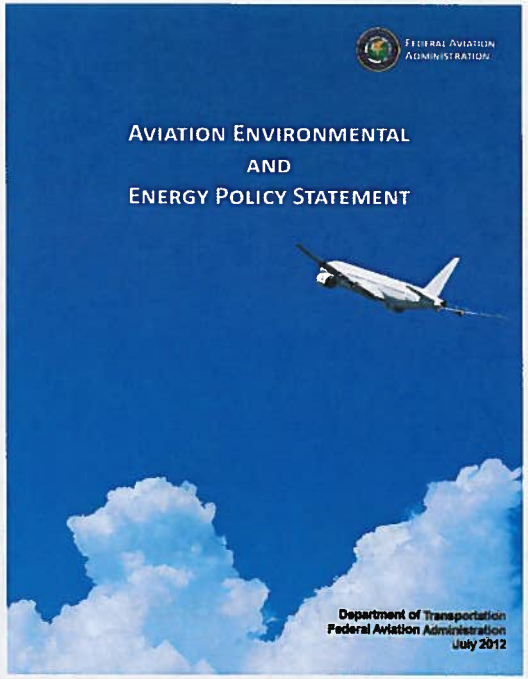


Source: U.S. Energy Information Administration | Annual Energy Outlook 2014

Aviation: Future Growth Perspective
Next Generation Air Transportation System

"The overarching environmental performance goal for NextGen is environmental protection that allows sustained aviation growth."

"The primary environmental and energy issues that significantly influence the capacity and flexibility of the national aviation system are aircraft noise, air quality, climate, **energy**, and water quality." emphasis added



"Aviation must have reliable and sustainable sources of energy and must use that energy efficiently and in a manner that is consistent with environmental protection. Continuing progress in energy efficiency and **pioneering advances in sustainable alternative aviation fuels** will be key components of NextGen." emphasis added

US Civilian Aviation Goals

- ***Climate Goal***: Limit the impact of aircraft CO_2 emissions on the global climate by achieving carbon neutral growth by 2020 compared to 2005, and net reductions of the climate impact from all aviation emissions over the longer term (by 2050)[1]
- ***Energy Goal:*** Improve National Airspace System (NAS) energy efficiency by at least two percent per year, and **develop and deploy alternative jet fuels for commercial aviation**.[2] emphasis added

[1] Goal unveiled by U.S. At COP/15 and documented in Canada, Mexico, U.S. Position presented at ICAO's 37th Assembly. See working paper titled "A more ambitious, collective approach to international aviation greenhouse gas emissions", section 2.3

[2] See ICAO Assembly Resolution A37---19: Consolidated statement of Continuing ICAO policies and practices related to environmental protection – Climate change, Section 23.g).

Development of Alternative Fuels in Washington State

- Biofuels
  - Biodiesel
  - Wood and MSW to Jet and other fuels and chemicals
    - Northwest Advanced Renewables Alliance
    - Advanced Hardwood Biofuels Northwest
    - FAA Center of Excellence for Alternative Jet Fuels and Environment
- Liquefied Natural Gas

Biodiesel

Producers in Washington

According to "Biodiesel Magazine"
Imperium Renewables, Grays Harbor - 100 million gallons per year
General Biodiesel, Seattle - 10 million gallons per year

According to "Biodiesel.org", the above two plus
Whole Energy Fuels, Anacortes - 2 million gallons per year
Gen-X Energy Group, Moses Lake - 15 million gallons per year

Advanced **Hardwood Biofuels** Northwest

- Advanced Hardwood Biofuels Northwest (AHB) is carrying out research and development to support a system for growing and converting hardwoods, such as hybrid poplars, into liquid biofuels.
- AHB is broken down into five main areas of focus: feedstocks, conversion, sustainability, education, and extension.
- Led by Dr. Rick Gustafson of the University of Washington
- http://hardwoodbiofuels.org
- Funded by USDA National Institute of Food and Agriculture

NARA
Northwest Advanced Renewables Alliance

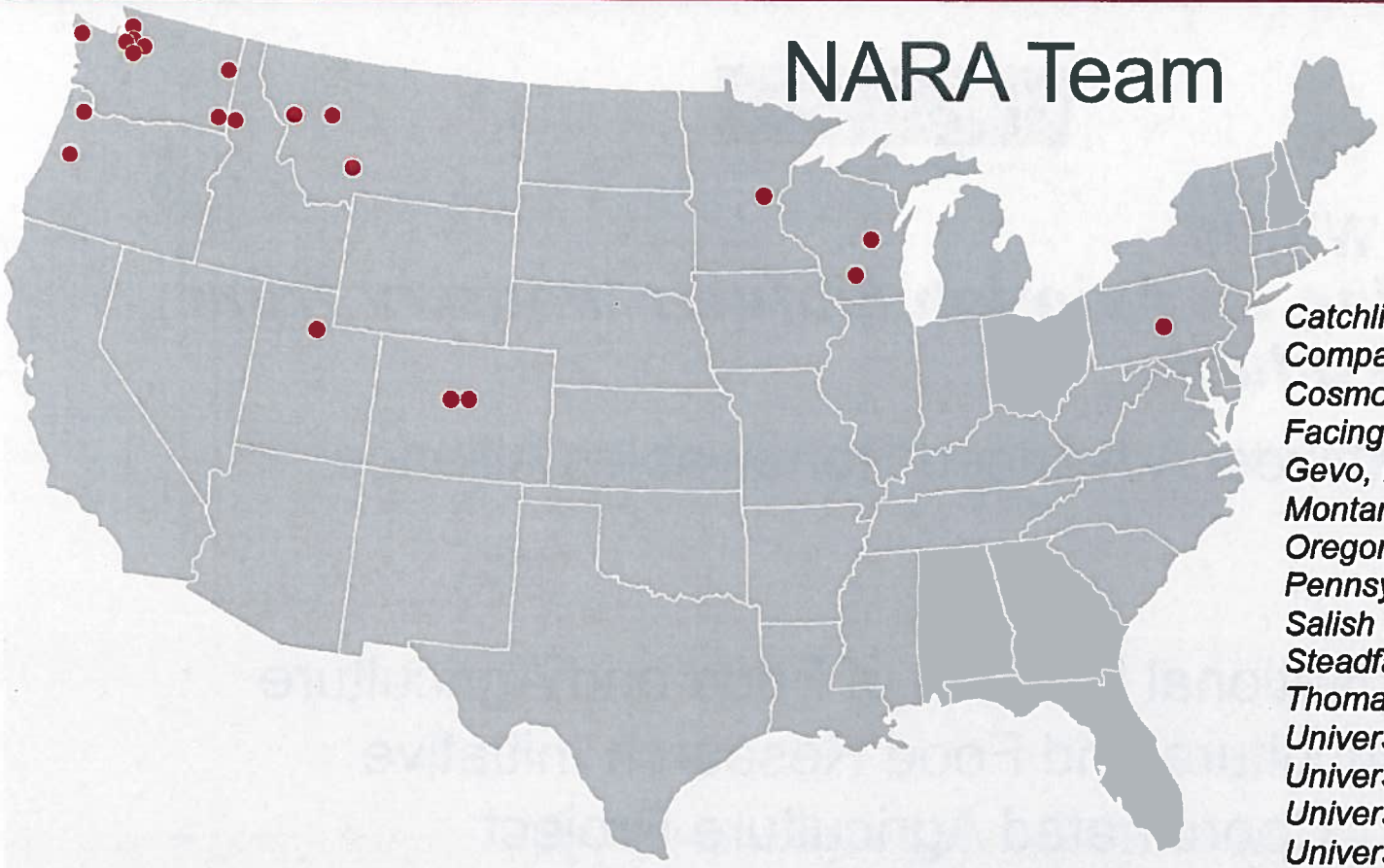
Wood to Wings
Envisioning an Aviation Biofuels Industry from Forest Residuals

