Advancements in Large Scale Plastic Pyrolysis Technology

STS-AIChE Southwest Process Technology Conference

Sudipto Chakraborty

Lummus Technology, Houston, Texas

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Sudipto Chakraborty is Technology Manager at Lummus Technology's Green Circle BU, leading the development of advanced plastic pyrolysis technology to convert mixed waste plastics into valuable raw materials through chemical recycling. With over 22 years of experience in refining, hydroprocessing, and catalyst design, he has worked at IOCL, UOP, and Albemarle. At UOP, Sudipto contributed to the world's first Ecofining biodiesel unit with Eni and designed major refining units, including the largest diesel hydrotreater for Yasref. At Albemarle, he supported global refineries such as ADNOC, Reliance, Chevron, and Motiva. Sudipto holds a gold-medal B.E. in Chemical Engineering from Jadavpur University and multiple U.S. patents. for innovations in plastic-to-petrochemical processes and has collaborated with Chevron R&D on pyrolysis oil hydrotreating and purification technologies.

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Agenda

- Plastic Recycling Landscape
- Lummus Plastic Pyrolysis Technology
- Technology Development
- Additional Configurations for Steam Cracker integration
  - Gas Recovery
  - Heavies Upgrading
- Pyrolysis Oil Quality
- Pyrolysis Oil Purification Process

Shredded plastic feedstock at New Hope Energy's facility in Texas, USA

Plastic Recycling Landscape

Plastic Waste by Category

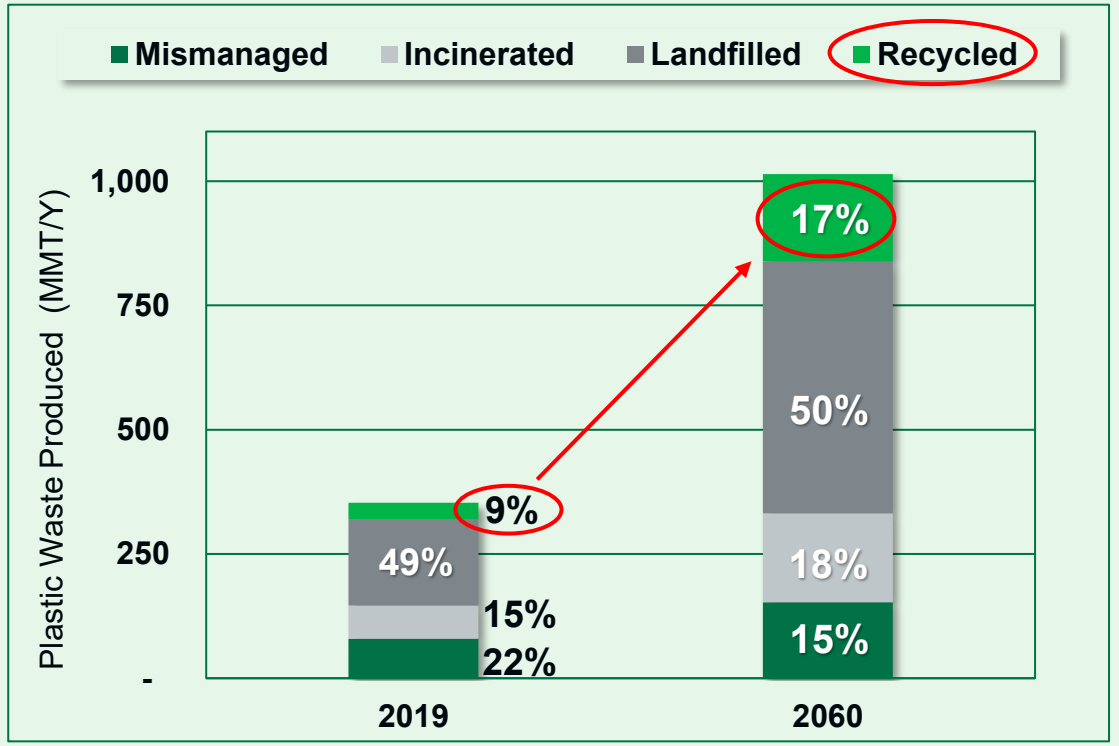
- **Today (2019)**
  - **9%** global plastic waste is recycled
  - 15% incinerated
  - 70+% mismanaged or sent to landfill
- **2060**
  - Recycling rates increase to 17%
  - Mismanaged % decreases

Plastic Waste Growth

- Plastic waste forecasted to triple by 2060
  - **170+ MMTPY** recycled plastic feedstock

Plastic Waste Projections

Plastic waste in million tonnes (MMT/Y) and shares (%) of plastic waste by category



