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SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

The Future of Transportation Fuels Demand, Supply, and Environmental Challenges

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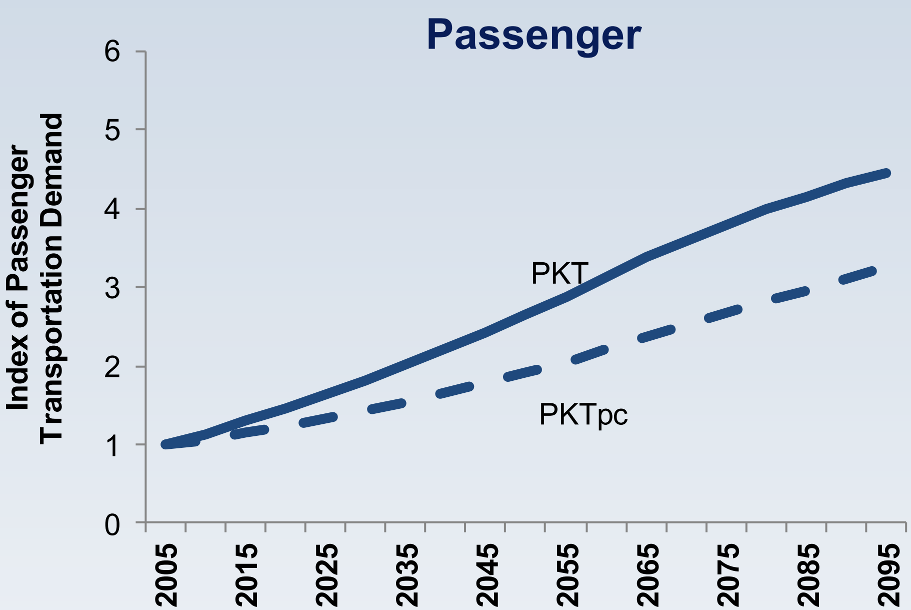
Outlines

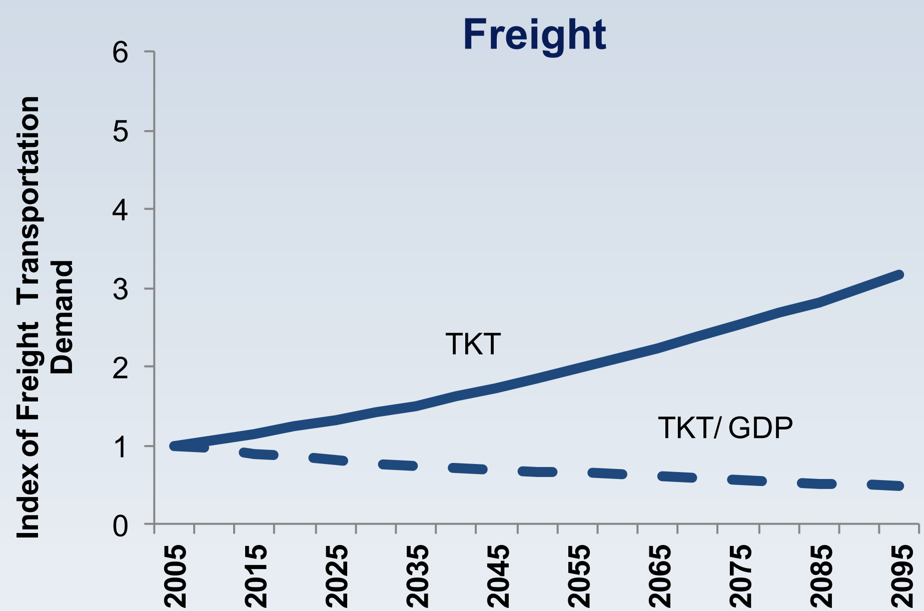
- The future of transportation fuels demand
- Technical and economic promises and challenges of alternative fuels
- Environmental impacts of alterative fuels
- The role of policies

Global Transportation Projections

- Global transportation service demand will grow substantially over the next century
  - Passenger transportation will shift to faster modes – in continuation of a trend already witnessed in many countries
  - Passenger transportation will shift to larger personal cars and light trucks
- Energy intensity (EI) of passenger travel and freight transportation will rise for developing countries and remain flat globally
- Total energy consumption by the global transportation sector grows from **91** EJ in 2005 to **317** EJ in 2100, increases GHG emissions from **6.9** to **19.2** MMT CO_2e with no climate policy, or **222** EJ and **8.3** MMT CO_2e with climate abatement.

(1) Global transportation service demand will grow substantially over the next century





TOTAL PKT	2005: 55 Trillion	2100: 250 Trillion	2005: 90 Trillion	2100: 290 Trillion	**TOTAL TKT**
KM / person / year	2005: 8,000	2100: 28,000	2005: 1,600	2100: 800	**TKT / 1000 $ GDP**

Same as level in the U.S. today

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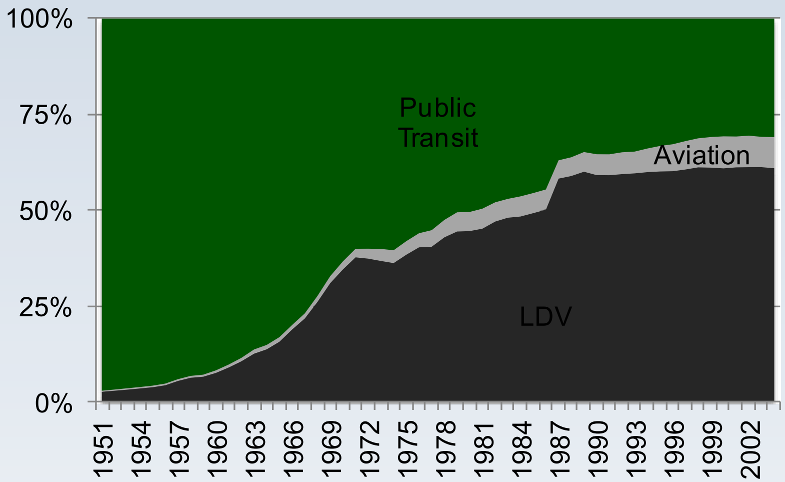
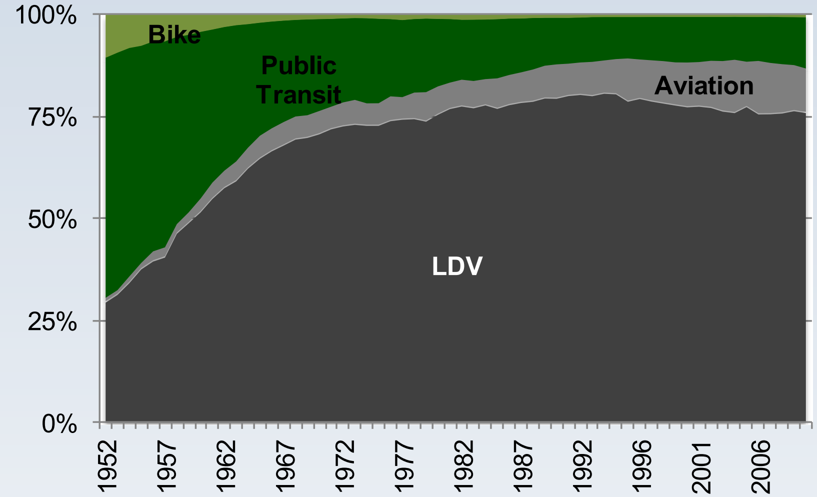
(2a) Passenger transportation will shift to faster modes – in continuation of a trend already witnessed in many countries (1/2)

Historical evolution of passenger transportation (PKT; ~1950 – ~2005)

