The Impact of Higher Ethanol Blend Levels on Vehicle Emissions in 5 Global Cities

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Seoul

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Life Cycle Modeling and Tailpipe Emissions Modeling

Tailpipe Emissions:

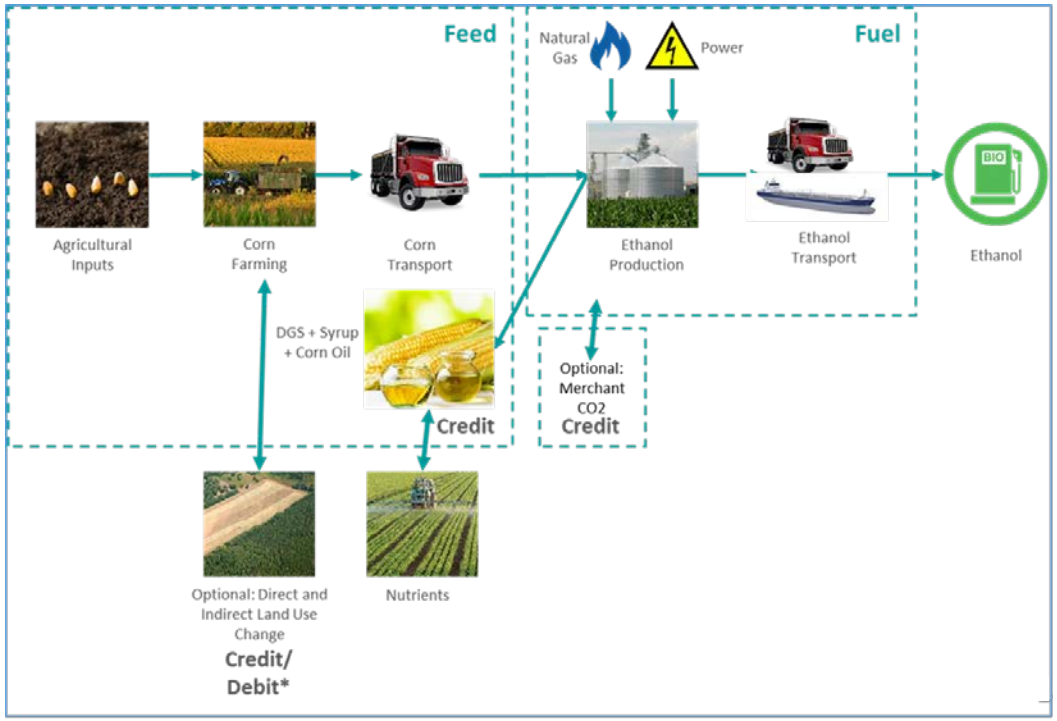
Assess **Local Air Emissions Impact** from Vehicle Traffic for key pollutants and air toxins:

- Particulate Matter,
- Carbon Monoxide,
- Nitrogen Oxides,
- Volatile Organics
- Air Toxins (Benzene; 1,3 Butadiene, Aldehydes)

Life Cycle Emissions:

Assess **Emissions Impact from Cradle to Grave (e.g. Well to Wheel WTW)**

- Useful for all emissions but particularly for emissions with global impact such as Greenhouse Gas Emissions (GHGs)



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Emissions Assessments

Life Cycle Emissions

Tailpipe Emissions

Life Cycle Analysis (LCA) of Corn Ethanol	Life Cycle Analysis of Petroleum-Based Fuels
Emissions contributions from:	**Emissions contributions from:**
Direct Land Use Change & International Land Use Change (iLUC)	Land Use, Spillage
Feedstock production including agricultural inputs and on-farm energy use: fertilizer inputs, tractor fuel, custom work, etc.	Oil Exploration and Extraction
Transportation from the field/farm to the Ethanol Plant	Transportation to the Refinery
Conversion at the Ethanol Plant including combustion of thermal fuel and use of purchased electricity Coproduct Product Considerations (animal feed, CO2 bottling)	Conversion at the Refinery
Distribution to the Blending Terminal/Gas Station	Distribution to the Enduser/Gas Station
Combustion in the Vehicle	Combustion in the Vehicle

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Life Cycle Greenhouse Gas Emissions Benefits of Ethanol Blended into Gasoline

- Carbon in the fuel is "carbon neutral" (absorbed during plant growth and released during combustion)
  - Carbon in gasoline is not carbon neutral and a net addition to the atmosphere.
- Therefore all GHG emissions from ethanol are due to production practices
- Ethanol Production Practices in agriculture and at the ethanol plant level are becoming increasingly efficient further widening the gap between gasoline and ethanol

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Tailpipe Emissions Benefits of Ethanol Blended into Gasoline

- Increased ethanol results in lower burned gas and exhaust temperatures.
- High Octane Rating (wanted by car manufacturers for higher knock resistance in engines)
  - In fuel formulations ethanol dilutes and substitutes for other octane enhancers such as benzene, toluene, and xylene.
- Oxygenate in Fuel (reduces certain emissions)
- Reduction in Key Toxins from Combustion Process

Tailpipe Emissions Benefits of Ethanol Blended into Gasoline: Published Vehicle Emissions Studies

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		E10	E20	
Hilton and Duddy	THC		-13.7%	
Karavalakis	THC	-12.8%	-22.9%	
Bertoa	THC	-65.0%	-59.0%	vs E5
SAE 1992	THC	-4.9%		
NREL	NMHC	-12.0%	-15.1%	
Storey	NMHC	-20.0%		
Bertoa	NMHC	-68.0%		vs E5
SAE 1992	NMHC	-5.9%		
ORNL 2012	NMHC	-7.0%	-17.1%	
ORNL 2012		-1.4%	-0.9%	
Average	THC/NMC	-21.9%	-21.5%	

		E10	E20	
Hilton and Duddy	CO		-23.2%	
Karavalakis	CO		-47.1%	
NREL	CO	-15.0%	-12.3%	
Storey	CO	3.0%	-14.0%	
Bertoa	CO	13.0%		vs E5
SAE 1992	CO	-13.4%		
ORNL 2012	CO	-2.4%	-20.4%	
Average	CO	-3.0%	-23.4%	

		E10	E20	
Hilton and Duddy	NOx		-2.4%	
Karavalakis	NOx	13.6%	22.1%	
Storey	Nox	-42.0%	-71.0%	
Bertoa	NOx	-24.0%		vs E5
SAE 1992	NOx	5.1%		
ORNL 2012	NOx	34.3%	12.3%	
Average	NOx	-11.8%	-17.1%	

Storey	PM	-6.0%	-36.0%	

		E10	E20	
SAE 1992	Benzene	-11.5%		
Bertoa	Benzene	-56.0%		vs E5
Karavalakis	Benzene	-29.0%	-36.0%	
Average	Benzene	-32.0%	-36.0%	