Northwest Advanced Renewables Alliance

USDA National Institute of Food and Agriculture
Agriculture and Food Research Initiative
Coordinated Agriculture Project

August, 2011 – July 2016

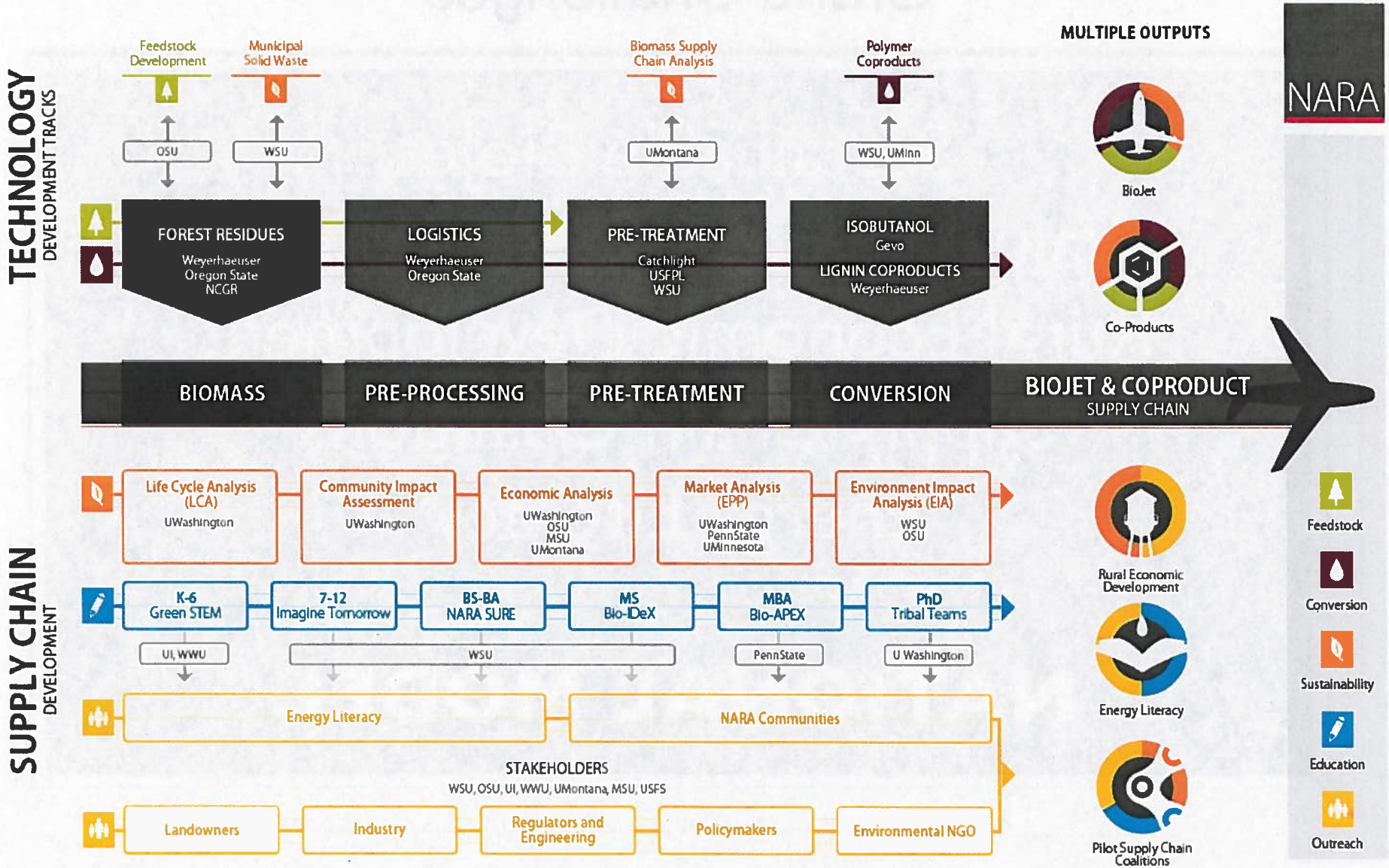
NARA Team



Catchlight Energy
Compañía Logística de Hidrocarburos
Cosmo Specialty Fibers
Facing the Future
Gevo, Inc.
Montana State University
Oregon State University
Pennsylvania State University
Salish Kootenai College
Steadfast Management
Thomas Spink International
University of Idaho
University of Minnesota
University of Montana
University of Utah
University of Washington
University of Wisconsin-Extension
USFS - Forest Products Lab
USFS - PNW Research Station
Washington State University
Western Washington University
Weyerhaeuser

Grand Challenges

NARA Team & Goal Diagram



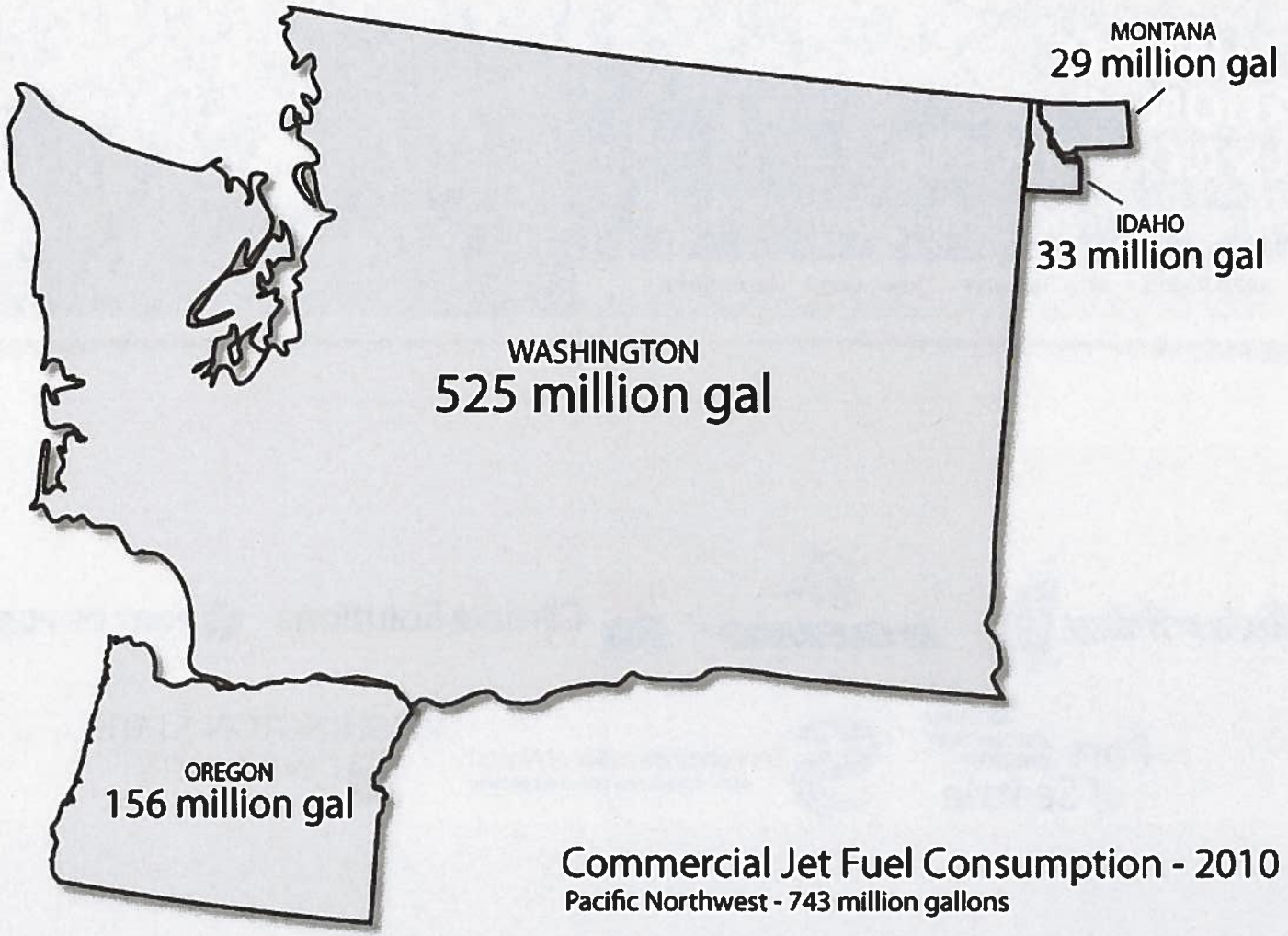
Why Aviation Fuels?