Source: OECD ENV-Linkages model

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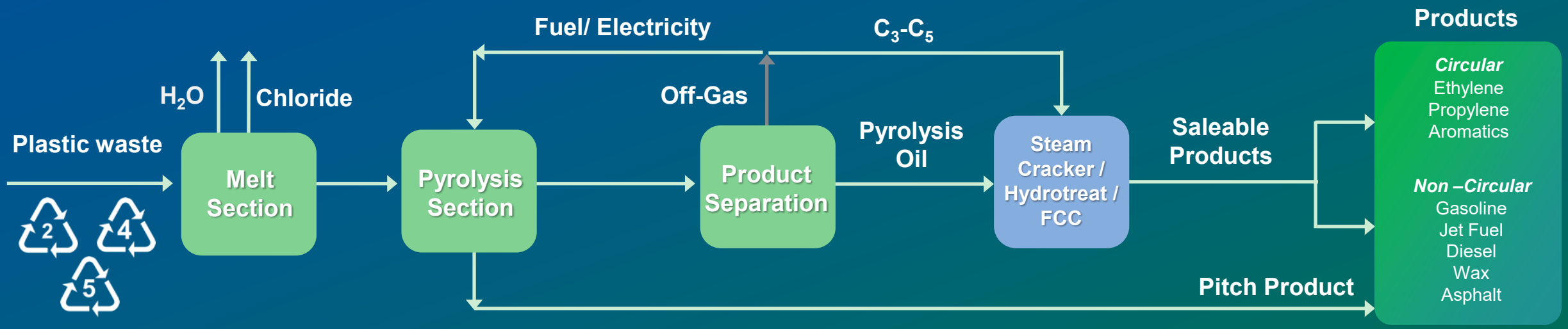
Large Scale Plastic Pyrolysis Technology

Large Scale Plastic Pyrolysis Technology



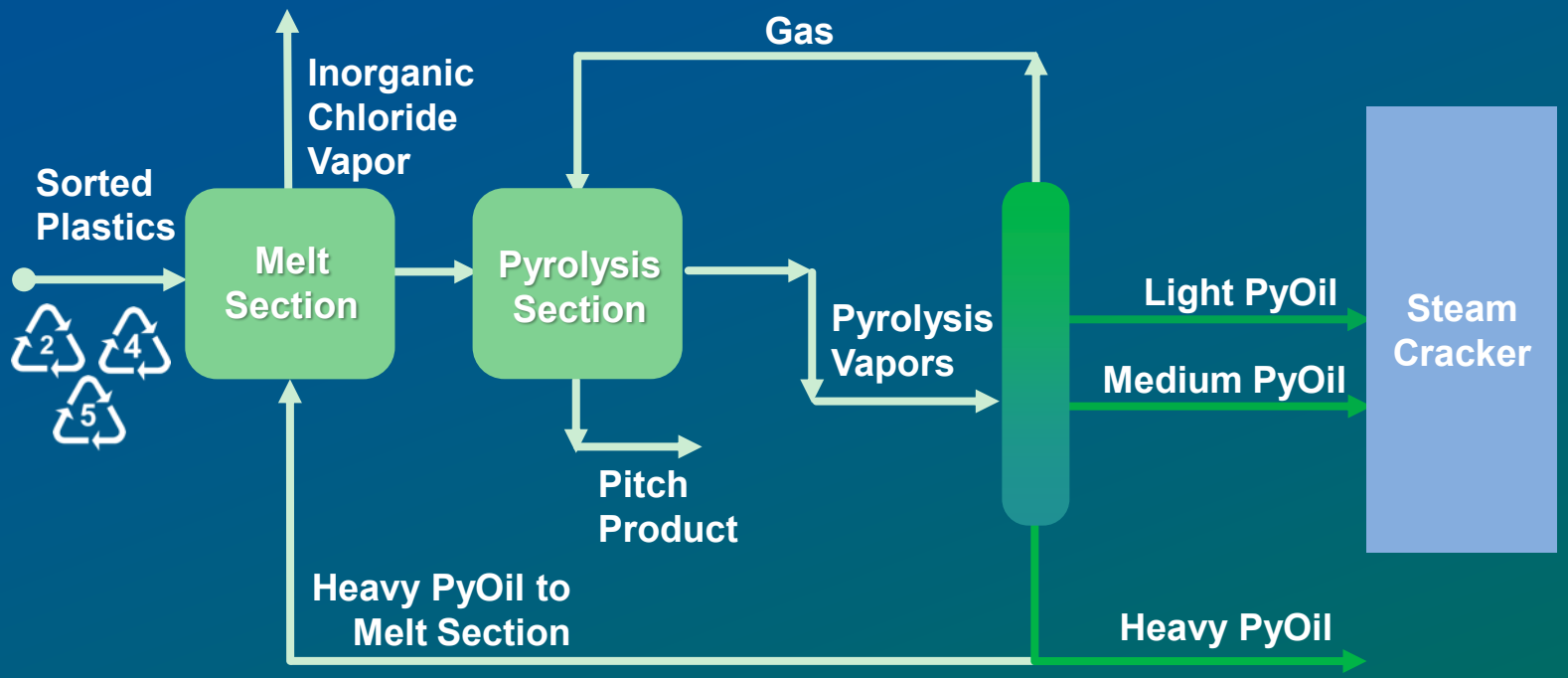
❖ **Fully continuous process**	❖ Easily integrated with refining & petchem assets
❖ Produces liquid pitch, **not char**	❖ Accepts **wide range of feedstock** mix
❖ High quality Pyoil products, **low in chlorides**	❖ No exotic metallurgy required
❖ Can be **powered by electricity** or fuel-fired	❖ **No solid waste** to manage