Karavalakis	1,3 –butadiene	-30.0%	-56.0%	
SAE 1992	1,3 –butadiene	-5.8%		
Average	1,3 –butadiene	-18.0%	-56.0%	

SAE 1992	Formaldehyde	19.3%		
Bertoa	Formaldehyde	-50.0%		vs E5
Karavalakis	Formaldehyde	-44.0%	-36.0%	
Average	Formaldehyde	-24.9%	-36.0%	

SAE 1992	Acetaldehyde	159.0%		
Bertoa	Acetaldehyde	75.0%		vs E5
Karavalakis	Acetaldehyde	16.0%	101.0%	
Average	Acetaldehyde	83.3%	101.0%	

egend:

HC = Total Hydrocarbon Emissions

MHC = Non Methane Hydrocarbons

O = Carbon Monoxide

Ox = Nitrogen Oxides

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Toxic Air Contaminants

- Ethanol generally decreases 1,3 Butadiene and Benzene, increases aldehydes but the weighted sum results in reduced cancer risk
- Stein et al./SAE In. J. Engines / Volume 6, Issue 1 (May 2013):
  - **"Increased ethanol in gasoline should decrease emission of 1,3 butadiene and benzene and increase emissions of acetaldehyde and formaldehyde** (later two due to incomplete combustion of ethanol). Due to much **higher toxicity weighting factors, 1,3-butadiene and benzene dominate the weighted sum** of these four toxics even in high ethanol content"
- "Unnasch and Henderson (2014) "Change in Air Quality Impacts Associated with the Use of E15 Blends Instead of E10".
  - Analysis of CRC Study E80 showed that "a change from E10 to E15 results in a 6.6% reduction in toxic risk. Furthermore, a "**reduction in 1,3 butadiene and benzene produces a decrease in impacts that is greater than their relative decrease in mass emissions"**

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Toxic Air Contaminants (California Air Resources Board)

- "Toxic air contaminant" means benzene, 1,3-butadiene, formaldehyde, or acetaldehyde.
- “In each test, the emission rate of each toxic pollutant shall be multiplied by its relative potency, as shown in the following table, and the four products shall be summed.”

	Relative Potency
1,3-butadiene	1.0
benzene	0.17
formaldehyde	0.035
acetaldehyde	0.016

ATTACHMENT A-13; State of California; California Environmental Protection Agency; AIR RESOURCES BOARD; Stationary Source Division CALIFORNIA TEST PROCEDURES FOR EVALUATING SUBSTITUTE FUELS AND NEW CLEAN FUELS IN 2015 AND SUBSEQUENT YEARS; Adopted: March 22, 2012

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Decrease in Air Toxins in California

Ambient and Emission Trends of Toxic Air Contaminants in California

Environmental Science & Technology Article

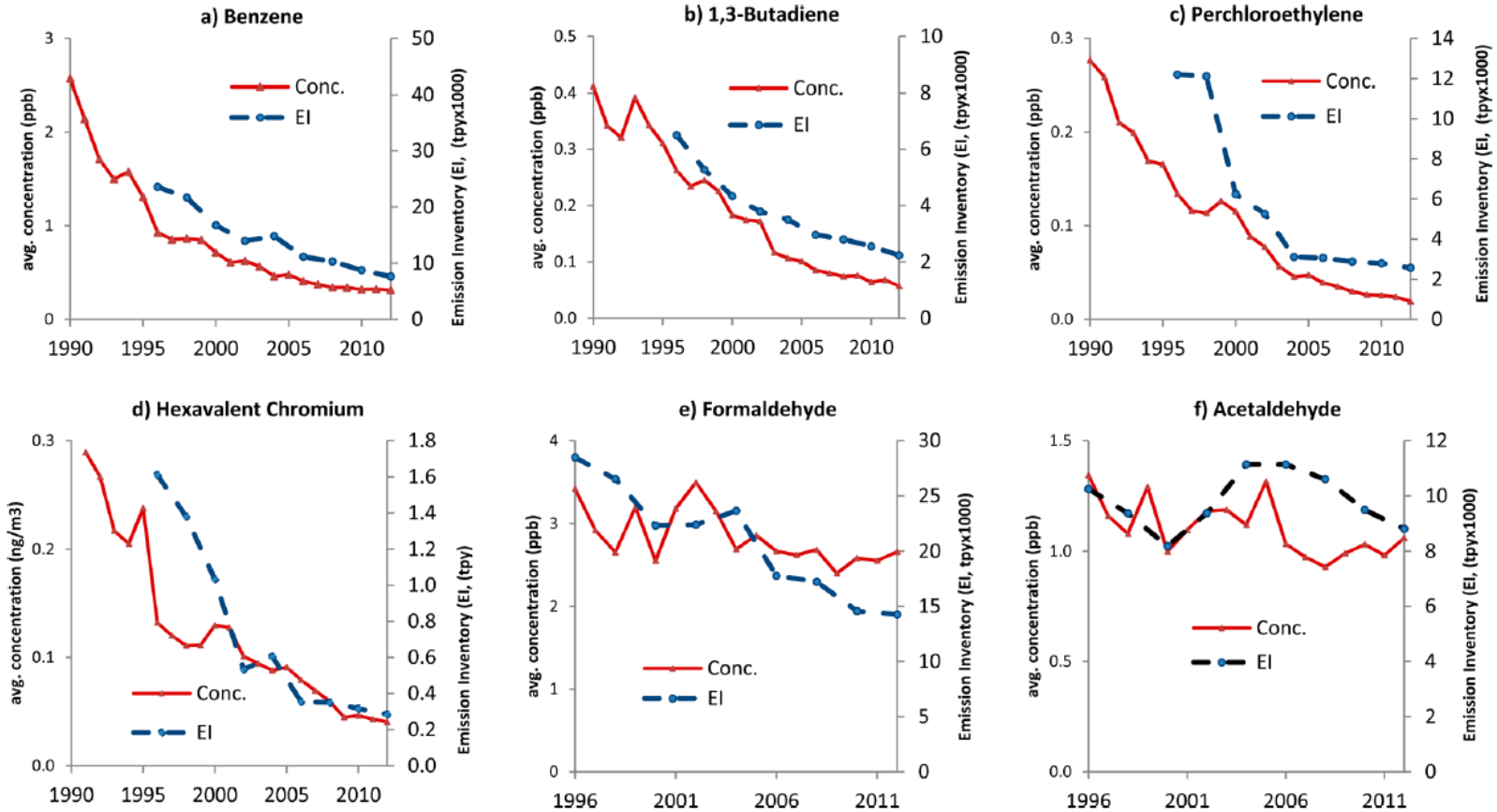

Figure 3. Statewide annual average concentrations and emissions inventory (EI) trends for six toxic air contaminants. EI data were available starting in 1996. (a) Benzene (1990–2012), (b) 1,3-Butadiene (1990–2012), (c) Perchloroethylene (1990–2012), (d) Hexavalent Chromium (1991–2012), (e) Formaldehyde (1996–2012), (f) Acetaldehyde (1996–2012).