Alaska Airlines · BOEING · Climate Solutions · PORT OF PORTLAND

Port of Seattle · Spokane International Airport · WASHINGTON STATE UNIVERSITY

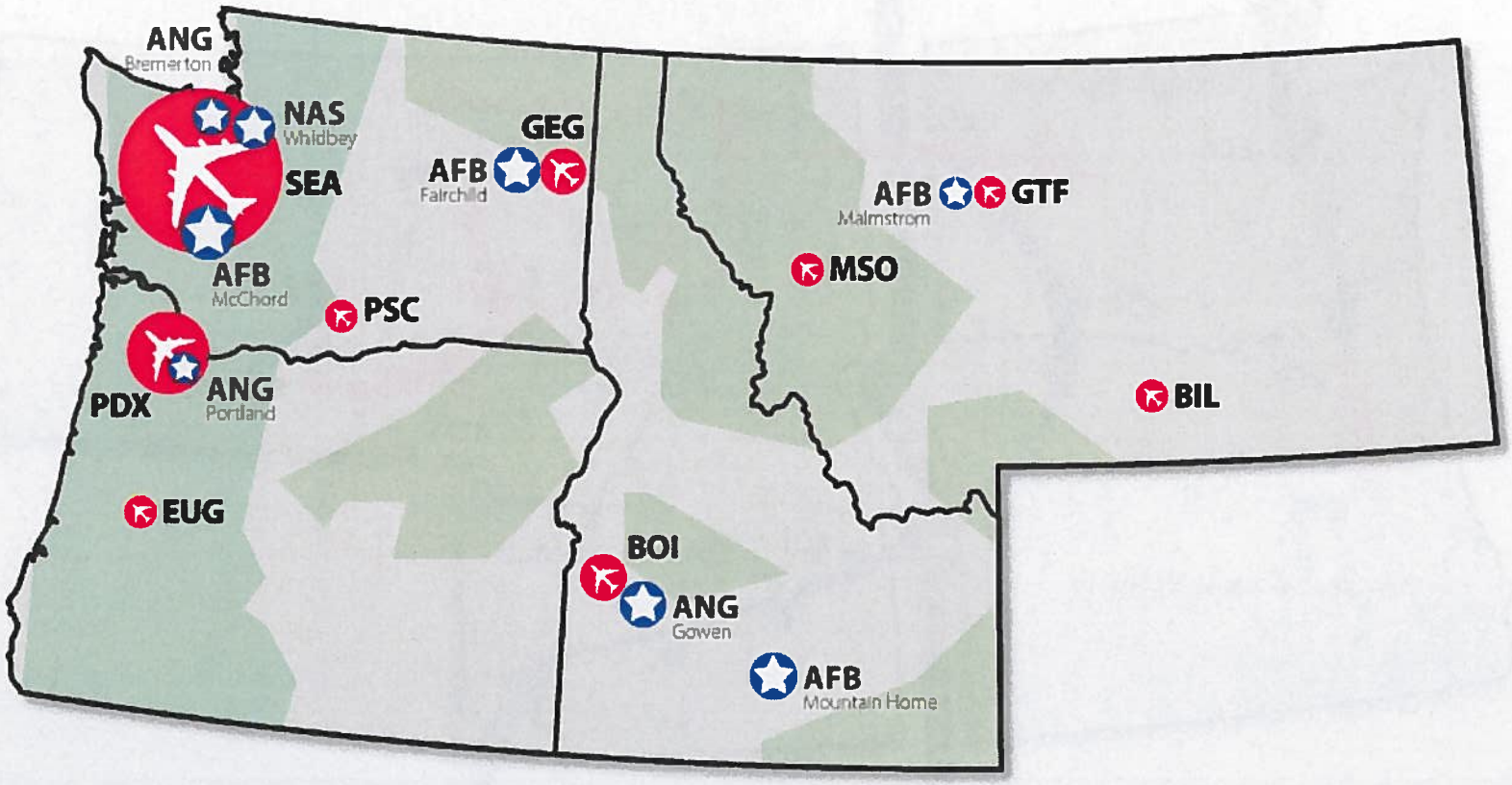
www.safnw.com

Regional Aviation Fuel Consumption

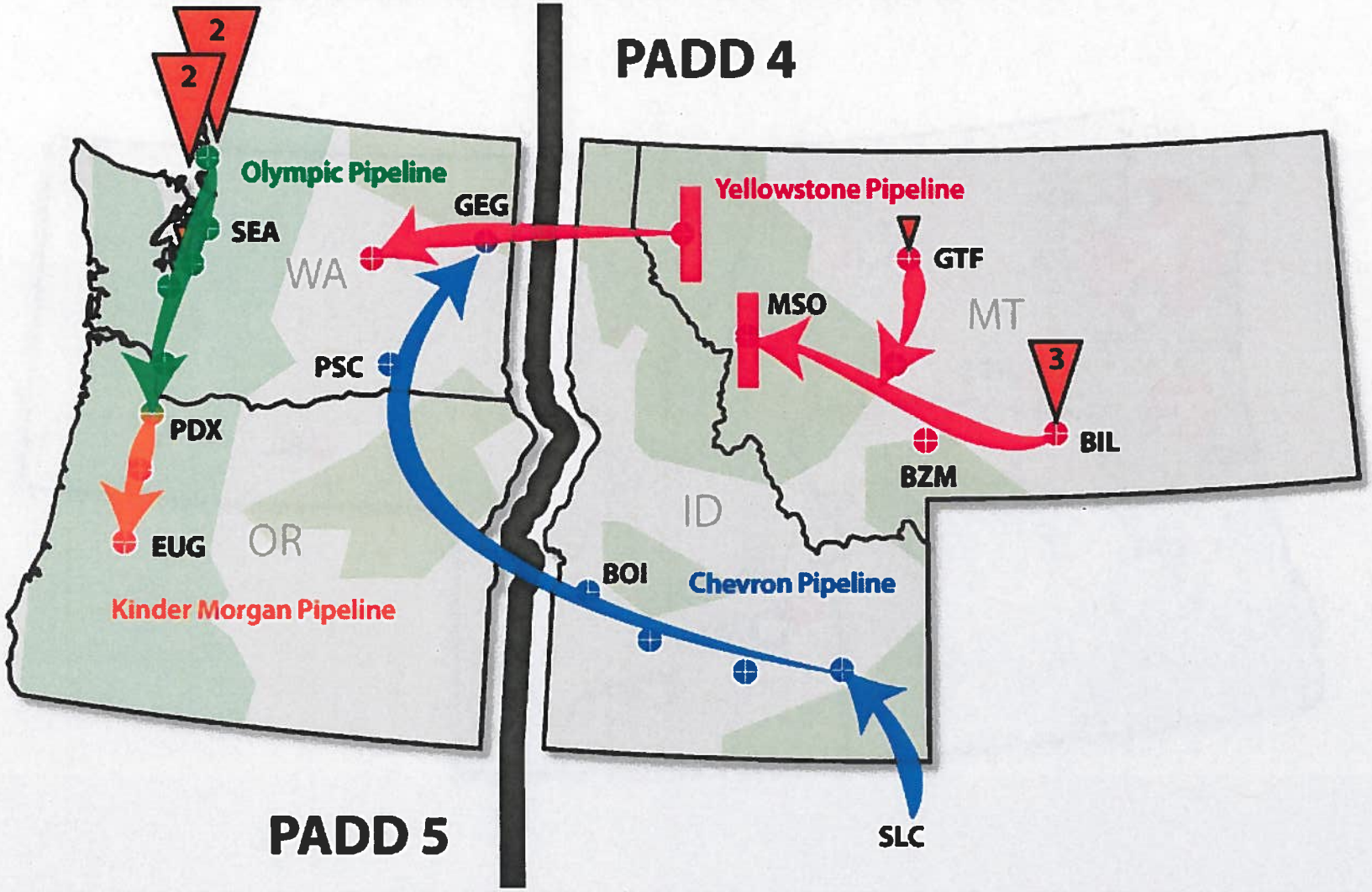


Commercial Jet Fuel Consumption - 2010
Pacific Northwest - 743 million gallons

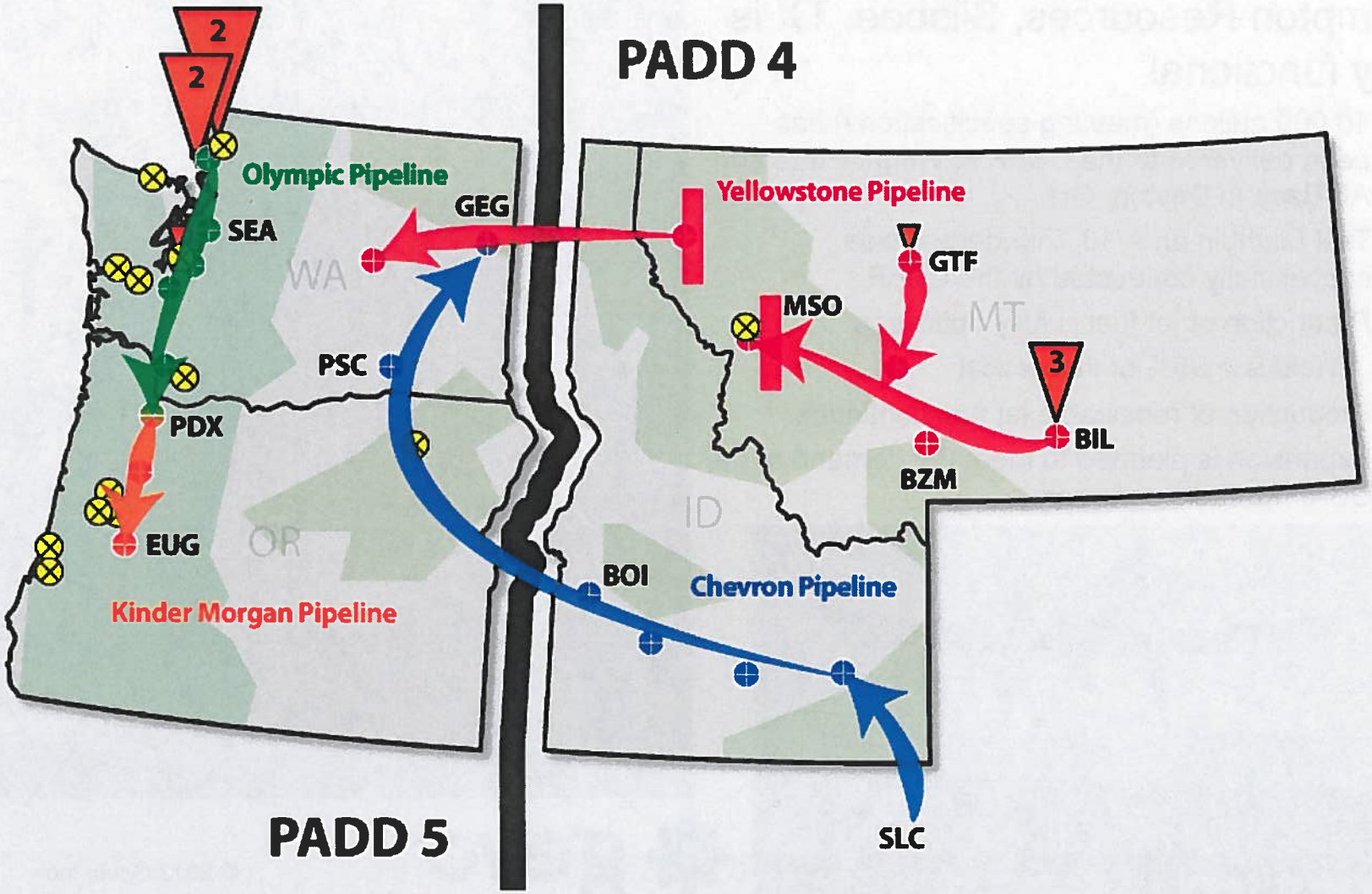
Aviation Fuel Demand Centers



Refined Products Production and Distribution



Dormant and Closed Pulp Mills



Isobutanol to Jet Fuel Demonstration

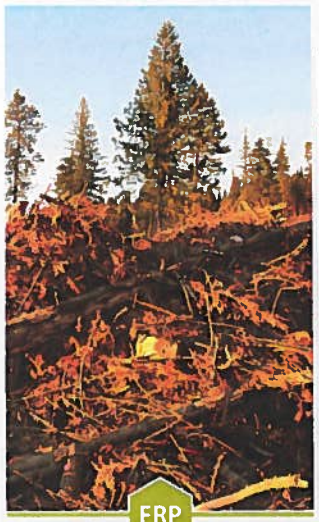
Demonstration unit at South Hampton Resources, Silsbee, TX is fully functional

- 10,000 gallons (meeting specifications) has been delivered to the USAF at Wright-Patterson AF Base in Dayton, OH
- Test Flight in an A-10 Thunderbolt was successfully conducted by the USAF