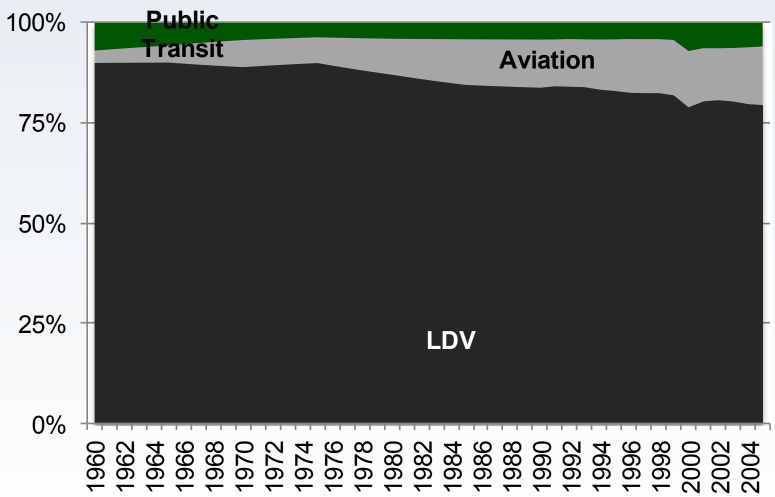
JAPAN



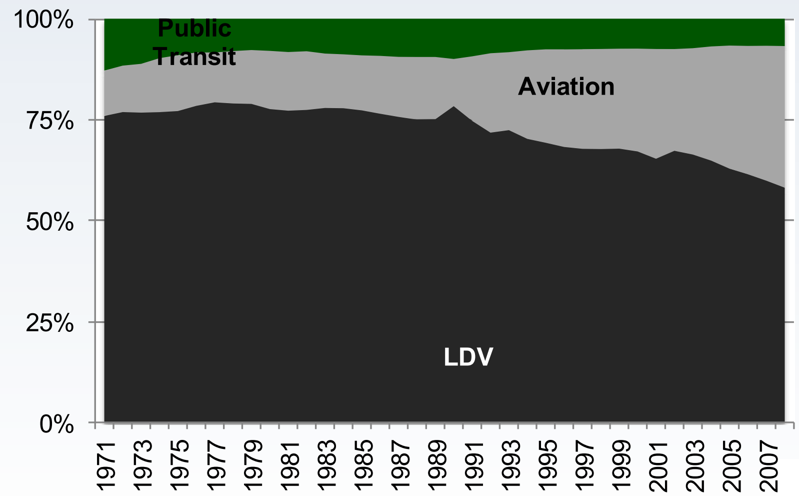
UK



USA



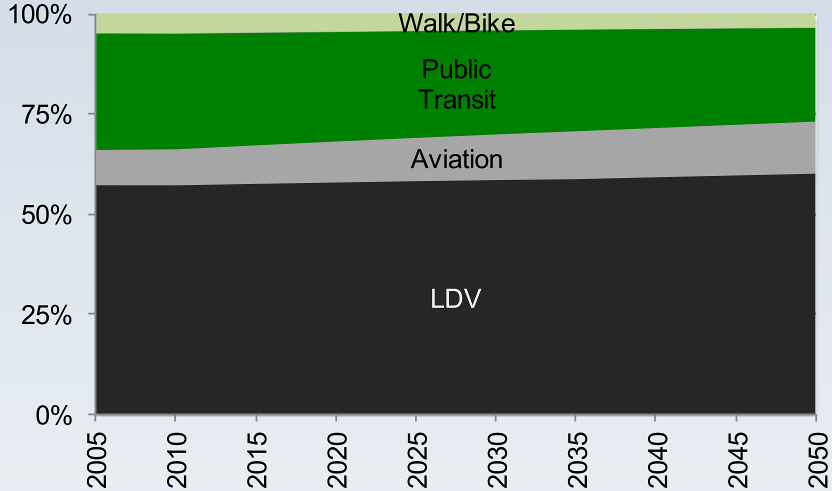
AUSTRALIA



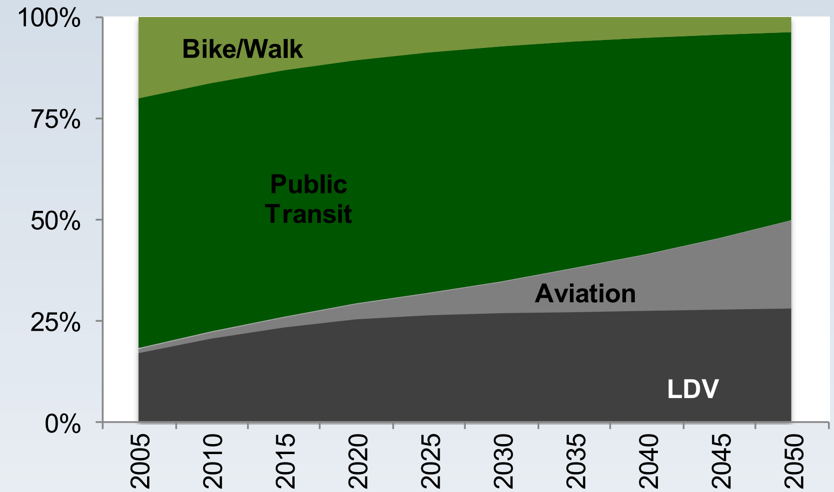
(2a) Passenger transportation will shift to faster modes – in continuation of a trend already witnessed in many countries (2/2)

Estimates of evolution of passenger transportation (PKT; 2005 – 2050)

JAPAN



INDIA



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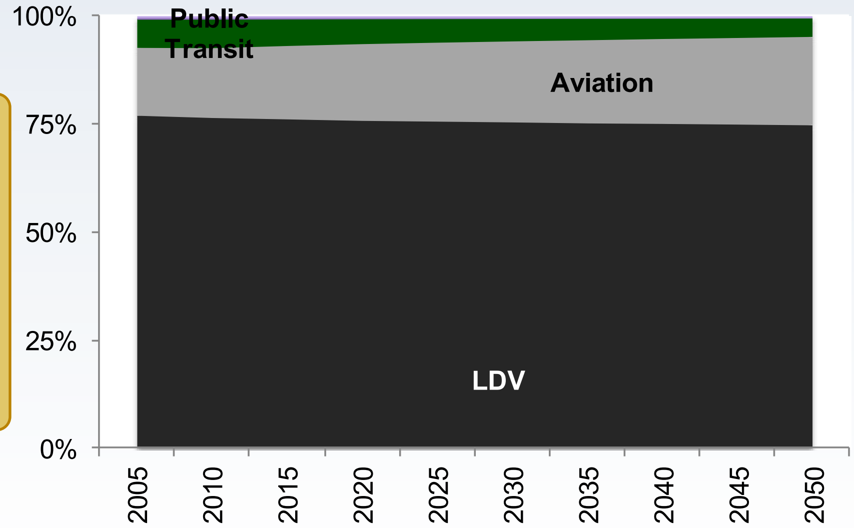
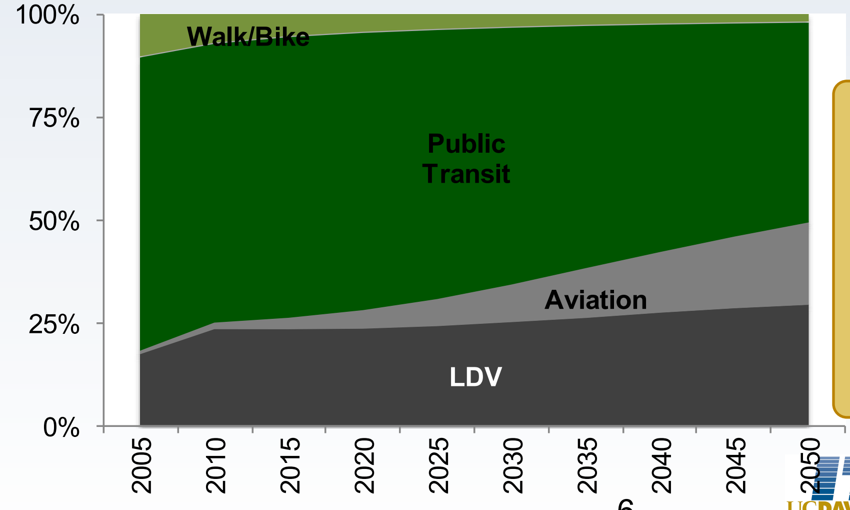


CHINA



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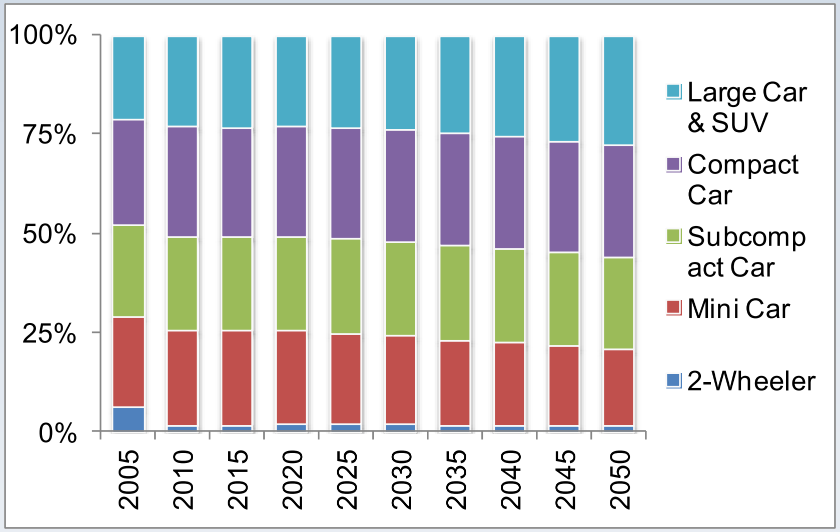
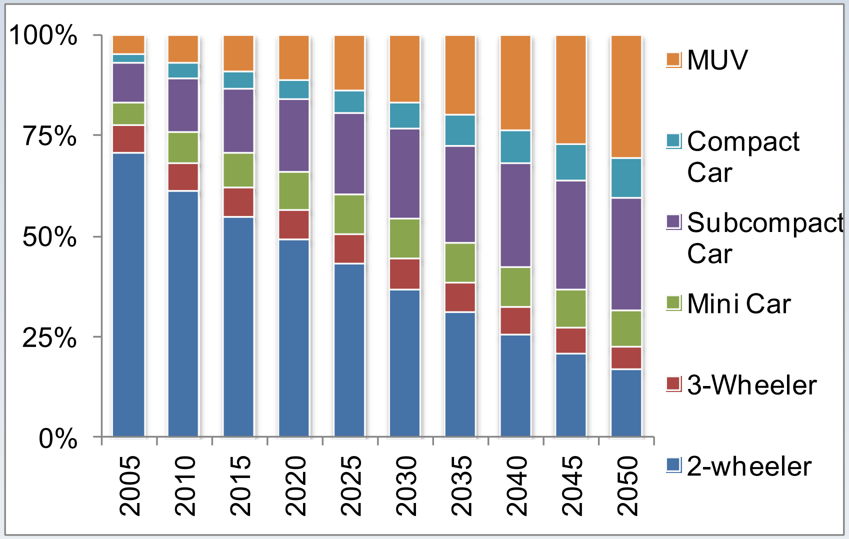
(2b) … and to larger personal cars and light trucks

Share of various size classes within the LDV sector (2005 – 2050)