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UIC/US Grains Council 5 Cities Study

GHG Modeling

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5 Cities Study

- This study examines the cumulative future **tailpipe** and **greenhouse gas emissions benefits** from adopting higher ethanol blends for the light duty vehicle market in light of current and predicted fuel demand in five major global cities.
- The study also assesses refinery profitability considerations associated with producing these fuels.
- The modeling spreadsheet is called the International Biofuels Emissions Analysis Model (iBEAM)
- The five cities of interest are:

Beijing, Mexico City, New Delhi, Tokyo, and **Seoul**

Study Contributors

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- Professor Jane Lin; University of Illinois at Chicago. Vice Chair of the Section on Energy and Environment at the Transportation Research Board (TRB).
- Brian West, John Storey, Shean Huff, John Thomas, Fuels, Engines, and Emissions Research Center, Oak Ridge National Laboratory.
- Kristi Moore, President Kmoore Consulting, former Vice President of Technical Services for the Renewable Fuels Association.

Analytics Support:

- Jordan Rockensuess, Intertek Laboratories.

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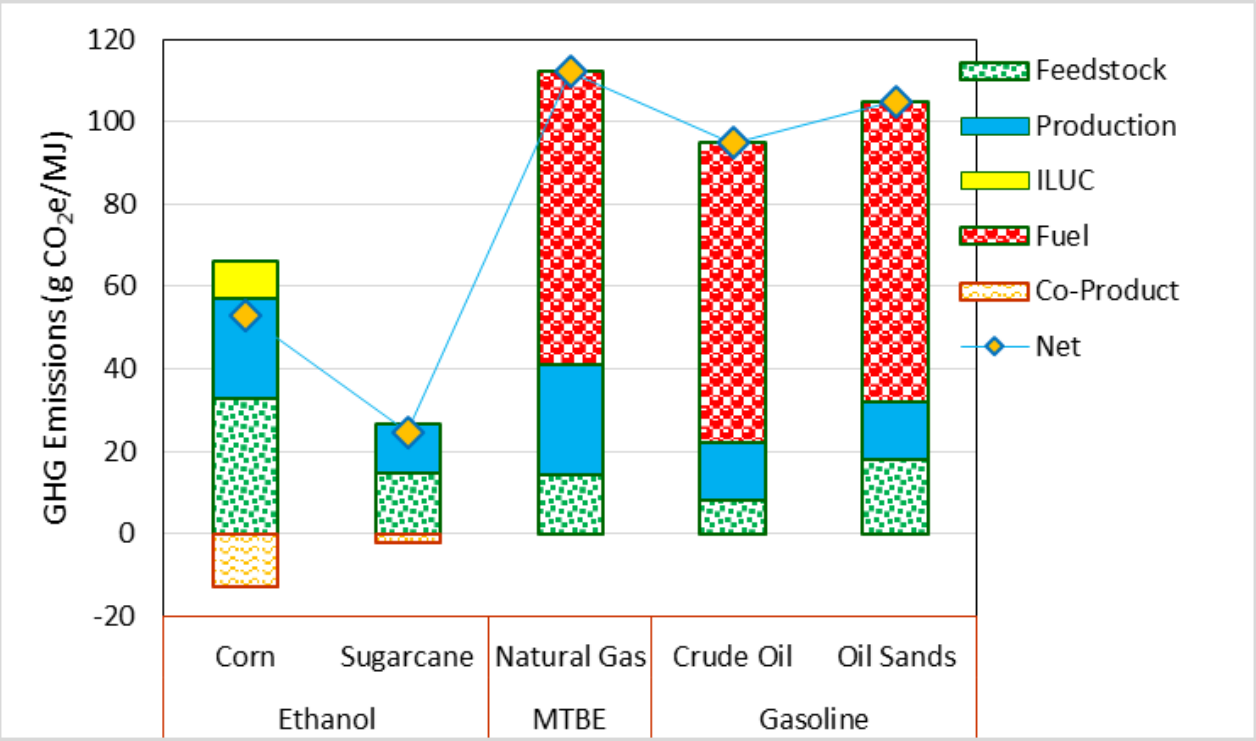
GHG Emissions

- Oxygenates can reduce GHG emissions
  - Low CI ethanol
  - Lower reformer severity



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GHG Models Used

- The iBEAM model displays the energy inputs and emissions from corn ethanol over the life cycle from farming to end use. The carbon in the corn is treated as biogenic carbon neutral and the approach follows the methods for ANL's GREET model and the Biograce Model
  - The **GREET model developed by Argonne National Laboratory** is the gold standard for U.S. based life cycle analysis and contains the most up to date information on corn ethanol production. A California version of the GREET model is used for the Low Carbon Fuel Standard. An earlier version was used by the US Environmental Protection Agency for the Renewable Fuel Standard modeling.
  - **The Biograce Mode**l is a European life cycle model that evaluates European fuel pathways under the Renewable Energy Directive (RED). Current Japanese modeling efforts are also closely aligned with the EU RED methodology.

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Annual Total Vehicle Distance Travelled

1. Project Annual Gasoline Passenger Car Population for each City (based on extrapolation of vehicle saturation levels complemented with literature citations)
2. Account for Electric Vehicle Share
3. Project vehicle distance traveled per gasoline passenger car per year
4. Multiply 1,2,3 to derive total kilometers driven by passenger cars in the city (Annual Vehicle Distance Travelled [km/year])
5. Also: Project Vehicle Retirement over time to derive new vehicles added each year.