- Production of jet fuel is fully optimized
  -Yield is > 95% of theoretical
- Production of renewable jet fuel continues
- Expansion is planned to meet the demand of the USAF for fuels certification

gevo®

Our Biomass Feedstock – Forest Residues

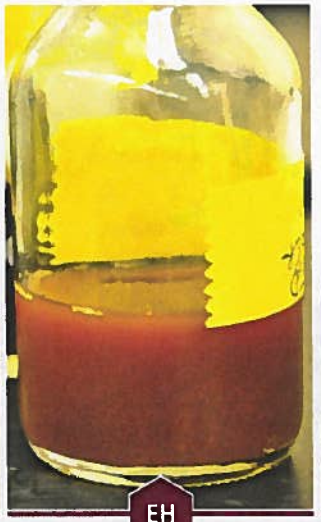
Our Target Feedstock



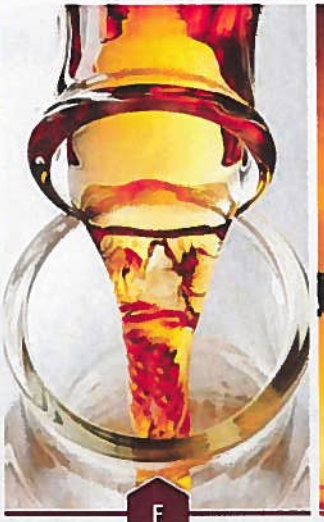
FOREST RESIDUES

TRANSPORTATION

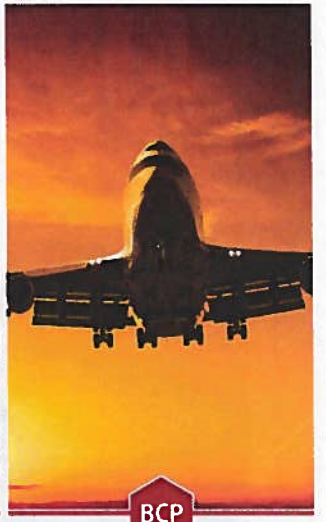
PRE-TREATMENT



ENZYMATIC HYDROLYSIS



FERMENTATION



BIOJET & CO-PRODUCTS

IMPROVEMENTS THROUGHOUT THE SUPPLY CHAIN

NARA
Northwest Advanced Renewables Alliance

SUPPLY CHAIN

FOREST RESIDUES PREPARATION

Primary feedstock targets include forest residues from logging and thinning operations. We are also considering mill residues and discarded woody material from construction and demolition, in regions where these materials are under utilized.