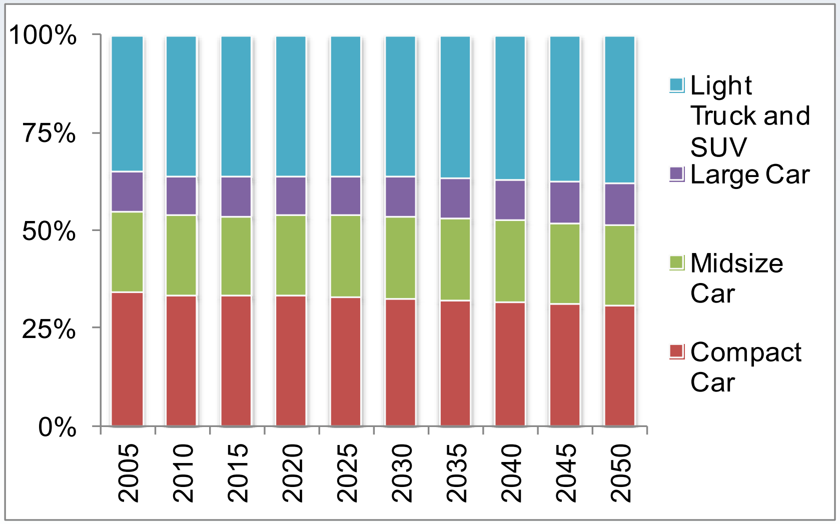
JAPAN

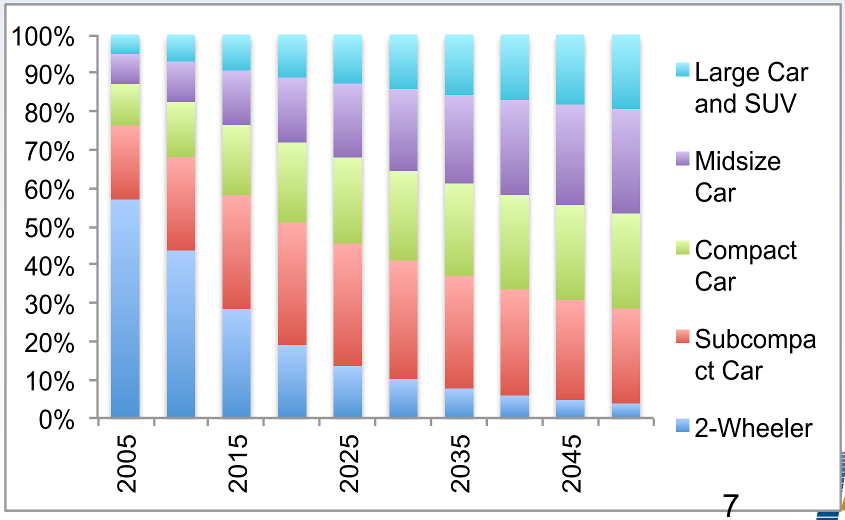




INDIA

USA





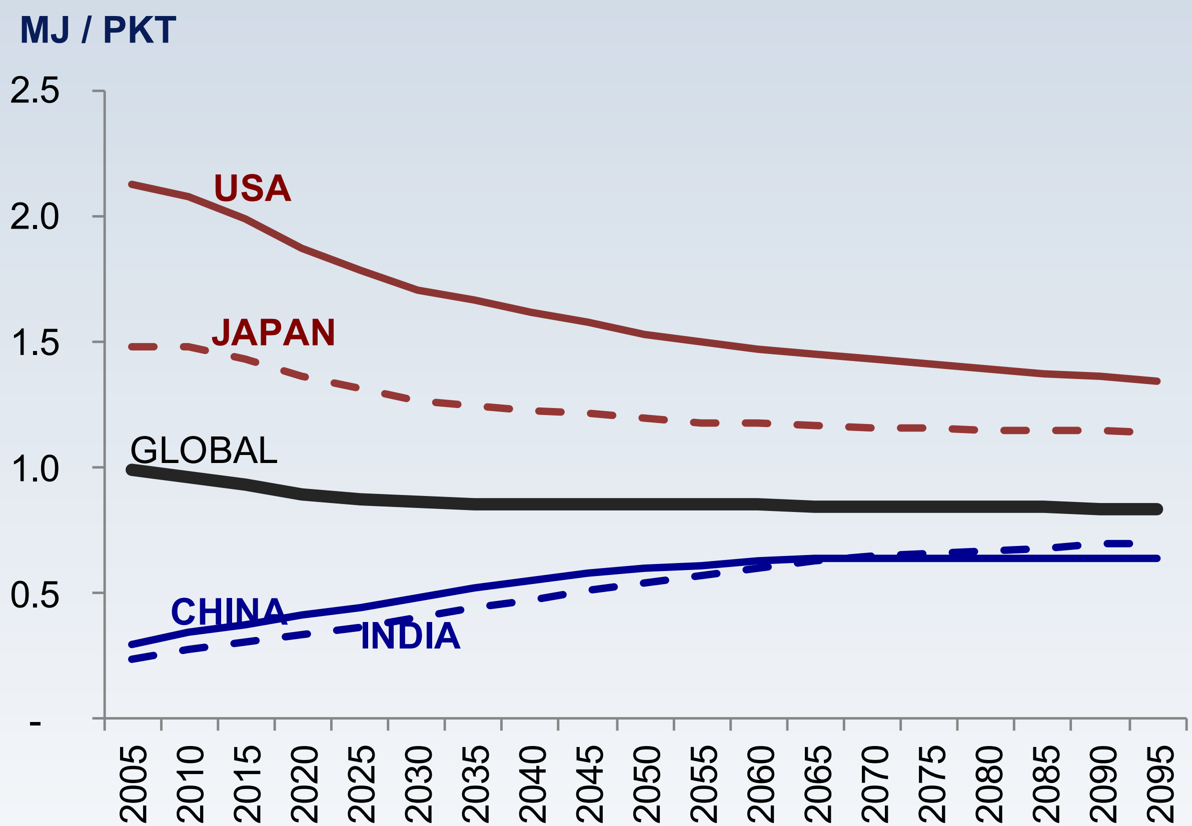
CHINA

(3) As a result, the energy intensity of passenger travel will rise for developing countries and remain flat globally

1. Technological progress
2. Penetration of BEVs and FCEVs

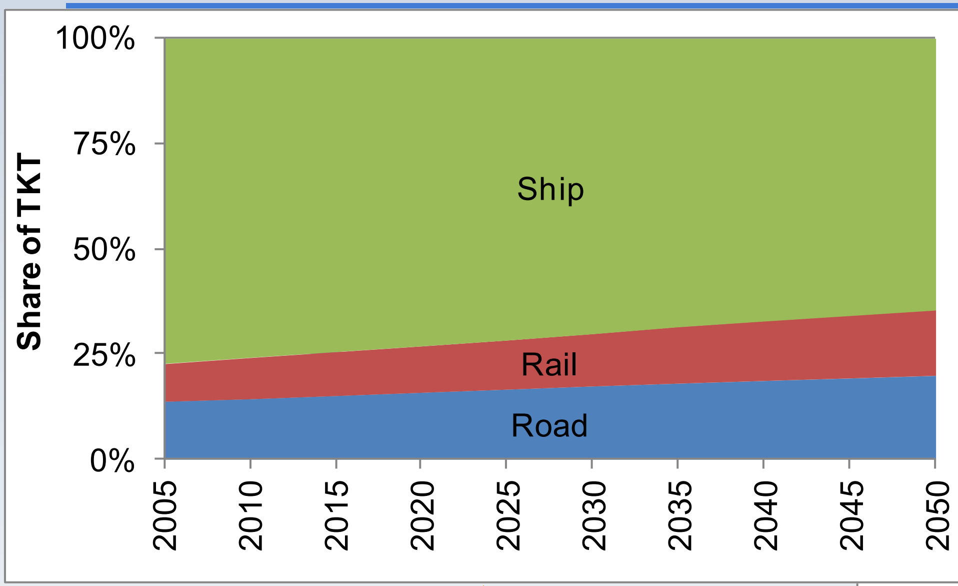
EI

1. Lower share of public modes – buses and trains
2. Higher share of aviation and LDVs
3. Upsizing of LDVs

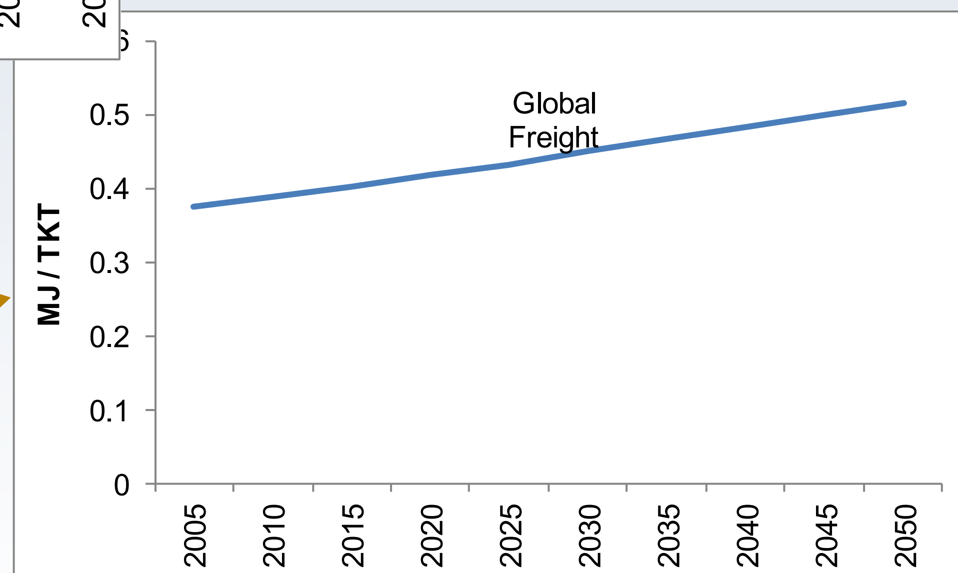


Globally, EI stabilizes at 0.9 MJ/PKT

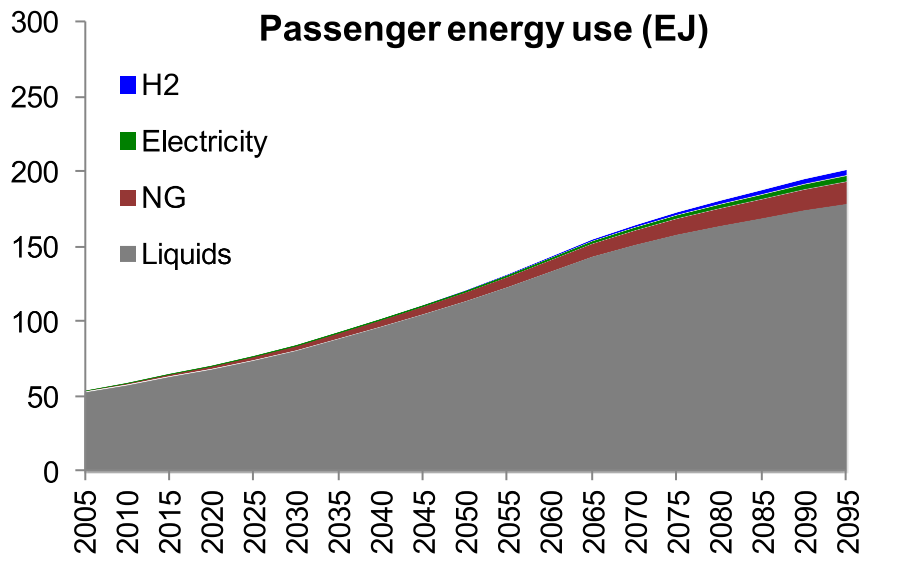
(4) Similarly in freight transportation, rising share of road (trucking) will increase the overall energy intensity