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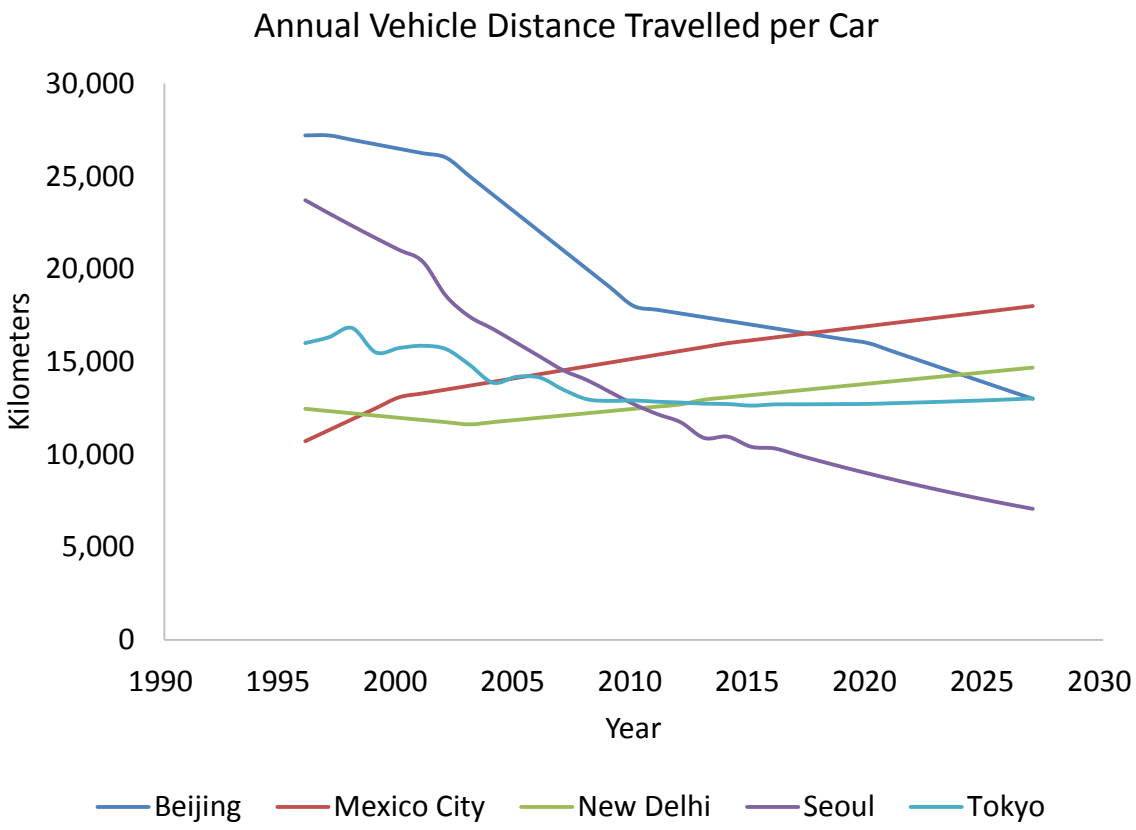
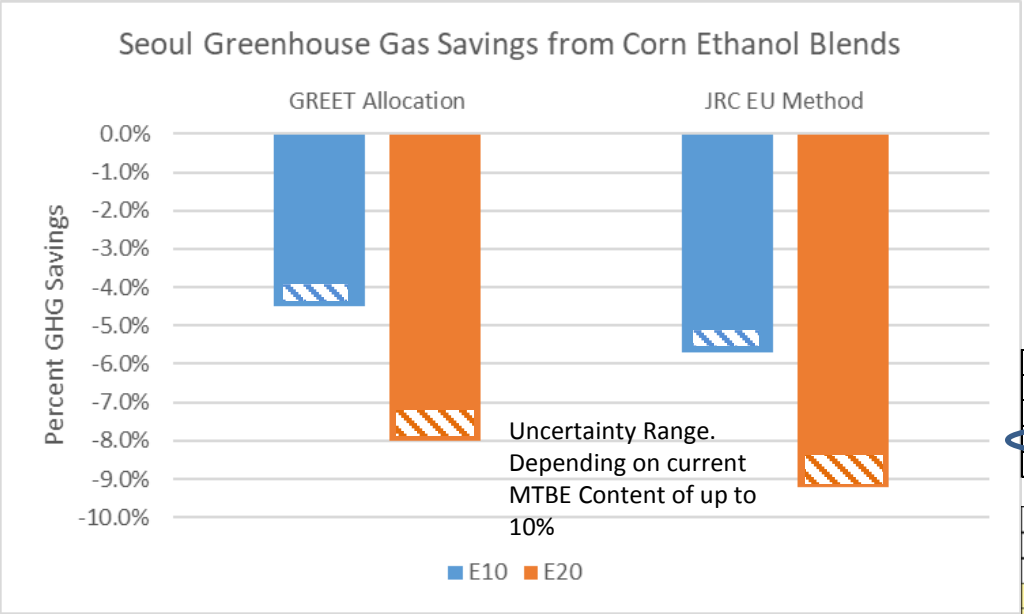
Annual vehicle distance travelled per car

- Seoul and Tokyo VDTs decrease due to their public transportation systems



GHG Savings for Seoul/Korea

- On a total tonnage and percentage basis the study shows GHG reductions for Seoul
- EV Adoption: We looked at projected global EV Vehicle Stock Turnover which projected to be about 6% by 2027.
  - Ethanol adoption into the existing fleet provides about the same benefits **but right now.**



10% or 20% Ethanol Substituting for up to 10% MTBE

Regional Gasoline CI

		GREET	JRC/Biograce	MTBE	ETBE
Beijing	BV	95.15	83.80	7.0%	0.0%
Mexico City	MV	95.18	83.80	11.1%	0.0%
New Delhi	NV	95.66	83.80	2.8%	0.0%
Seoul	SV	95.22	83.80	10.0%	0.0%
Tokyo	TV	95.23	84.11	0.0%	6.4%

Enthanol Transport Distance (mi)					
	Beijing	Mexico City	New Delhi	Seoul	Tokyo
Mode	BV	MV	NV	SV	TV
Rail	1,050	1,050	1,050	1,050	1,050
Marine	11,898	655	11,090	11,571	10,663
Truck	100	100	100	100	100

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UIC/US Grains Council 5 Cities Study

Tailpipe Emissions Modeling

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5 Cities Study

"Amid worsening air quality, the Seoul Metropolitan Government activated the city's free public transport program three times last week, along with other measures including a mandatory alternate no-driving program in the public sector on days when the daily density average of particulate matter exceeds 50 micrometres per cubic metre for two consecutive days."

Foreigners in South Korea unsure how to respond to dangerous air pollution

A man wears a surgical mask in Seoul on Jan 16, as the density of fine dust in the air is forecast to be 'bad' nationwide. PHOTO: EPA-EFE

PUBLISHED JAN 22, 2018, 4:43 PM SGT

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U.S. News 4/20/2018

"More than 95% of the world's population lives with unsafe levels of air particle pollution"

U.S.News CIVIC

Air Pollution Contributes to Global Deaths

Roughly one out of nine deaths around the world due to air pollution, study finds.

By **Lindsay Huth**, Staff Writer
April 20, 2018, at 3:36 p.m.

In 2016, there were 6.1 million deaths worldwide as a result of air pollution, according to report. (R S IYER/AP)

MORE THAN 95 PERCENT OF the world's population lives with unsafe levels of air particle pollution as measured by the World Health Organization's air quality guidelines, including a large swath of populations stretching from Africa to the Middle East and South Asia, according to a recently released report.