TRANSPORTATION

Feedstocks are transported from the collection site to a conversion facility. Chipping can take place at the loading or in a preprocessing facility.

PRE-TREATMENT

Wood chips are treated to make the sugar polymers (polysaccharides) accessible to degrading enzymes. These processes allow the lignin to be available for separation.

ENZYMATIC HYDROLYSIS

Specific enzymes are added to hydrolyze (cleave) the polysaccharides and generate simple sugars (monosaccharides).

FERMENTATION

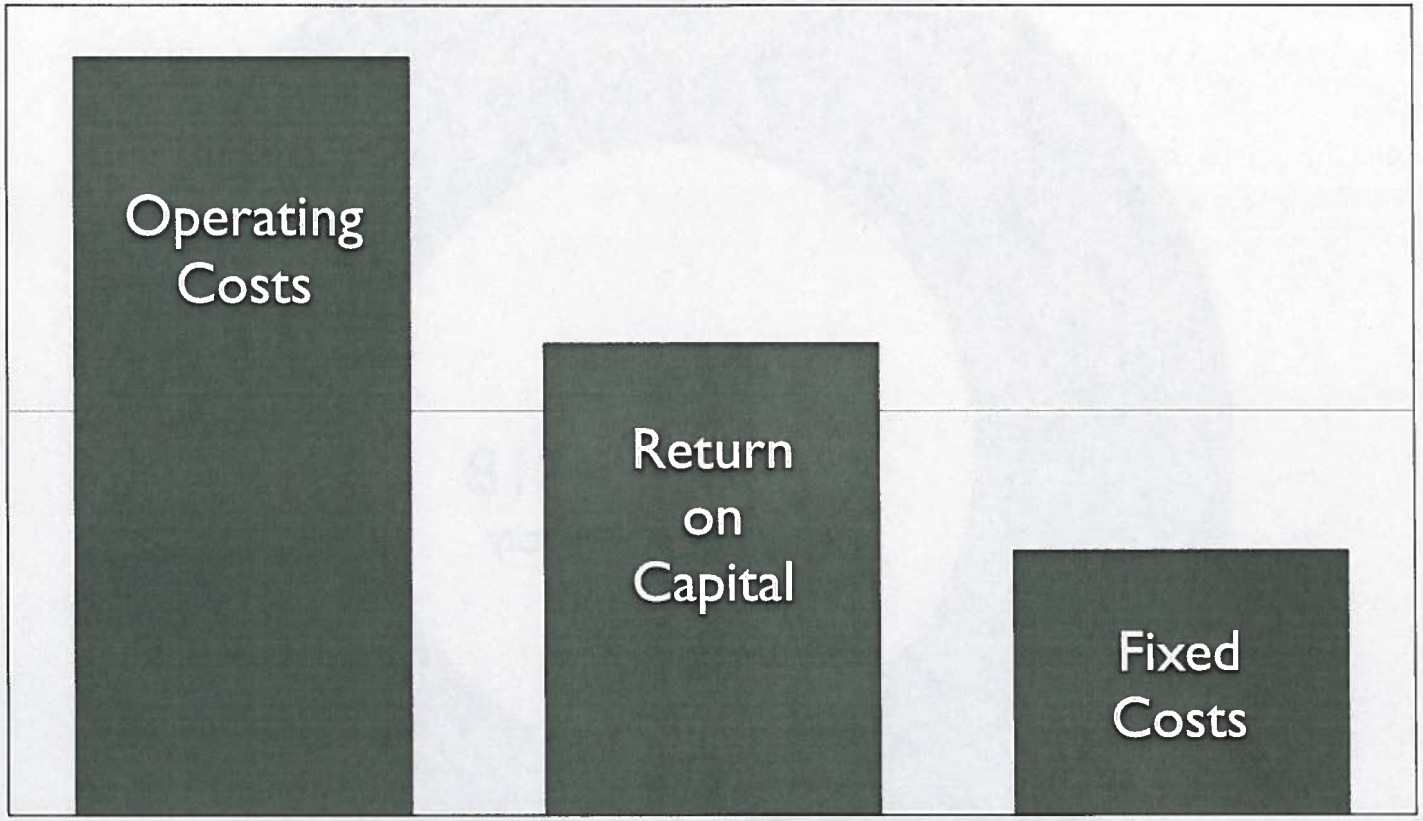
Specialized yeast convert the monosaccharides into isobutanol.

BIOJET & CO-PRODUCTS

Aviation fuels can be generated from the platform molecules derived from wood sugars. Lignin can be used to generate co-products such as epoxies, structural materials and bio-based plastics. As an alternative, lignin can be burned to produce renewable energy.

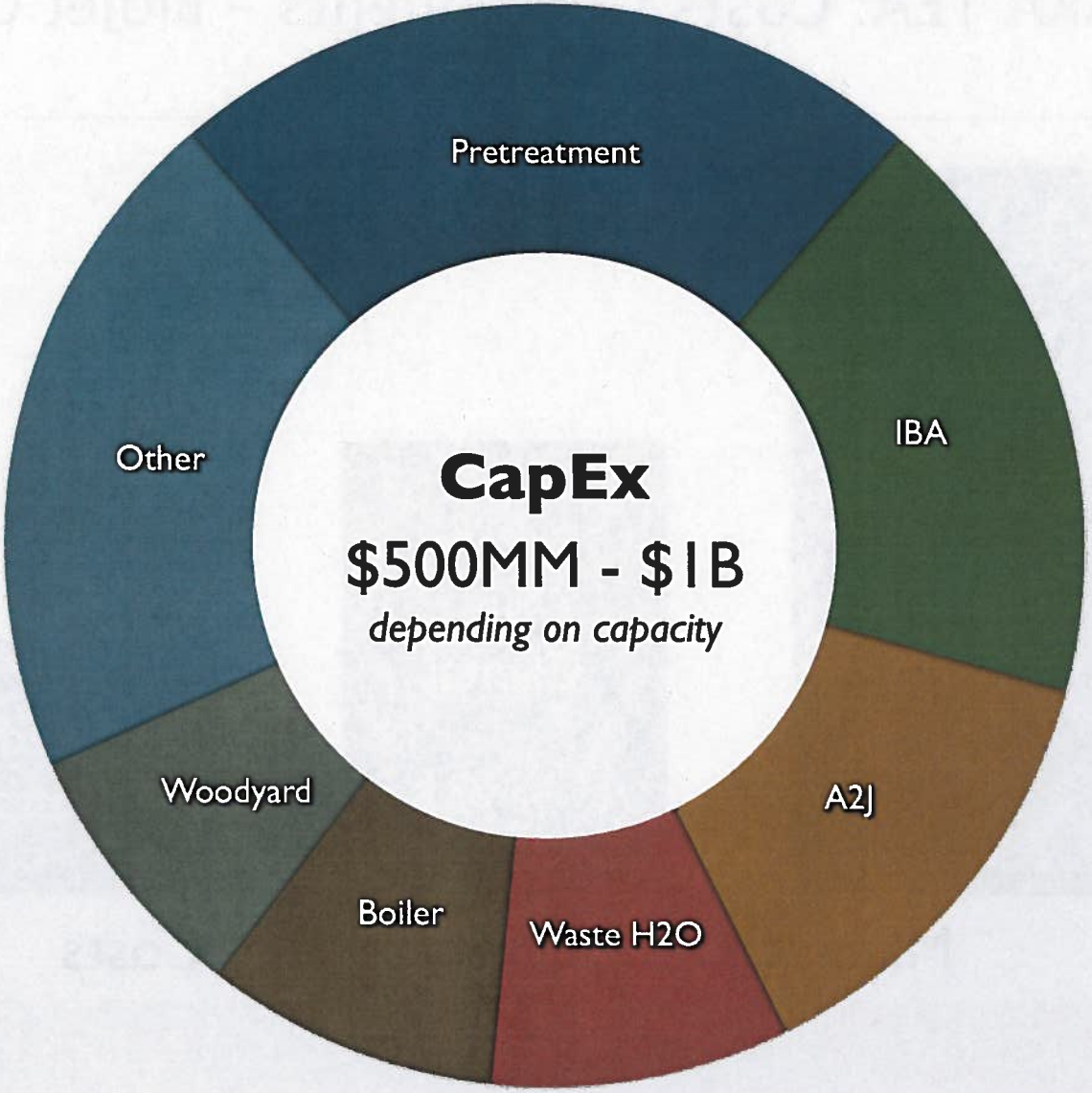
ONE BONE DRY **TON** WOODY BIOMASS + DIESEL + HEAT, WATER, & CHEMICALS = **~600** **POUNDS** LIGNIN AND **~59** **GALLONS** ISOBUTANOL OR **~42** **GALLONS** BIOJET