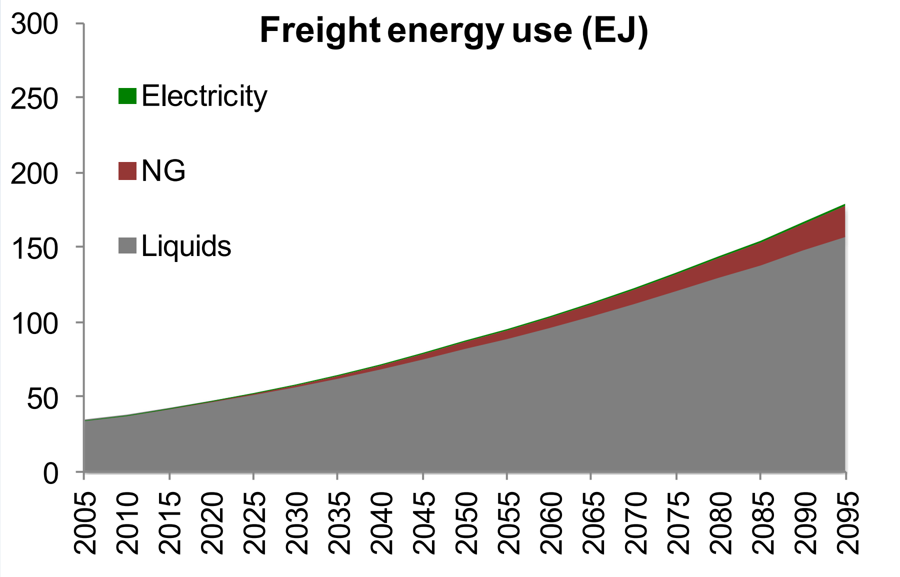


Note: This includes international shipping



(5) Total energy consumption by the global transportation sector grows from 85 EJ in 2005 to 380 EJ in 2100





Transportation Energy consumption grew at ~2.5% historically; versus 1.8% estimated above

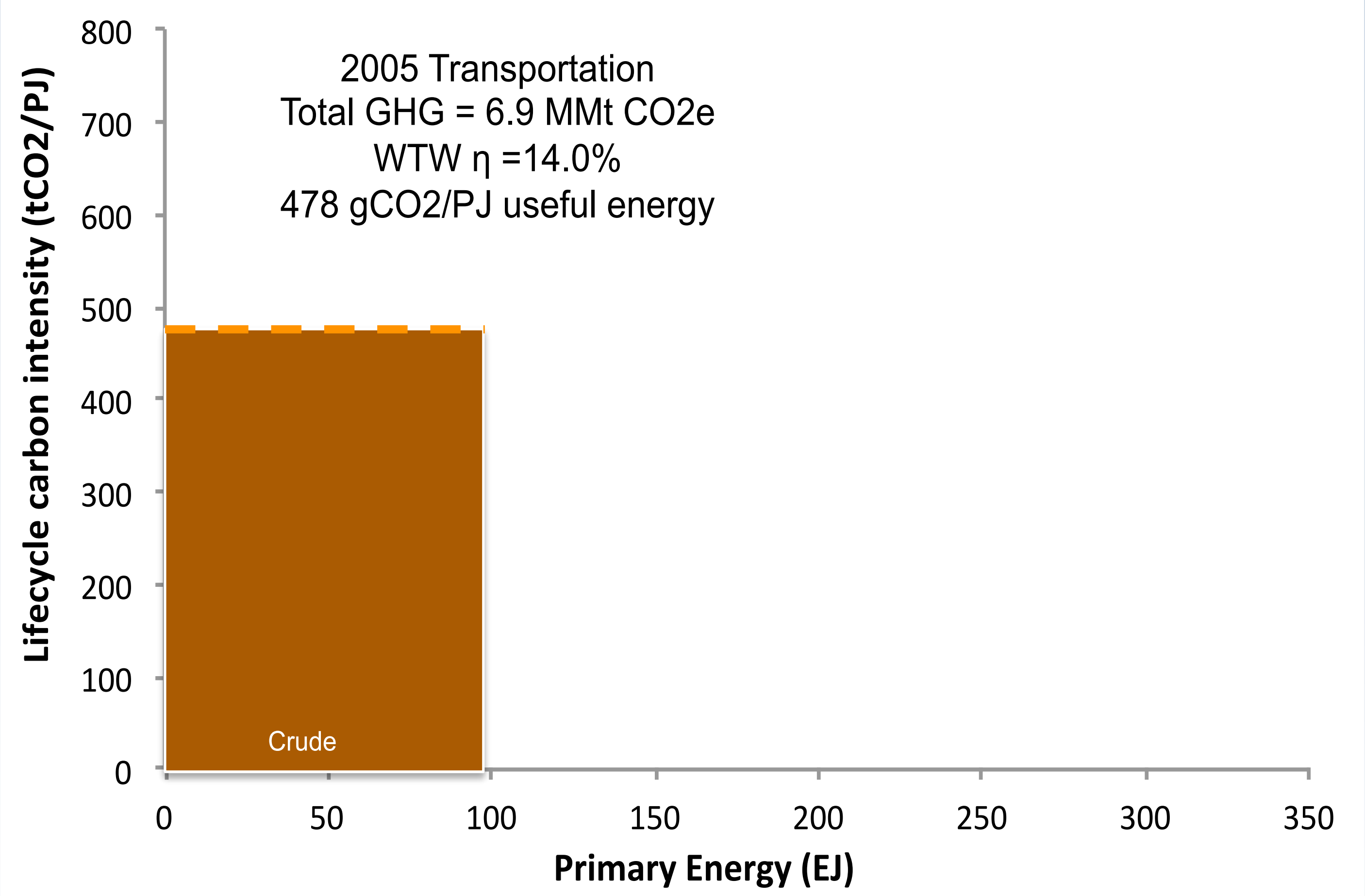
Passenger: 50 EJ → 200 EJ

Freight: 35 EJ → 180 EJ

Summary of trends (passenger only)

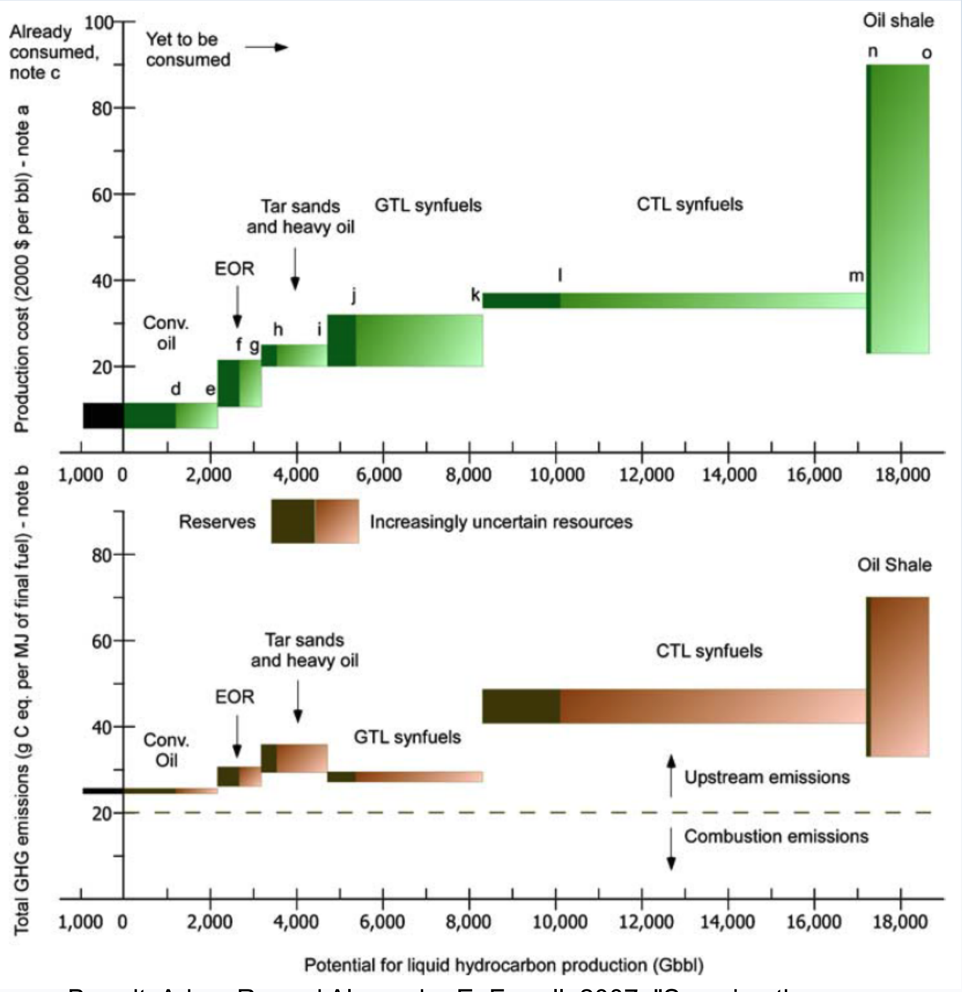
Global transportation demand will rise to the levels observed in the U.S. today (somewhat higher)	2005: 2050: 2100:	8,000 PKT /person /year 16,000 28,000
Aviation and private cars will have the dominant market share	2005: 2005: 2100:	54% 67% 80%
Global average EI in 2100 will be only marginally lower than 2005 level despite large tech. improvements	2005: 2050: 2100:	1.00 MJ/PKT 0.85 0.85

Transportation Sector is Almost Entirely Based on Crude Today



Notes: Source: Yeh, Sonia, Gouri Shankar Mishra, Geoff Morrison, Jacob Teter, Raul Quiceno, and Kenneth Gillingham. 2012. "Effects of structural change and climate policy on long-term shifts in lifecycle energy efficiency and carbon footprint." Manuscript.