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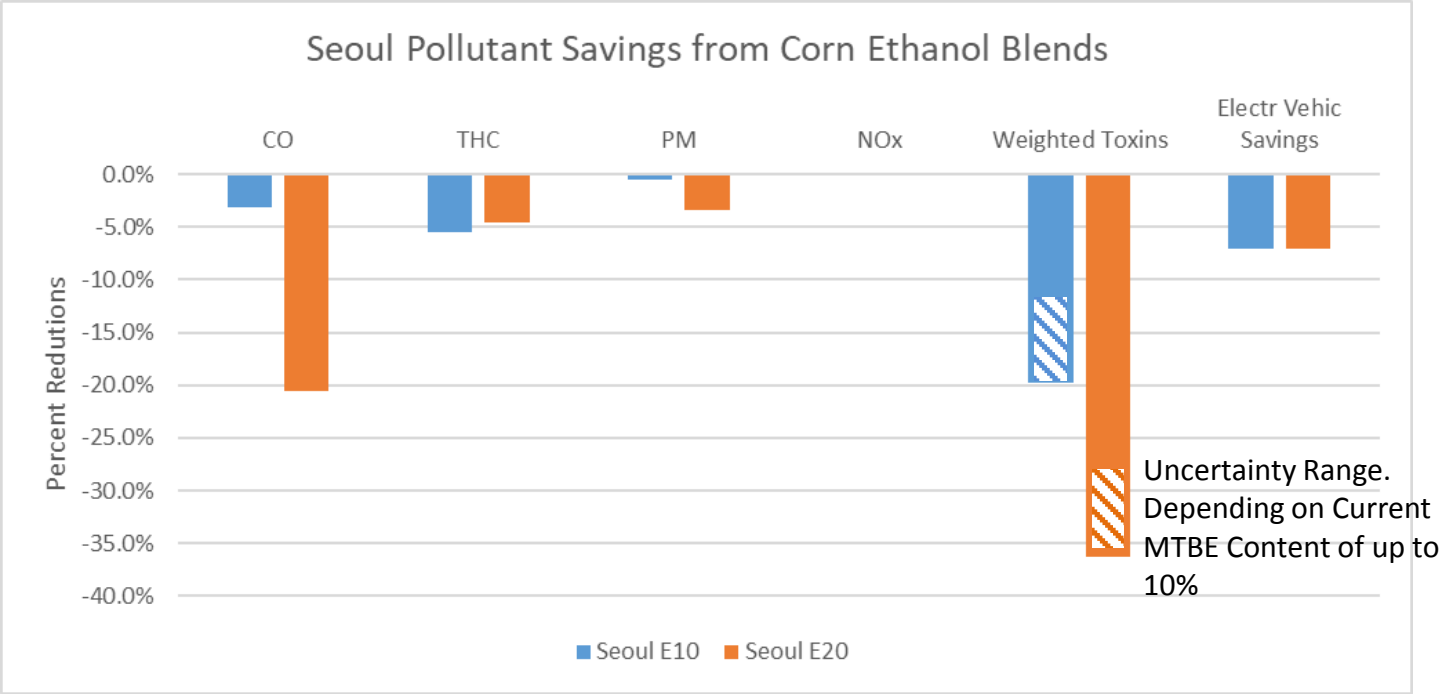
Tailpipe Emissions Results for Seoul

Significant Emissions Reductions with Ethanol



- Significant Total Hydrocarbon Reductions (THC, VOC).
  Resulting in likely reduced risk of Ozone Formation for the Cities
- Significant Weighted Toxins Reductions.
  Resulting in Lower Cancer Risk for the Cities
- Reduced CO Emissions reduces heart disease and other health effects

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Sustainability of Biofuels Tracking

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Sustainability Tracking

- Land Use Change can be assessed using satellite imagery or new software tools.
- New software tools streamline this process:
  - See Global Risk Assessment Service Tool https://www.gras-system.org/
- European Union utilizes “voluntary schemes” to verify compliance with the EU's biofuels sustainability criteria.
  - They check that biofuel production did not take place on land with high biodiversity, that land with high carbon stock was not converted for biofuel production, and that the production of biofuels leads to a sufficient level of greenhouse gas emissions savings. Several schemes also take into account additional sustainability aspects such as soil, water, air protection and social criteria.
- International Sustainability and Carbon Certification (ISCC) is the most commonly used “voluntary scheme”

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ISCC opens European Market

European Commission

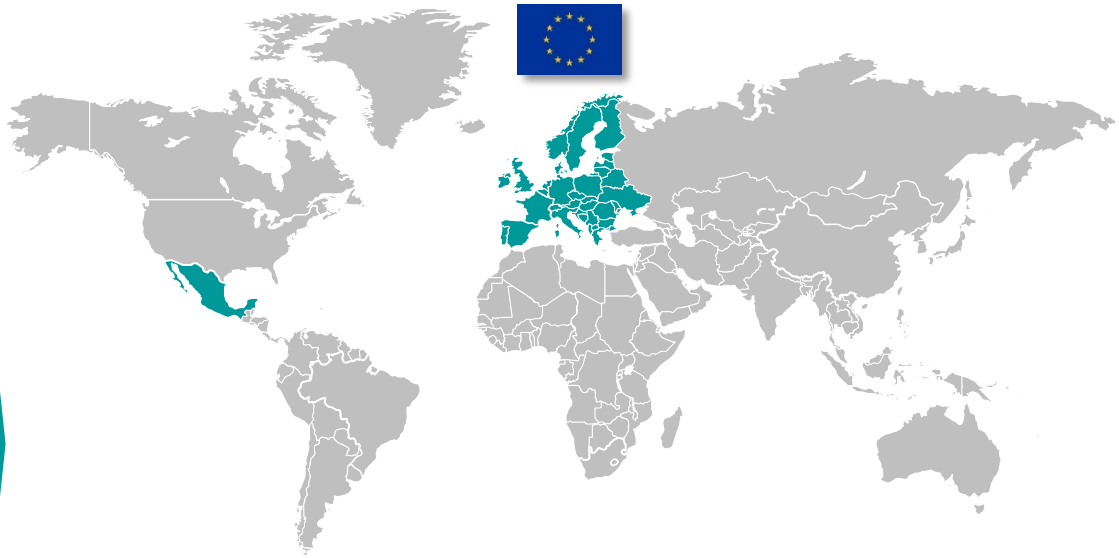
European Commission

Renewable Energy Directive

Fuel Quality Directive

recognizes

ISCC
International Sustainability & Carbon Certification



ISCC certificates prove compliance with European legislation under the Renewable Energy Directive and the Fuel Quality Directive.

ISCC enables certified companies to export bioenergy to the European Union.