NARA TEA: Costs Components – BioJet ONLY



Major Contributions to Fuel Costs

NARA TEA Status: CapEx



DEVELOPMENT SITES: Suitability Criteria

GREENFIELDS

Non-industrial sites

Wildlife habitats

Agricultural land

Resource land

Ecological value

GRAYFIELDS

Existing industrial sites

No assumed contamination

Community blight

BROWNFIELDS

Existing industrial sites

Real or perceived contamination

Community blight

Human health hazard

Owner liability

Valuable and attractive locations

DEVELOPMENT SITES: Existing Assets

SITE

Location, Infrastructure

Environmental permitting

EQUIPMENT

Operating Companies

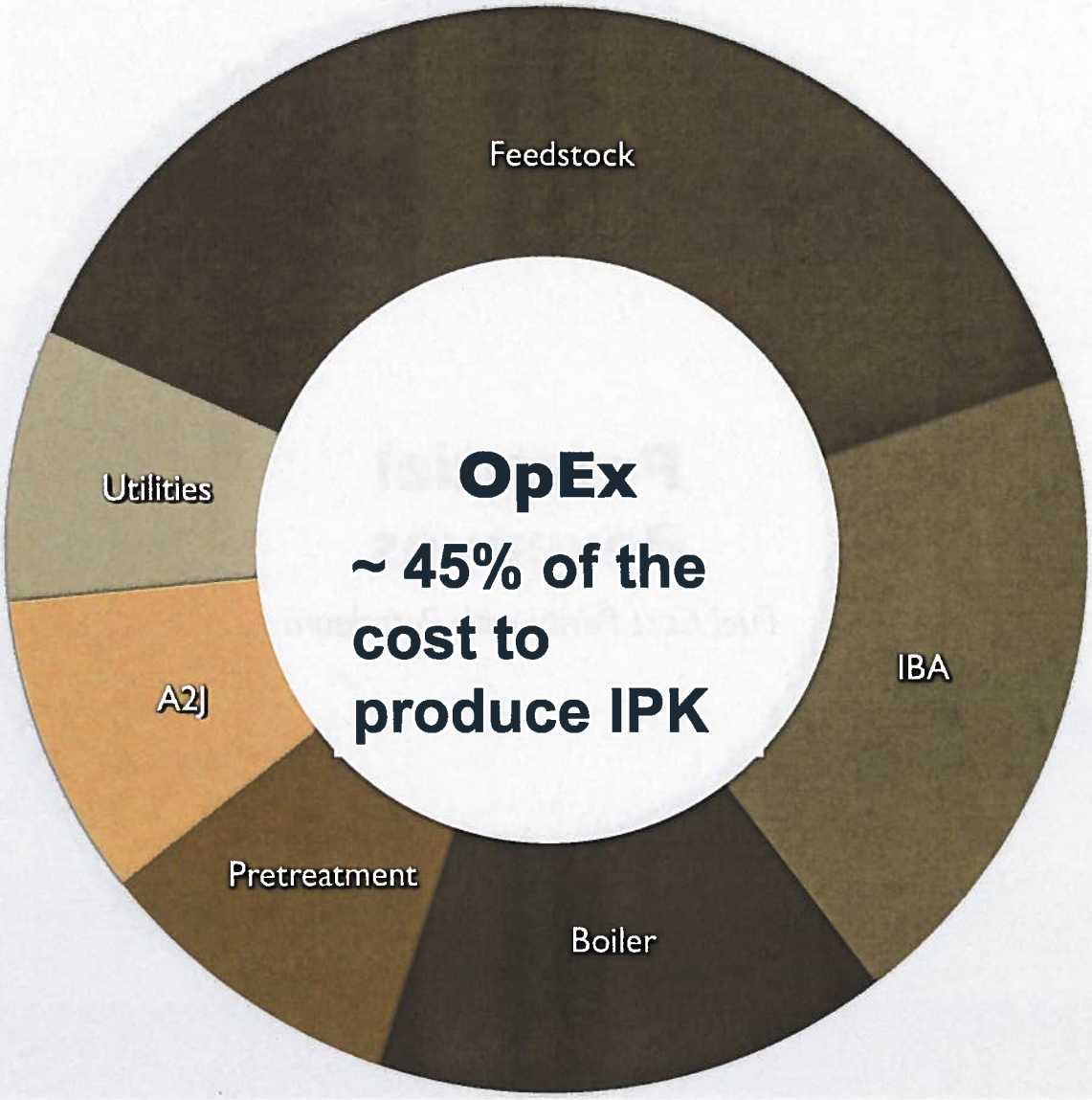
Infrastructure

COMMUNITY

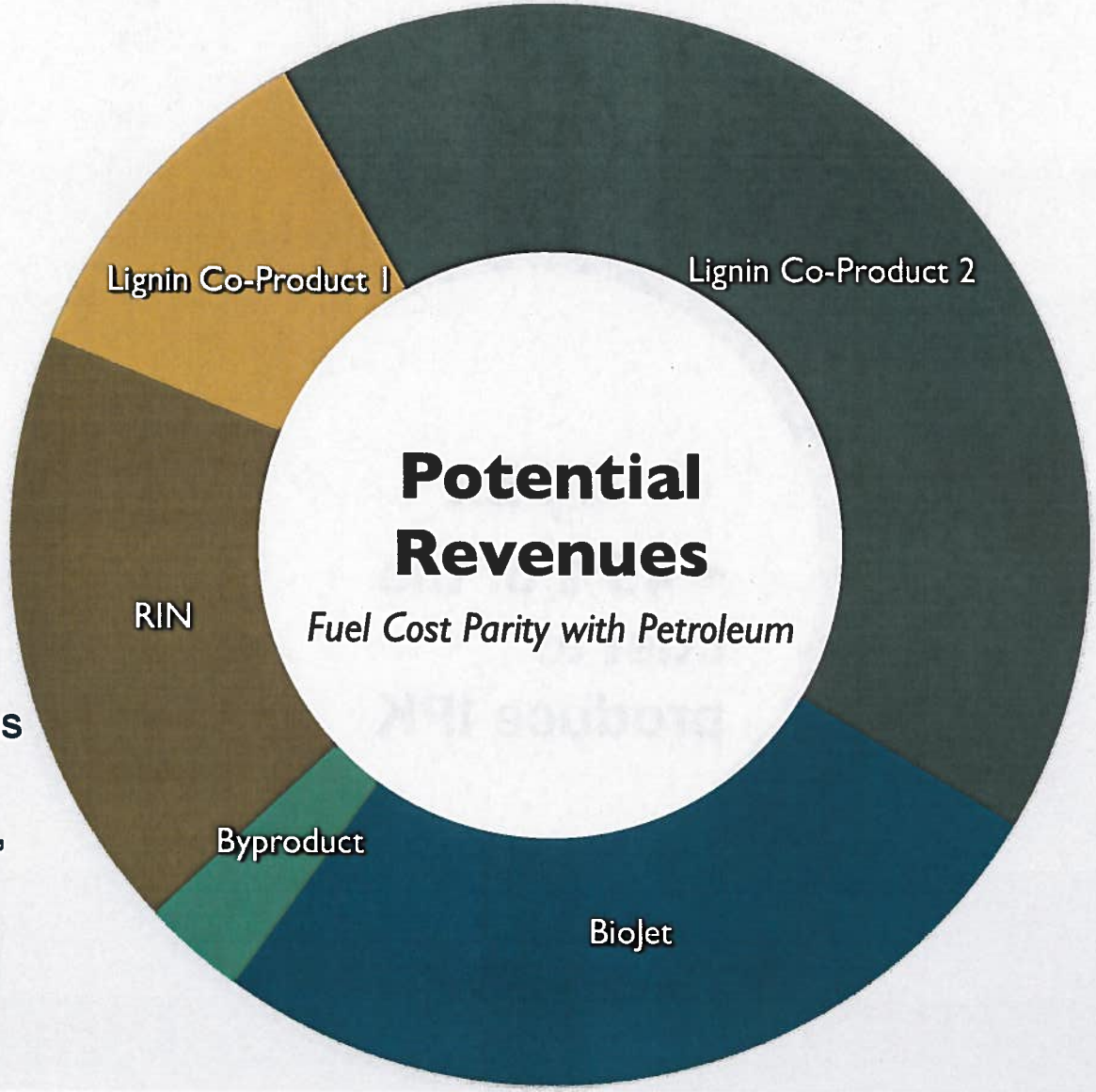
Workforce housing

Cultural and public buildings

NARA TEA Status: OpEx



ONE Potential Co-Products Scenario



Products, such as lignosulfonates, activated carbon, ethanol, iso-octane, etc. can enhance the revenue stream

What's Ahead for NARA?

Years 4 and 5 (project ends July 31, 2016) – Deliver 1000 gallons of biojet fuel and stand up a supply chain (desired)

- Continue to optimize the technical pathway
  - Reduce CapEX
  - Reduce OpEx
  - Focus on high value and volume co-products

- Continue to optimize the logistical pathway
  - Further develop and evaluate depot models
    - Transportation alternatives
    - Size reduction alternatives

- Continue educational programming
  - K-12 curricula development
  - High school and undergraduate research opportunities
  - Graduate education opportunities
  - Public engagement and education (Extension)

ASCENT - FAA Center of Excellence for Alternative Jet Fuels and the Environment

Ralph Cavalieri, Director
Washington State University

R. John Hansman, Co-Director
Massachusetts Institute of Technology