Without Policy, Share of Carbon Intensive Liquid Fuels is increasing



Brandt, Adam R., and Alexander E. Farrell. 2007. "Scraping the bottom of the barrel: greenhouse gas emission consequences of a transition to low-quality and synthetic petroleum resources." Climatic Change no. 84:241-263. doi: DOI 10.1007/s10584-007-9275-y.

- Annual global oil & gas capital expenditure to pass $1-trillion mark in 2012
- Our projected *cumulative* transportation fuel use 2005-2100 is on the order of 5,000 EJ.
- 18,000 Gbbl (shown on the figures) is ~110,000 EJ.

Urgency in Addressing Transportation Energy Challenges

- Energy security
  - Oil imports cause huge economic losses
  - 2/3 of oil used for transportation (in US)
  - High and volatile fuel prices affect business and consumers
- Climate change
  - 1/3 of GHG emissions are from transportation
- Other environmental impacts: air quality, land use, water quality, etc.

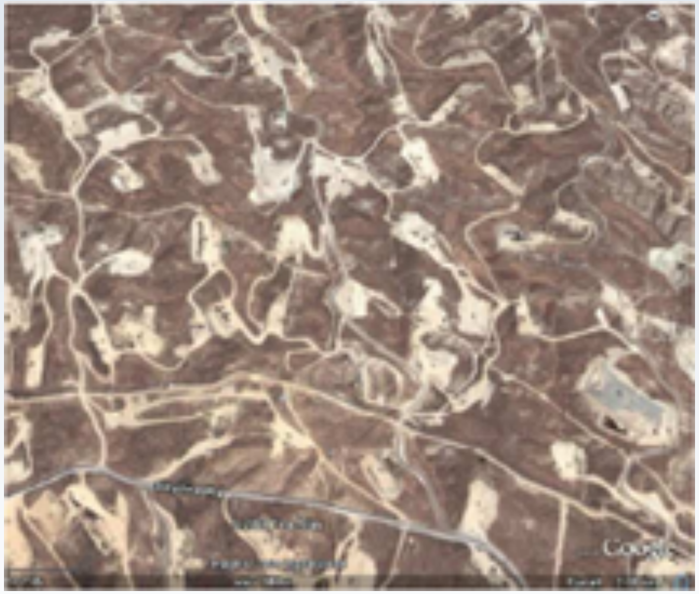
Fossil Fuel and Biofuel Land Disturbance

- Biofuels, if produced from carbon-rich land (e.g. tropical forest), will have very large negative greenhouse gas (GHG) benefits
- Land use impacts of oil and gas development can be non-trivial and permanent: habitat loss, fragmentation, and ecological and environmental impacts

Land Use Disturbance of Conventional Oil Production

- Conventional oil wells
  - Construction materials, infrastructure of roads, pipelines, power plants, processing facilities, loading docks, dormitories, airstrips, gravel pits, utility lines, as well as environmental facilities such as retention/settling ponds, landfills, brine water disposal, and fuel gas collector

California



Alberta

Images extracted from Google Earth and attributed to Telemetrics, TeleAtlas and Digital Globe 2009

Land Use Intensity of Oil Sands Production

- Boundary includes oil sands production and transport, upgrading, as well as upstream natural gas production and transport (sensitivity analysis)
- Land use disturbance
  - Surface mining: mine sites, overburden storage, tailings ponds, and end pit lakes

Surface mining

In situ

Source: Jordaan, Sarah M., David W. Keith, and Brad Stelfox. 2009. Quantifying land use of oil sands production: a life cycle perspective. *Environmental Research Letters 4 (2):024004*.

Tailings Ponds CH_4 Emissions

- Bitumen is recovered from the mined oil sands by a causic, hot water extraction process. Large amount of waste water is produced in the process.
- Tailings water delivered to settling facility and formed the mature fine tailings (MFT), which may take decades to a century to settle
- Tailings pond CH_4 emissions have been reported in all major mature fine tailings (MFT) sites in Northern Alberta.
- Reported daily flux of 10^8 L CH_4/day or 26,000 tons CH_4/yr at MLSB

Methane bubbles at Mildred Lake Settling Basin (MLSB)

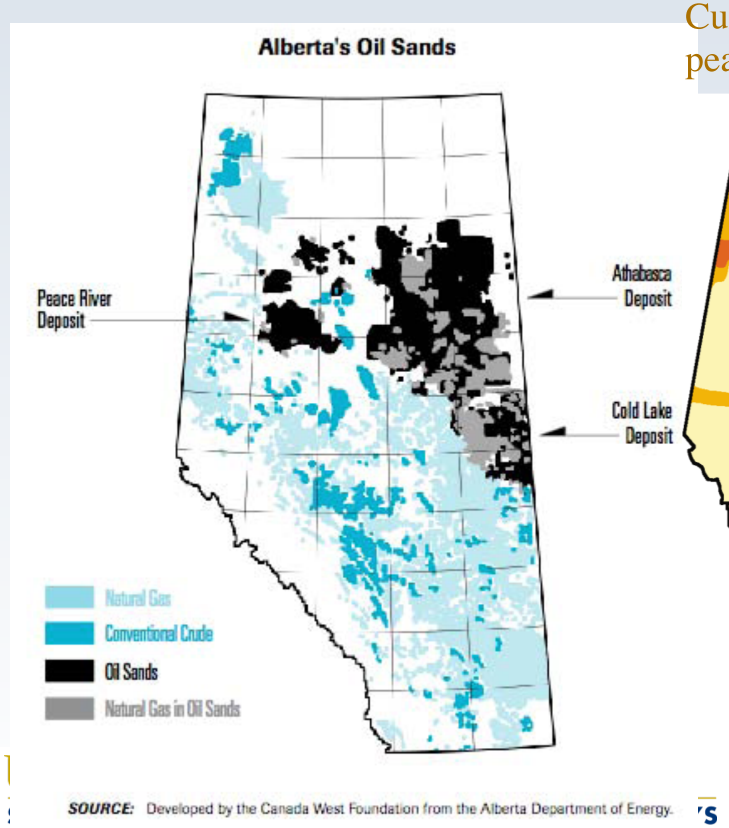
Source: Sego, David. 2008. Environmental impact of the oil sands development. In *2008 Gussow-Nuna Geoscience Conference*.

Tailings Management Options

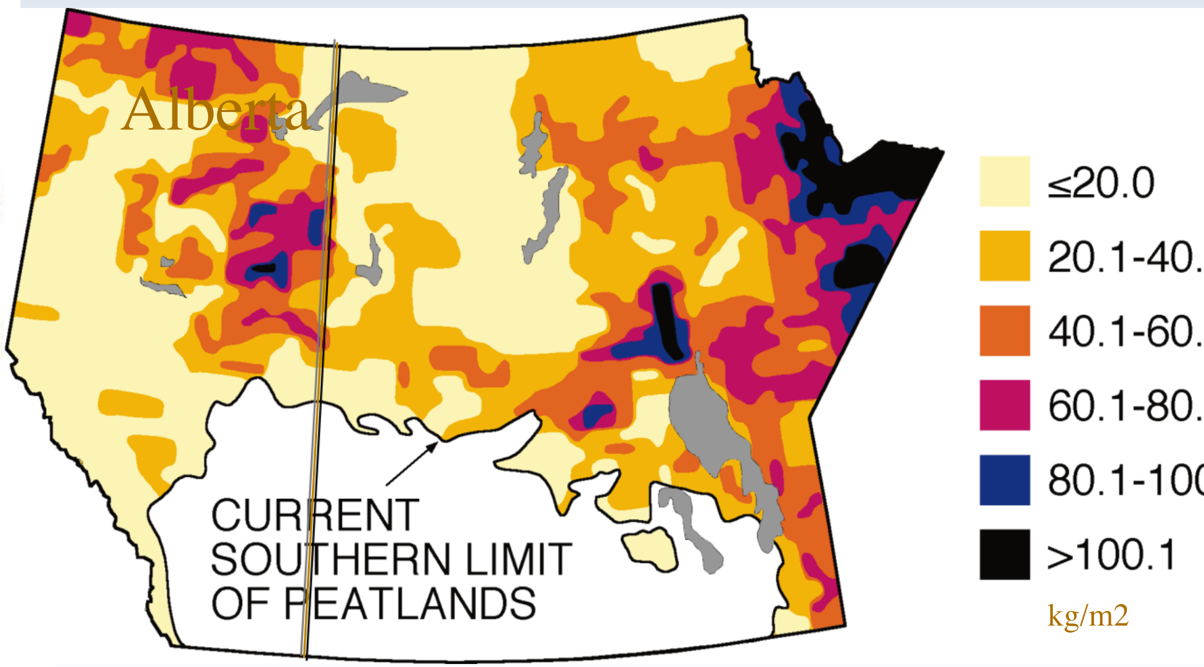
- "Wet landscape": MFT would be transferred to an abandoned mine pit and then capped with water to form a "lake."
- "Dry landscape": adding calcium sulfate or polymer flocculent to MFT to quickly release most of water allow re-vegetation on the dried landscape.
- Methanogens have been observed in both type of ponds.
- Naphtha diluents, used for oil sands processing, and citrate, used as a water softening agent, both could possibly support methane (CH4) biogenesis in large anaerobic settling basins.
- Difficult to predict the evolution of tailings pond management and the land use footprint and GHG emissions.
- We use the values reported in the literature before 2009 but these values will need to be updated once more data becomes available in the future.