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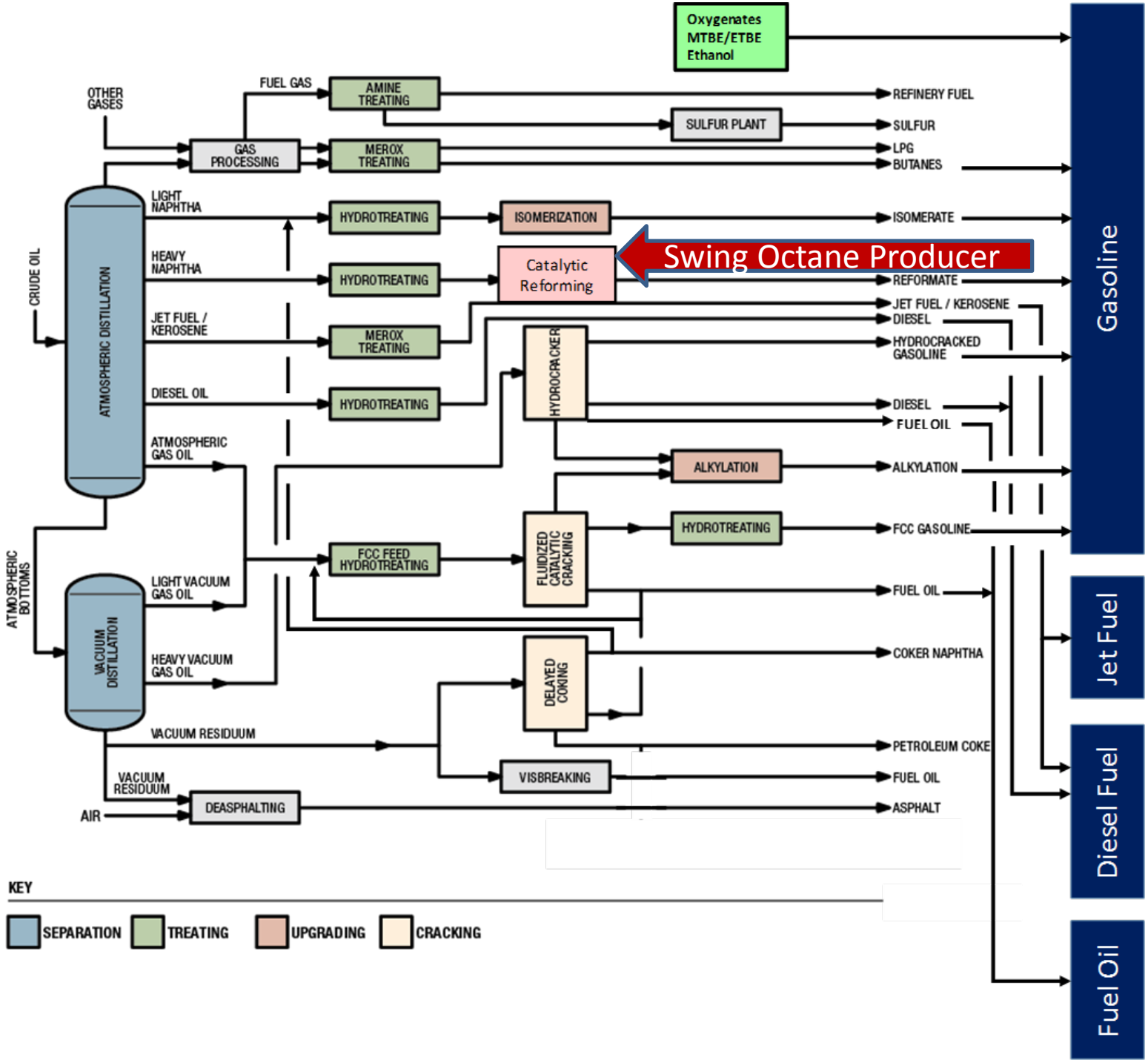
Selected ISCC certified companies in Asia Region

ISCC Certificates Asia			
Certificate	**Certificate Holder**	**Scope**	**Country**
EU-ISCC-Cert-US201-70600396	New Energy (Asia) Limited	Trader	Hong Kong
EU-ISCC-Cert-US201-70600397	Renewable Energy Asia (Shanghai) Trading Co. Ltd.		China
EU-ISCC-Cert-DE119-65182353	Stepan Asia Pte Ltd	Biodiesel Plant	Singapore
EU-ISCC-Cert-DE129-35216997	Wing Sing (Asia) Limited	Trader	Hong Kong
EU-ISCC-Cert-ID215-23180223	JKL Asia International PTE Ltd.	Collecting Point	Singapore
EU-ISCC-Cert-DE100-61122018	Lops Asia Pte Ltd.	Trader	Singapore
EU-ISCC-Cert-DE104-12381701	Louis Dreyfus Company Asia Pte Ltd.	Trader with Storage	Singapore
EU-ISCC-Cert-DE119-65175973	Asia Oils Pte Ltd	Trader	Singapore
ISCC-PLUS-Cert-60175973	Asia Oils Pte Ltd	Trader	Singapore
EU-ISCC-Cert-IT206-1038157	Zhongnan Petrochemical Singapore Pte. Ltd	Trader	Singapore

PCU = Peterson Control Union

BVC = Bureau Veritas Certification

Country-Specific Octane and Refinery Profitability Considerations


Oxygenates
MTBE/ETBE
Ethanol
OTHER GASES
FUEL GAS
AMINE TREATING
REFINERY FUEL
SULFUR PLANT
SULFUR
GAS PROCESSING
MEROX TREATING
LPG
BUTANES
CRUDE OIL
ATMOSPHERIC DISTILLATION
LIGHT NAPHTHA
HYDROTREATING
ISOMERIZATION
ISOMERATE
HEAVY NAPHTHA
HYDROTREATING
Catalytic Reforming
Swing Octane Producer
REFORMATE
JET FUEL / KEROSENE
DIESEL
JET FUEL / KEROSENE
MEROX TREATING
HYDROCRACKER
HYDROCRACKED GASOLINE
DIESEL OIL
HYDROTREATING
DIESEL
FUEL OIL
ATMOSPHERIC GAS OIL
ALKYLATION
ALKYLATION
HYDROTREATING
FCC GASOLINE
ATMOSPHERIC BOTTOMS
FCC FEED HYDROTREATING
FLUIDIZED CATALYTIC CRACKING
LIGHT VACUUM GAS OIL
FUEL OIL
VACUUM DISTILLATION
HEAVY VACUUM GAS OIL
DELAYED COKING
COKER NAPHTHA
VACUUM RESIDUUM
PETROLEUM COKE
VISBREAKING
FUEL OIL
VACUUM RESIDUUM
DEASPHALTING
ASPHALT
AIR
Gasoline
Jet Fuel
Diesel Fuel
Fuel Oil
KEY
SEPARATION
TREATING
UPGRADING
CRACKING