ASCENT
AVIATION SUSTAINABILITY CENTER

FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Scope of Work: Meeting Environmental and Energy Challenges Confronting Aviation

Scope of Work: Meeting Environmental and Energy Challenges Confronting Aviation

- Better scientific understanding and improved tools for integrated environmental analysis
- Mature new aircraft technologies
- Advance development of alternative aviation fuels
- Explore and demonstrate clean, quiet, and energy efficient operational procedures
- Policies, environmental standards, market based measures, and environmental management system

- **Alternative Jet Fuels**

3.1.1. Feedstock Development, Processing and Conversion

3.1.2. Regional Supply and Refining Infrastructure

3.1.3. Environmental Benefits Analysis

3.1.4. Aircraft Component Deterioration and Wear

3.1.5. Fuel Performance Testing

- **Environmental**

3.1.6. Aircraft Noise and Impacts

3.1.7. Aviation Emissions and Impacts

3.1.8. Aircraft Technology Assessment

3.1.9. Energy Efficient Gate-to-Gate Aircraft Operations

3.1.10. Aviation Modeling and Analysis

Overview of Award

FAA Center of Excellence for Alternative Jet Fuels and Environment

- Award announced September 13, 2013
- The COE is a partnership among 16 universities that will engage other universities, commercial firms, and government laboratories to conduct research and education.
- Cooperative Agreements have been placed with each of the university partners.
- Duration: Five years; renewable once (ten year total)
- Funding: At least $4 million annually from FAA plus; 100% cost share requirement

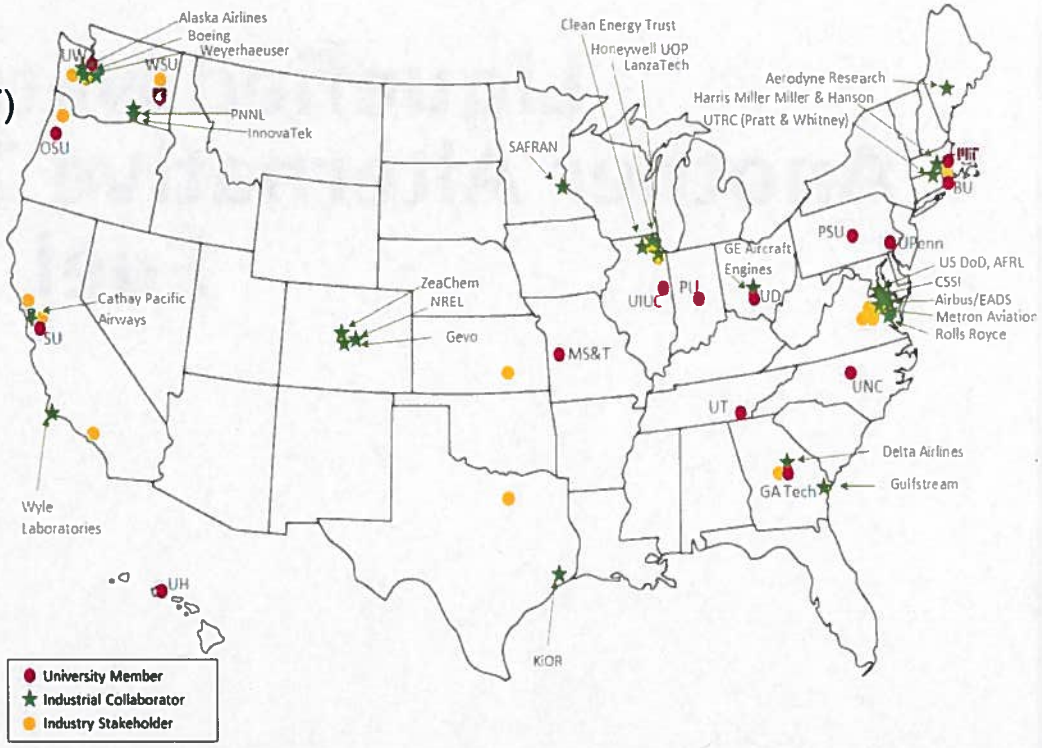
ASCENT Team

Lead Universities:

- Washington State University (WSU)*
- Massachusetts Institute of Technology (MIT)

Core Universities:

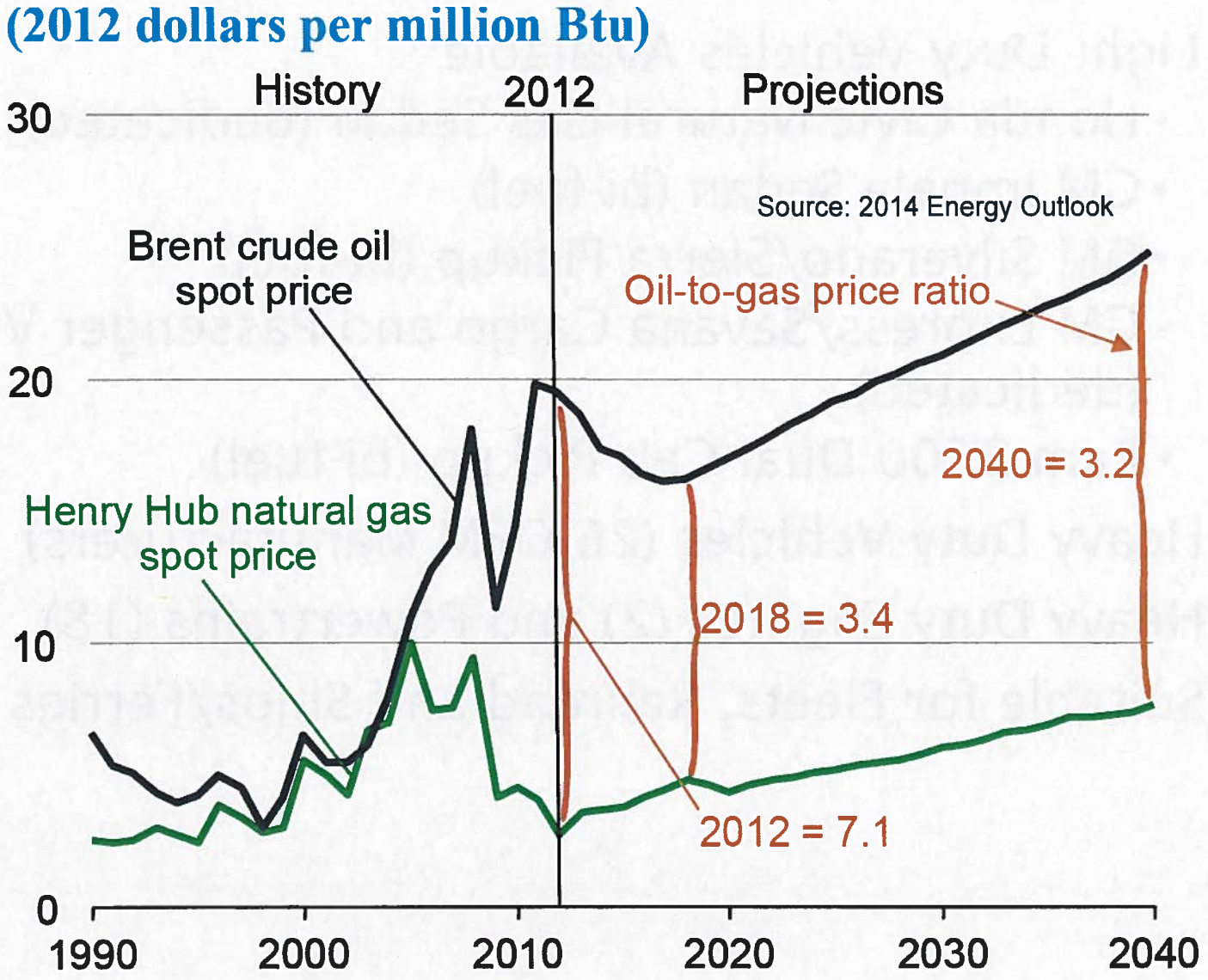
- Boston University (BU)
- Georgia Institute of Technology (Ga Tech)
- Missouri University of Science and Technology (MS&T)
- Oregon State University (OSU)*
- Pennsylvania State University (PSU)*
- Purdue University (PU)*
- Stanford University (SU)
- University of Dayton (UD)
- University of Hawaii (UH)*
- University of Illinois at Urbana-Champaign (UIUC)*
- University of North Carolina at Chapel Hill (UNC)
- University of Pennsylvania (UPenn)
- University of Tennessee (UT)*
- University of Washington (UW)*



* Denotes USDA NIFA AFRI-CAP Leads and Participants & Sun Grant Schools

Liquefied Natural Gas Another Alternative Transportation Fuel

Natural Gas Price Differential

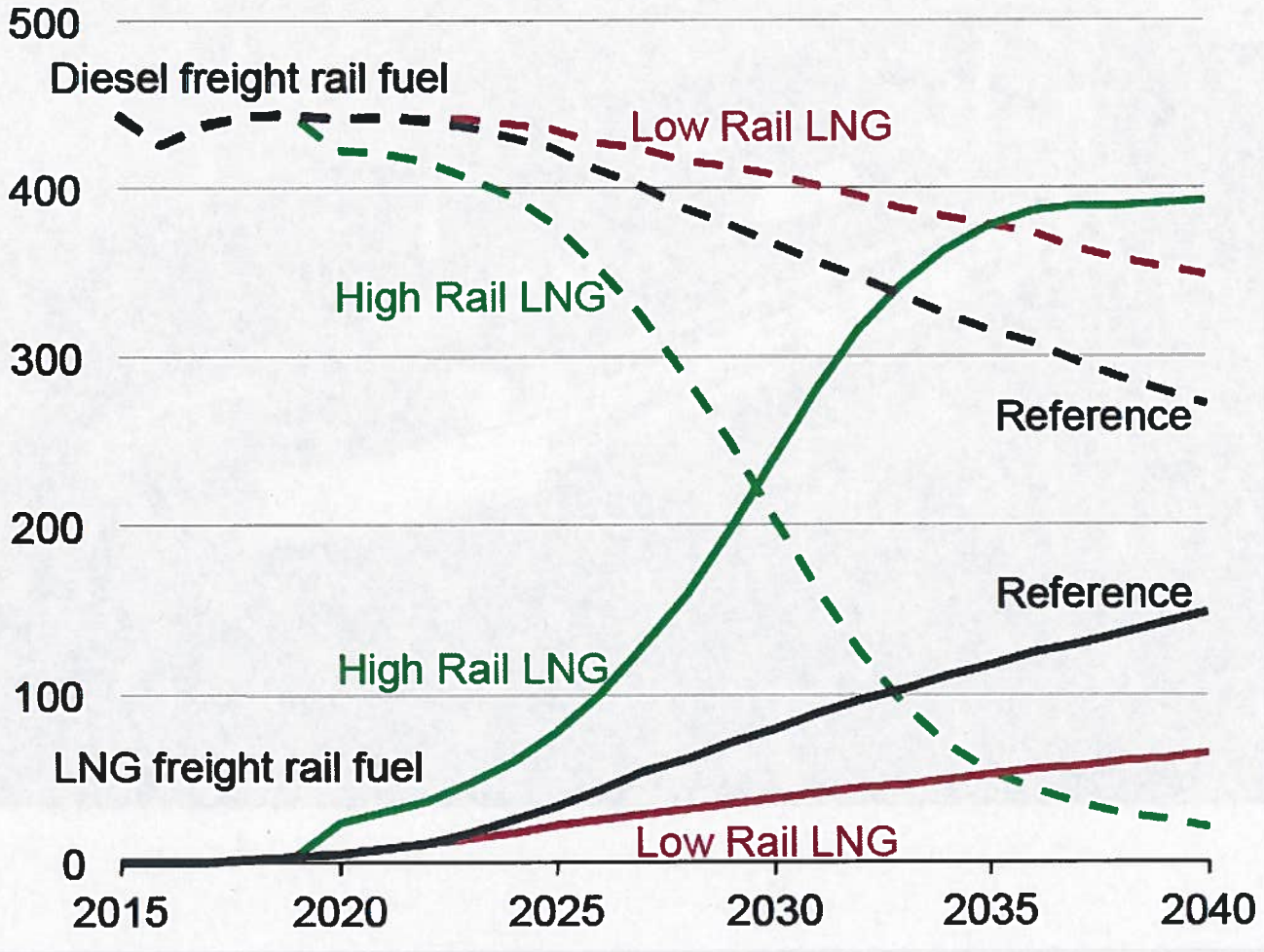


Liquefied Natural Gas Vehicles

- Light Duty Vehicles Available
  - Honda Civic Natural Gas Sedan (dedicated)
  - GM Impala Sedan (bi-fuel)
  - GM Silverado/Sierra Pickup (bi-fuel)
  - GM Express/Savana Cargo and Passenger Vans (dedicated)
  - Ram 2500 Dual-Cab Pickup (bi-fuel)
- Heavy Duty Vehicles (26 OEM Manufacturers)
- Heavy Duty Engines (2) and Powertrains (18)
- Suitable for Fleets, Railroad and Ships/Ferries

The Future for LNG in Railroad

An In-depth Study by Energy Information Agency



Washington State Ferries LNG Project