Peatland Emissions from Fossil Fuel Land Use Can be Significant

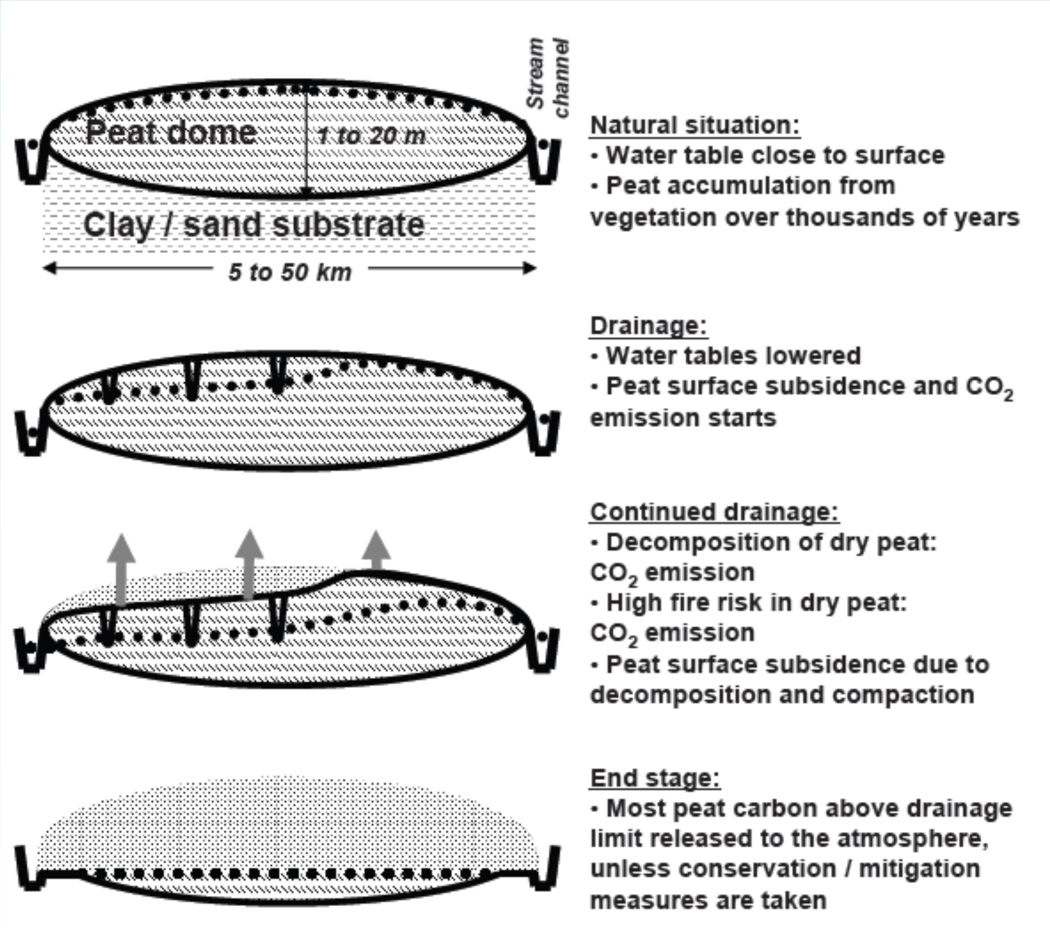
- Boreal peatlands store 85% of global peat, contain ~ 6 times more carbon than tropical peatlands
- We estimate that 15% and 23% of conventional oil and oil sands development areas occur in peatland, respectively.



Current carbon storage in the surface and below-ground component of peatlands across continental western Canada. Source: Vitt et al (2000)



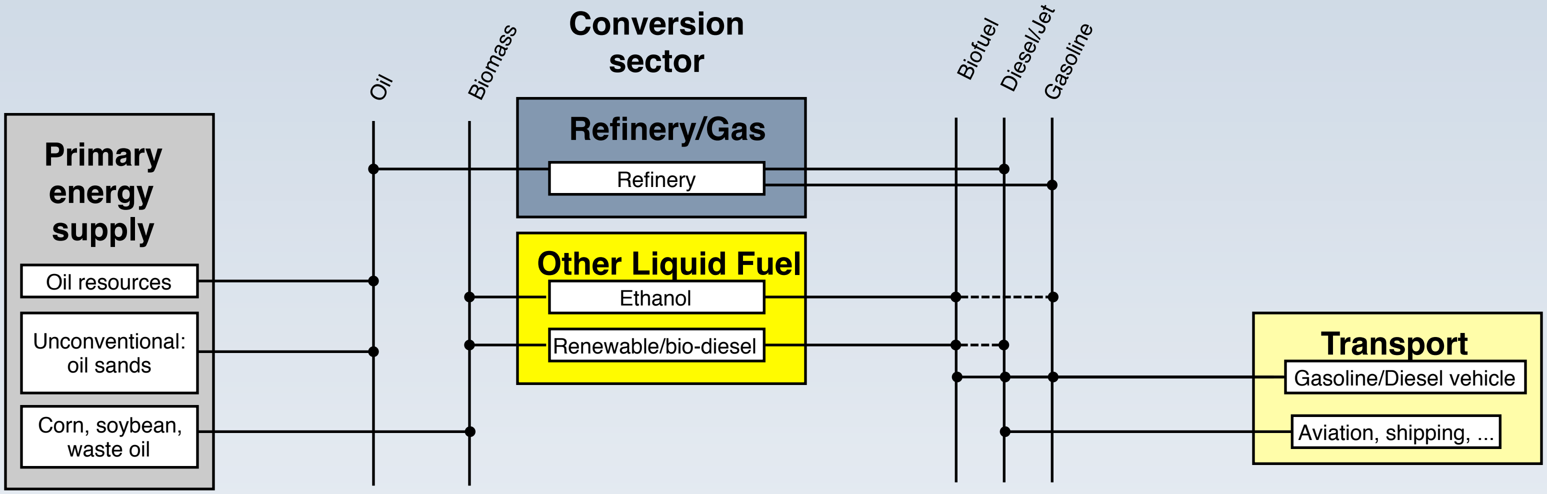
Peatland Drainage and Carbon Emissions



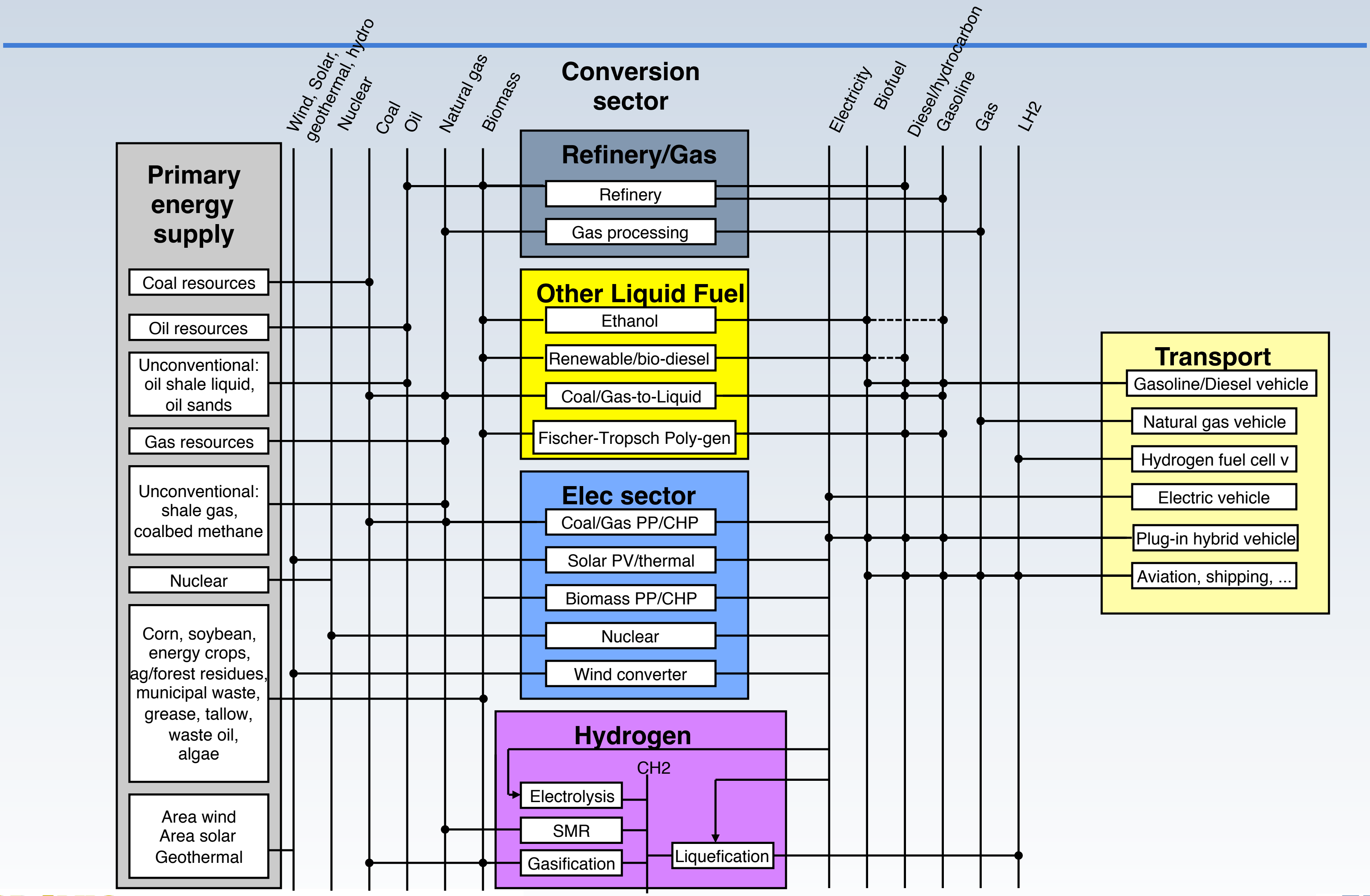
Schematic illustration of progressive subsidence of the peat surface in drained peatland, due to peat decomposition resulting in CO_2 emission, as well as compaction.