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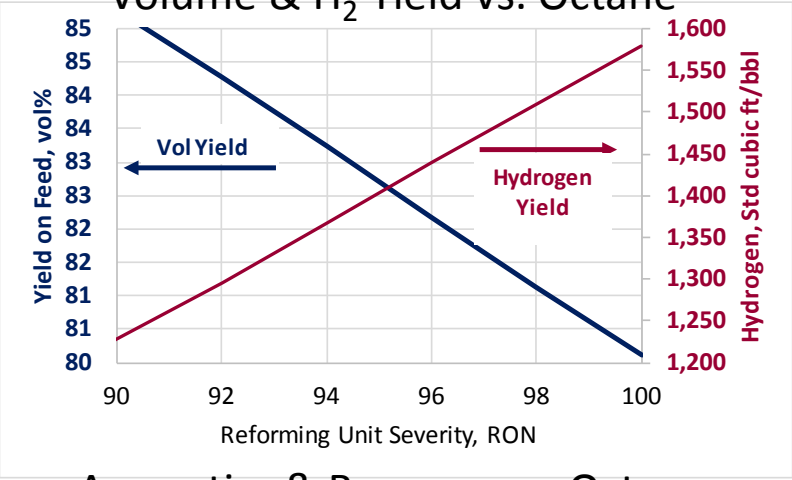
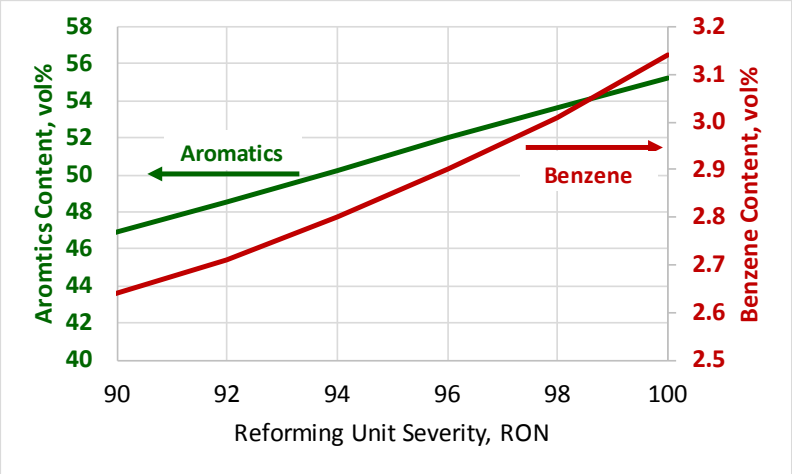
Focus on: Catalytic Reforming Unit or Reformer

- The Reformer is the major producer of high octane for gasoline blending.
- The severity **Research Octane** or RON of the unit is adjusted to meet overall gasoline octane specifications for finished gasoline resulting from blending all gasoline range components.
- Most of the octane in reformate from the catalytic reforming unit comes from aromatics produced in this process, which results in volume loss due **to hydrogen removal in making aromatics.**
- The extent of volume loss depends on the severity that the catalytic reforming unit is operated at: **higher severity (RON) results in more octane, hydrogen, and aromatics, but less volume**.
- The catalytic reforming unit is an important source of hydrogen in the refinery.

Volume & H_2 Yield vs. Octane



Aromatics & Benzene vs. Octane



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Higher Volume vs. Lower Hydrogen Production

- **When oxygenates (like ethanol in E10 or E20) are added in gasoline blending, there is less need for octane from the catalytic reforming unit** and more hydrotreated naphtha feed to the catalytic reforming unit can be bypassed around this unit and blended directly to gasoline and/or the **severity (RON) of the catalytic reforming unit can be reduced.**
- The result is **more gasoline production as a result of adding oxygenates and less processing in the catalytic reforming unit.**
- However, as a result of operating at lower severity and processing less feed, **there is less hydrogen produced from this unit.**

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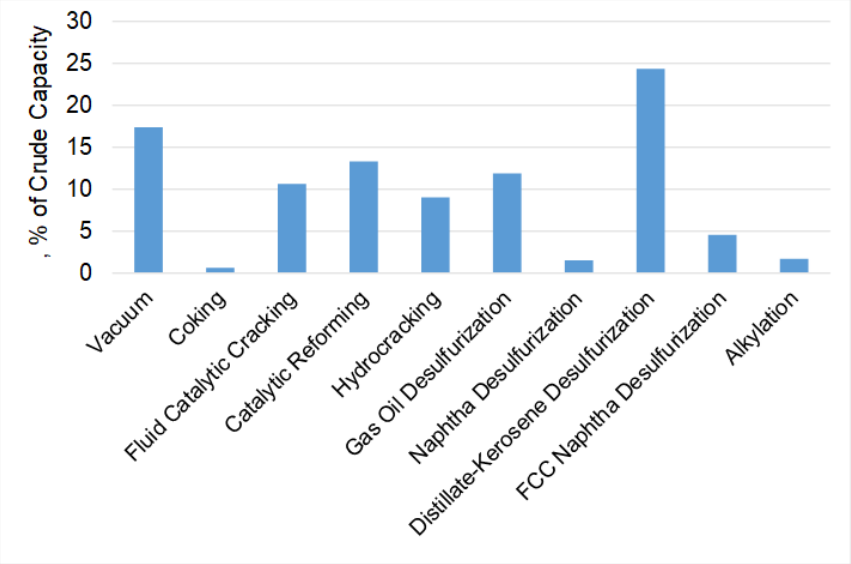
Established Refinery Profile for each of the Studied Countries

City: South Korea

- Despite its lack of domestic energy resources, South Korea is home to some of the largest and most advanced oil refineries in the world.
- According to the Oil & Gas Journal (OGJ), 3 of the 10 largest crude oil refineries in the world are located in South Korea, making it one of Asia's largest petroleum product exporters.
- According to Facts Global Energy (FGE), South Korea exported about 1.3 million BPD of refined oil products in 2015, mostly in the form of middle distillates such as gasoil, gasoline, and jet fuel. Oil product imports, about 0.9 million BPD in 2015, were primarily naphtha and LPG.
- The future growth rate of oil product exports will depend on demand from regional trading partners, which has been weak over the past few years, and on rising competition from new Asian and Middle Eastern refineries.
- According to OGJ, South Korea had about 3 million BPD of crude oil distillation refining capacity at the end of 2016 and ranked sixth largest for refining capacity in the world.
- Korean refineries are increasingly producing light, clean oil products as a result of refinery upgrades in recent years. The high degree of sophistication of South Korean refineries results in high capacity utilization.

The breakdown of South Korean refining capacity by major processing units as percent of crude oil



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Calculated Net Revenue Impact for Refiners in Each Country From Ethanol Use

- Based on Refinery Profile the Incremental hydrogen and incremental gasoline were determined for each case vs. the Base Case for each country.
- Net revenue impact from changes in hydrogen and gasoline production relative to the Base Case for each city.
- The cost of hydrogen was calculated from the cost of natural gas using yields from a steam methane reforming unit hydrogen plant model operating on natural gas and steam.
- An estimate of additional operating costs for the hydrogen plant is included.
- Result: All ethanol blended fuels return equal or increased revenue for refiners across all studied cities and their current MTBE use.