Source: Hooijer et al. (2010): CO2 emissions from drained peat in Southeast Asia

Reference Energy System (RES)
Today's Transportation Fuels



Potential Future Transportation Fuels



Fuel du jour Phenomenon

- 30 years ago – Synfuels (oil shale, coal)
- 25 years ago – Methanol
- 20 years ago – Electricity (Battery EVs)
- 10 years ago – Hydrogen (Fuel cells)
- 5 years ago – Corn ethanol (Biofuels)
- Today – Electricity
- What's next?

Without policy intervention, we'd start all over with unconventional oil

BIOFUEL can be Derived from A Wide Range of Feedstock

Forest biomass

Agricultural residues

Waste streams

Energy crops

Source: Nathan Parker, ITS Davis

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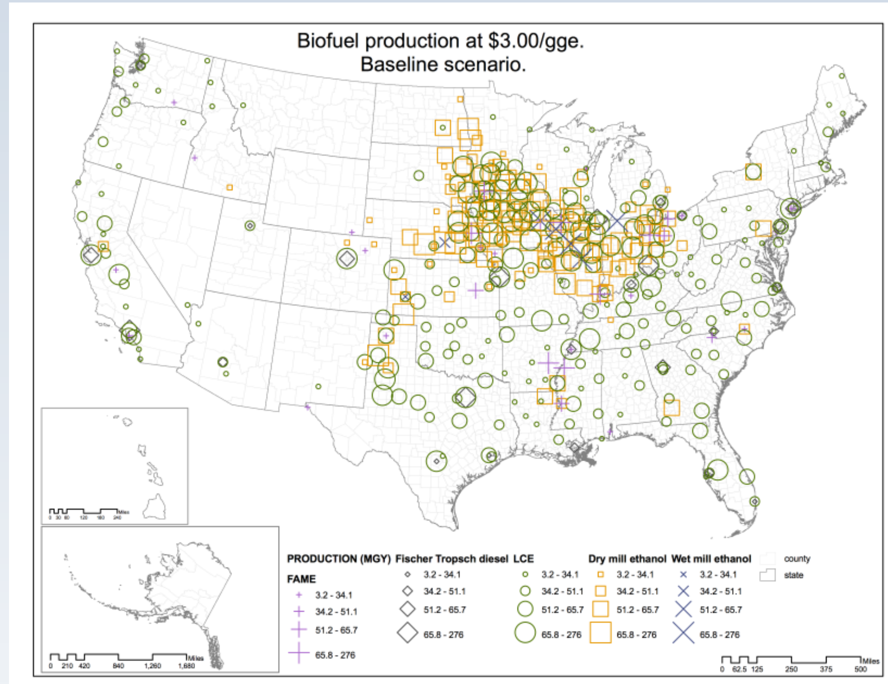
BIOFUEL from Domestic Sources can have Large Potentials

- Estimates for total *sustainably* available biofuels vary widely.
- Between $3 and $4/gge estimates range from 6.5% to 22% of total LDV vehicle fuel demand.
- 200 to 250 commercial scale cellulosic biorefineries needed, costing $60-120 billion.



Source: Nathan Parker, ITS Davis

- A mixed of wastes and residues, corns, energy crops, soy/ canola, tallow and grease is available.

BIOFUEL Concerns for Sustainability

- Public perception of some sustainability issues associated with biofuels present a challenge for future development of biofuels
  - e.g. food price increase, global land use conversion, biodiversity loss, water and soil quality, water demand, human/labor rights
- Global waves of sustainability reporting requirements and certification schemes
  - Not all biofuels are created equal
  - Performance-based standards are necessary to encourage innovation and improve sustainability
- Certification won't address some important issues of sustainability, e.g. cumulative effects on the environment, and land use conversion in response to higher commodity prices
  - Gov policies and monitoring will be required

ELECTRICITY and Electric/Plugin Vehicles

Vehicles

- Battery performance- price, durability and ability to fast charge.
- Cost of batteries may encourage small battery PHEVs beyond early markets.

Electricity/Infrastructure

- How to provide charging to multi-unit dwellers / developing fast charging systems
- If PEV charging demand is coordinated with grid system goals, grid will be capable of sustaining vehicles for decades.
  - Time of charging and regional variation in CO_2 and criteria emission

Source: Tom Turrentine, ITS Davis

ELECTRICITY Low Cost/Carbon Fuel

- Replacing gasoline fuel with electricity fuel lowers the cost of driving since electricity is cheaper per mile than gasoline

At \$3/gallon, gasoline-mile cost of driving **\$0.12/mile**
At \$0.13/kWh, electric-mile cost of driving **\$0.03/mile**

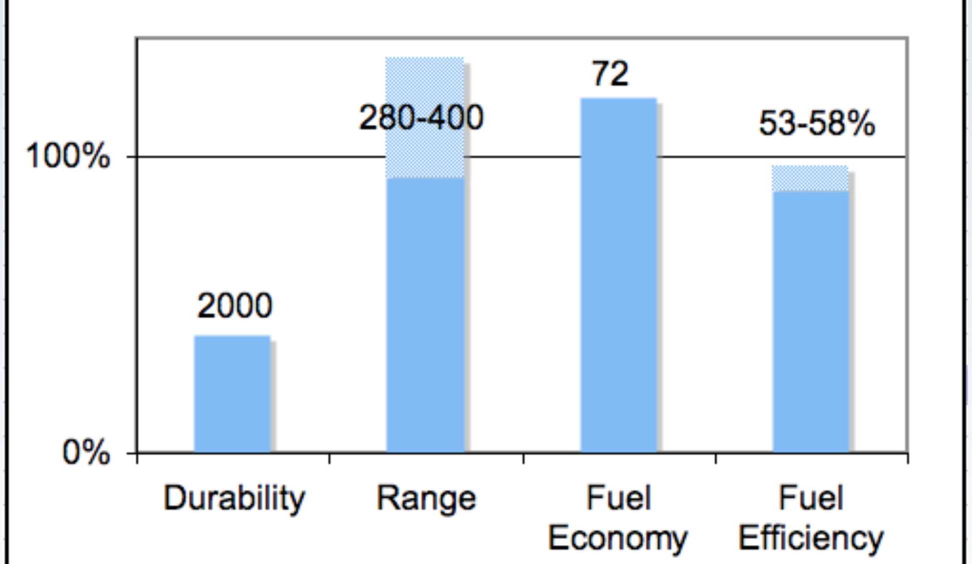
Carbon intensity of gasoline mile is **438** gCO_2e/mile
Carbon intensity of electric mile in California is **189** gCO_2e/mile after adjusting for efficiency (60% reduction in carbon intensity)

The calculation excludes the equipment costs (e.g., incremental vehicle costs for batteries, motors, charging equipment for grid-connection-capable vehicles)

HYDROGEN Fuel Cell Vehicles Rapidly Approaching Technology Goals

- FC durability
- FC cost
- H2 Storage
- Low Cost, Low-C H2 production

	Today	*2015*
In-use durability (hrs)	2000	5000
Vehicle range (miles/tank)	280-400	300
Fuel economy (miles per kg H2)	72	60
Fuel cell efficiency	53-58%	60%
Fuel cell system cost ($/kW)	$61	$30
H2 storage cost ($/kWh)	$8-$23	$4



Source: Ogden, Joan M., Joshua M. Cunningham, Michael A. Nicholas (2010) Roadmap for Hydrogen and Fuel Cell Vehicles in California: A Transition Strategy through 2017. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-10-04.

Fuel Infrastructure Design Challenges

	Central Hydrogen	Electricity	Biofuels
Resource collection extraction	Use existing infrastructure for fossil resources (natural gas, coal)	Existing infrastructure	Wastes require collection, energy crops require dedicated operation, part of larger Ag system
Resource transport	Existing infrastructure	Existing infrastructure	Low energy density limits transport distances
Conversion facility	Large-scale reformers/ gasifiers	Existing infrastructure	Biorefinery (including feedstock processing and conversion)
Fuel transport	Trucks or pipelines	Existing infrastructure distribution may require upgrades	Existing infrastructure for "drop-in fuels" Conventional, but not existing liquid fuels transport for incompatible fuels
Fuel refueling	New H2 refueling stations	Widespread vehiclechargers	Conventional infrastructure

Fuel Transition Needs

	Hydrogen	Electricity	Biofuels
Resources	Diversity of resources available for H_2 production	Diversity of resources available for electricity production	Limits on providing enough low-carbon biomass for all transportation
Technologies	Hydrogen production (fossil conversion and electrolysis) and storage are critical technology	No major technology limitations for infrastructure	Biorefineries are critical technology
Economics	High initial costs – large economies of scale associated with stations and central production	Relatively low initial investment costs for home charging compared to other fuels	Biorefineries are primary cost and scale dependent
Transitions	Vehicle adoption will determine the rate of infrastructure deployment, requires significant coordination	Vehicle adoption will determine the rate of infrastructure deployment	Rapid deployment of biofuels in next few decades (RFS), no vehicle-related limitations

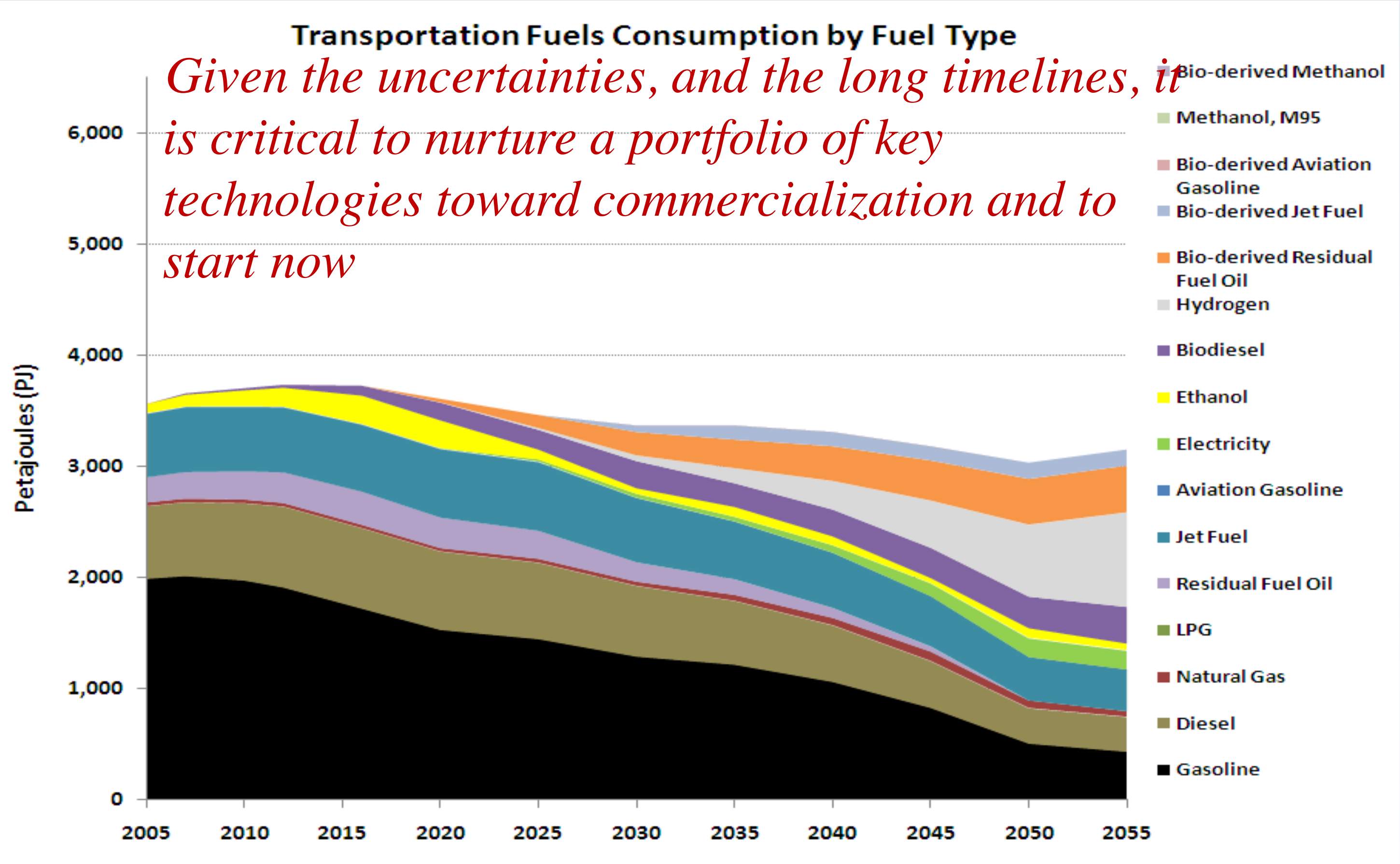
Fuel and Infrastructure Challenges for Alt Fuels

- Each fuel type (biofuel, electricity, and H_2) has challenges in deploying infrastructure
  - But infrastructure deployment is focused on different parts of supply chain for different fuels and pathways
  - Important to analyze infrastructure deployment along many different axes
- Biofuels challenges are widespread supply and conversion infrastructure, and resource availability
- Electricity requires least new infrastructure (home chargers), limited by vehicle deployment
- H_2 requires biggest infrastructure changes, new refueling stations and production and delivery (for central H_2), coordination for chicken and egg

Sustainability

- Research: work with academic communities and stakeholders to improve the scientific understanding of sustainability impacts of *ALL* fuels
- Incentives: **directly incentivize the development and use of low-GHG /sustainable fuels through performance-based standards and market mechanisms. Gov shouldn't pick winners! But policies are needed to level the playing field!**
- Standards: adopt enforceable, effective sustainability policies to
  - Prevent conversion of ecologically sensitive and high-carbon areas and environmental degradation for fuels production;
  - Continuous monitoring and assessments of unintended consequences within or beyond the production areas

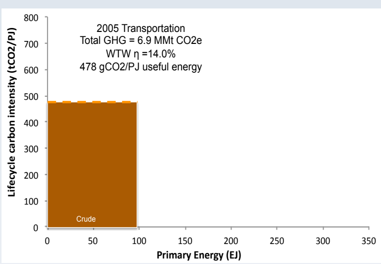
California: A portfolio approach will give us the best chance of meeting stringent goals for a sustainable transportation future

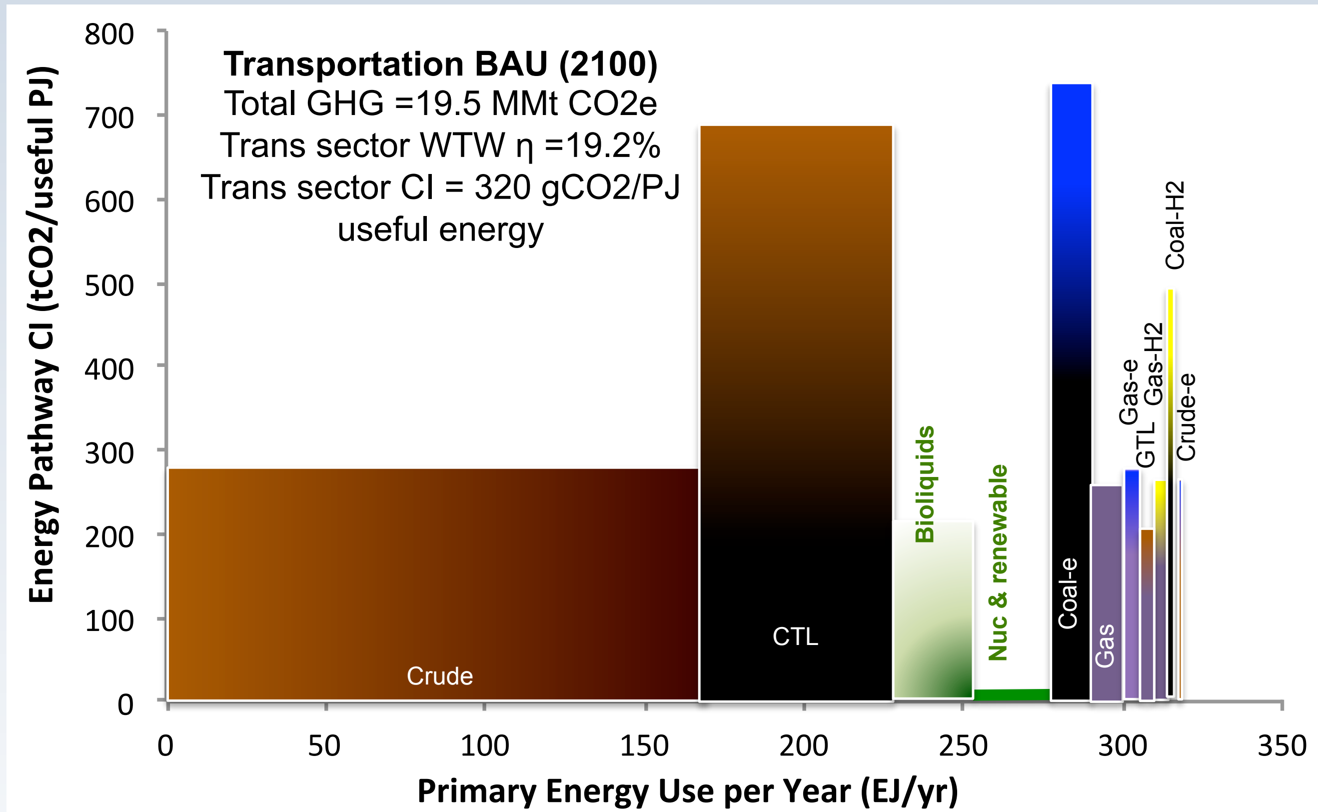


McCollum, David L. (2011) Achieving Long-term Energy, Transport and Climate Objectives: Multi-dimensional Scenario Analysis and Modeling within a Systems Level Framework. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-11-02

Huge Global Investment Needed to Meet Increased Demand for Crude and “Unconventional” Energy Carriers

2005





Increased demand for crude and “unconventional” energy carriers, including **CTL**, biomass to liquid (**BTL**), **GTL**, and **electricity** and **hydrogen** from **coal** and **natural gas** dampen improvements in technology efficiency and increase lifecycle CI

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Source: Yeh, S, Mishra, GS, Morrison G, Teter J, Quiceno R, and Gillingham K. 2012. "Effects of structural change and climate policy on long-term shifts in lifecycle energy efficiency and carbon footprint.” submitted to ES&T.

Carbon Policy Reduces Total Primary Energy Use and Total GHG Emissions with More Renewables and Higher Efficiencies