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Summary Points

- Corn ethanol in gasoline blends…
  - reduces Greenhouse Gas Emissions on a life cycle basis.
    - Continued advances in agriculture including conservation management practices as well as
    - advances in biorefining continuously reduces GHG emissions of corn ethanol relative to gasoline.
  - reduces tailpipe emissions of key pollutants (including volatile organic compounds, particulate matter, carbon monoxide, and weighted air toxins)
  - Reduces tailpipe and Greenhouse Gas Emissions right now with the existing vehicle fleet. With electric vehicles we have to wait a long time to realize emissions reductions since the vehicle stock needs to change.
- International markets can benefits tremendously from US produced corn ethanol:
  - Corn ethanol's greenhouse gas reductions allows international markets to comply with Paris Climate Agreements
  - Tailpipe emissions reductions allows global polluted cities to clean up air emissions
- Refiners can profit from ethanol blends
- Satellite-based tools can be used to ensure sustainability of bioethanol feedstock production.

Appendix: Study Assumptions and Projections for Seoul

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- Seoul: Assumed Exhaust Emissions Standards through Study Time Frame

	Seoul				
	Exhaust Emission Factors (g/km)				
Year	CO	THC	NOx	PM	HC Evap
1996	2.11	0.4	0.25	0.001563	2.00
1997	2.11	0.4	0.25	0.001563	2.00
1998	2.11	0.4	0.25	0.001563	2.00
1999	2.11	0.32	0.25	0.001563	2.00
2000	2.11	0.32	0.25	0.001563	2.00
2001	2.11	0.32	0.25	0.001563	2.00
2002	2.11	0.16	0.25	0.001563	2.00
2003	2.11	0.16	0.25	0.001563	2.00
2004	2.11	0.16	0.25	0.001563	2.00
2005	2.11	0.16	0.25	0.001563	2.00
2006	2.11	0.16	0.25	0.001563	2.00
2007	2.11	0.16	0.25	0.001563	2.00
2008	2.11	0.16	0.25	0.001563	2.00
2009	2.11	0.047	0.031	0.001563	2.00
2010	2.11	0.047	0.031	0.001563	2.00
2011	2.11	0.047	0.031	0.001563	2.00
2012	2.11	0.047	0.031	0.001563	2.00
2013	1	0.047	0.031	0.001563	1.20
2014	1	0.047	0.031	0.001563	1.20
2015	1	0.047	0.031	0.001563	1.20
2016	1	0.047	0.02	0.001563	1.20
2017	1	0.047	0.02	0.00125	1.20
2018	1	0.027	0.02	0.00125	0.95
2019	1	0.027	0.02	0.00125	0.95
2020	1	0.027	0.02	0.00125	0.47
2021	1	0.025	0.01	0.000938	0.47
2022	1	0.01	0.01	0.000938	0.35
2023	1	0.01	0.01	0.000938	0.35
2024	1	0.01	0.01	0.000938	0.35
2025	1	0.01	0.01	0.000938	0.35
2026	1	0.01	0.01	0.000938	0.35
2027	1	0.01	0.01	0.000938	0.35

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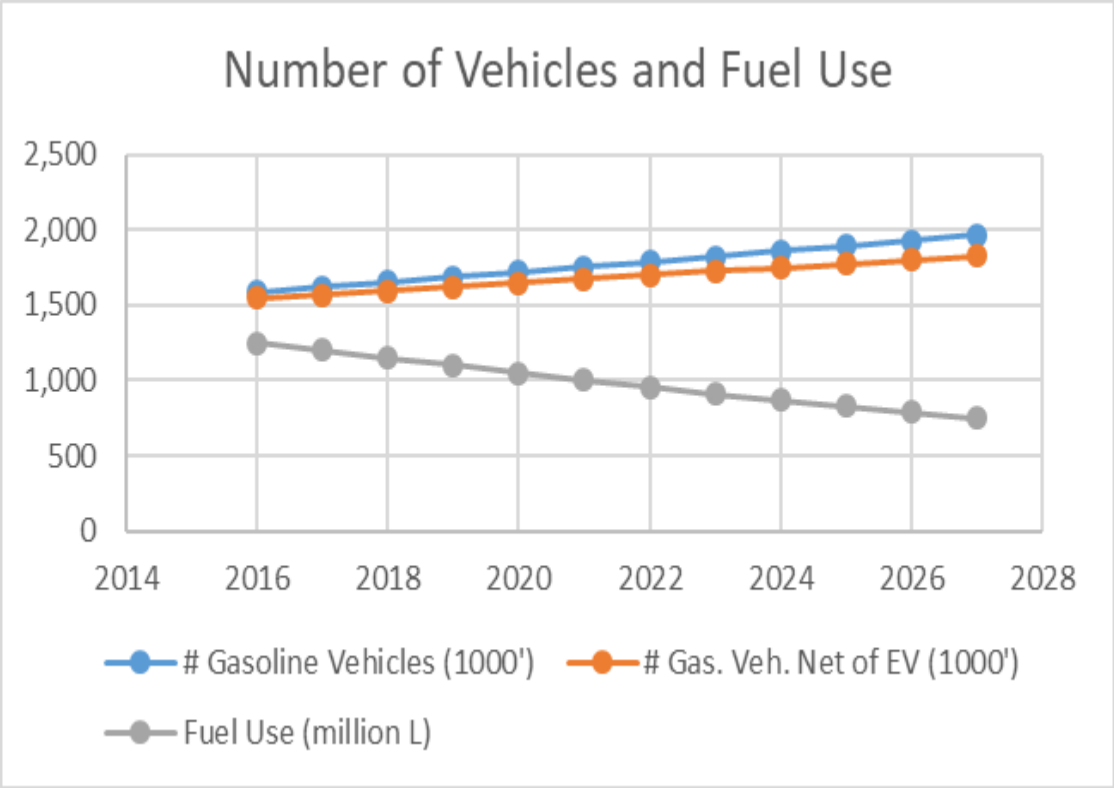
Seoul: Vehicle, Fuel Use, Fuel Economy (FE) and Vehicle Distance Travelled (VDT) Projections

Year	# Gasoline Vehicles (1000')	# Gas. Veh. Net of EV (1000')	Fuel Use (million L)	FE (L/100 km)	VDT (million km/year)
2016	1,590	1,546	1,248	7.82	15,967
2017	1,622	1,572	1,200	7.66	15,664
2018	1,655	1,597	1,151	7.49	15,367
2019	1,689	1,623	1,102	7.31	15,076
2020	1,722	1,648	1,051	7.11	14,790
2021	1,756	1,674	1,003	6.91	14,509
2022	1,791	1,700	957	6.72	14,233
2023	1,826	1,726	912	6.53	13,962
2024	1,861	1,752	869	6.35	13,696
2025	1,896	1,778	828	6.16	13,435
2026	1,931	1,803	789	5.99	13,178
2027	1,967	1,829	751	5.81	12,927