Feedstock Requirements and Certification

- Technology can process industrial waste plastic feedstock as well as post-consumer waste plastic feedstock.
  - Technology is ISCC certified for 100% PCR.
- Average particle size of the plastic feedstock material should be less than 2 inch.
- Technology can process higher limits of PS, PVC, however not recommend.

Physical composition	Specific Material (Dry Basis By Weight)	Min	Max
Preferred Plastics	Polypropylene (PP / HDPP)	85%	100%
	Polyethylene (HDPE / LDPE)		
	Polystyrene (PS)	0%	10%
Unwanted Materials	PET	0%	2.0%
	ABS	0%	1.0%
	Polyesters and other fibres	0%	1.0%
	Others (polycarbonate, polylactide, materials including fire retardants, etc)	0%	0.5%
	Paper, Cardboard	0%	0.5%
	Inerts, glass and metalics	0%	1.0%
	Other biogenic materials including wood	0%	0.25%
	PVC	0%	2.0%
	Moisture	0%	8.0%

Plastic Pyrolysis Unit (Base Case)

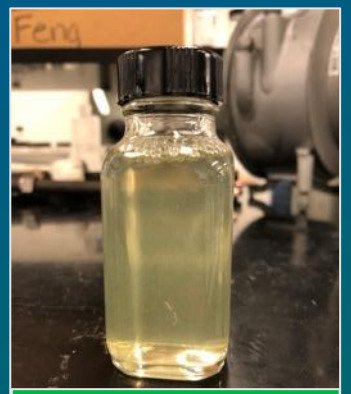


Advantages
Gas internally fuels process
Minimum CAPEX/OPEX
Small footprint

Product Yield

High conversion to circular products

- Produces cracker grade renewable feedstock
- Multiple options for producing olefins from Heavy PyOil
- Pitch can be used as binder for certain asphalt grade like PG 64



Light PyOil

Heavy PyOil

	Product	% By Weight
Steam Cracker	Cracked Gas C_1-C_5	22-30%
Steam Cracker	**Light PyOil** 70 - 200°C	16-20%
Steam Cracker	**Medium PyOil** 200 - 360°C	33-37%
Thermal Cracking/ FCC/ISOCracking	**Heavy PyOil** 360 - 640°C	14-18%
Asphalt Binder	Pitch	3-7%
	Total	**100%**

R&D Chemical Recycling Focus

Technology Development & Manufacturing Center

Pasadena, TX

- Rheology analysis
- Cold flow studies
- Heavy Oil Thermal Cracking (HOTC)
- Downstream processing
  - Steam Cracking
  - FCC
- Melting behavior
- Reaction studies
- Py oil purification
  - Chlorides
  - Oxygenates
  - Nitrogen
  - Sulfur
- Coordination with Universities

Chevron Lummus Global

Richmond, CA

- Hydrotreating
- Hydrocracking
- Novel Py oil purification

Pyrolysis Technology Development

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Scale Up

Batch → Continuous

Added Proprietary Melt Tank to separate melt & pyrolysis functions

- Converted process to continuous
- **100%** capacity increase

Feed System

Added Feed Injector to pre-melt the feedstock before melt tank

- Densifies feed
- Removes moisture

Reactor Internals

Designed reactor internals to control and optimize residence time

- **500%** capacity increase

Heating Efficiency

Melt Loop

Implemented heavy oil melt circulation to enhance melt plastic flow characteristics and stabilize feed viscosity

Recycle Streams

Introduced pyoil recycle streams to stabilize viscosity fluctuations from variations in plastic feed

Thermal Fluid

Consistent heat source to process to keep temperature profile stable and protect from operational upsets

Pyrolysis Technology Development

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Process Optimization

Electric Reactor

Electrified reactor heating mechanism to reduce carbon footprint and increase heating efficiency

Reactor Zone-Based Heating

Optimized zone-based operating parameters to maximize liquid yield without char formation

Continuous Pitch Removal

Converted pitch removal system to continuous to increase run lengths

Product Recovery

Separation System

Developed multiple configurations for product separation to tailor product cuts to exact client specifications

Gas Recovery

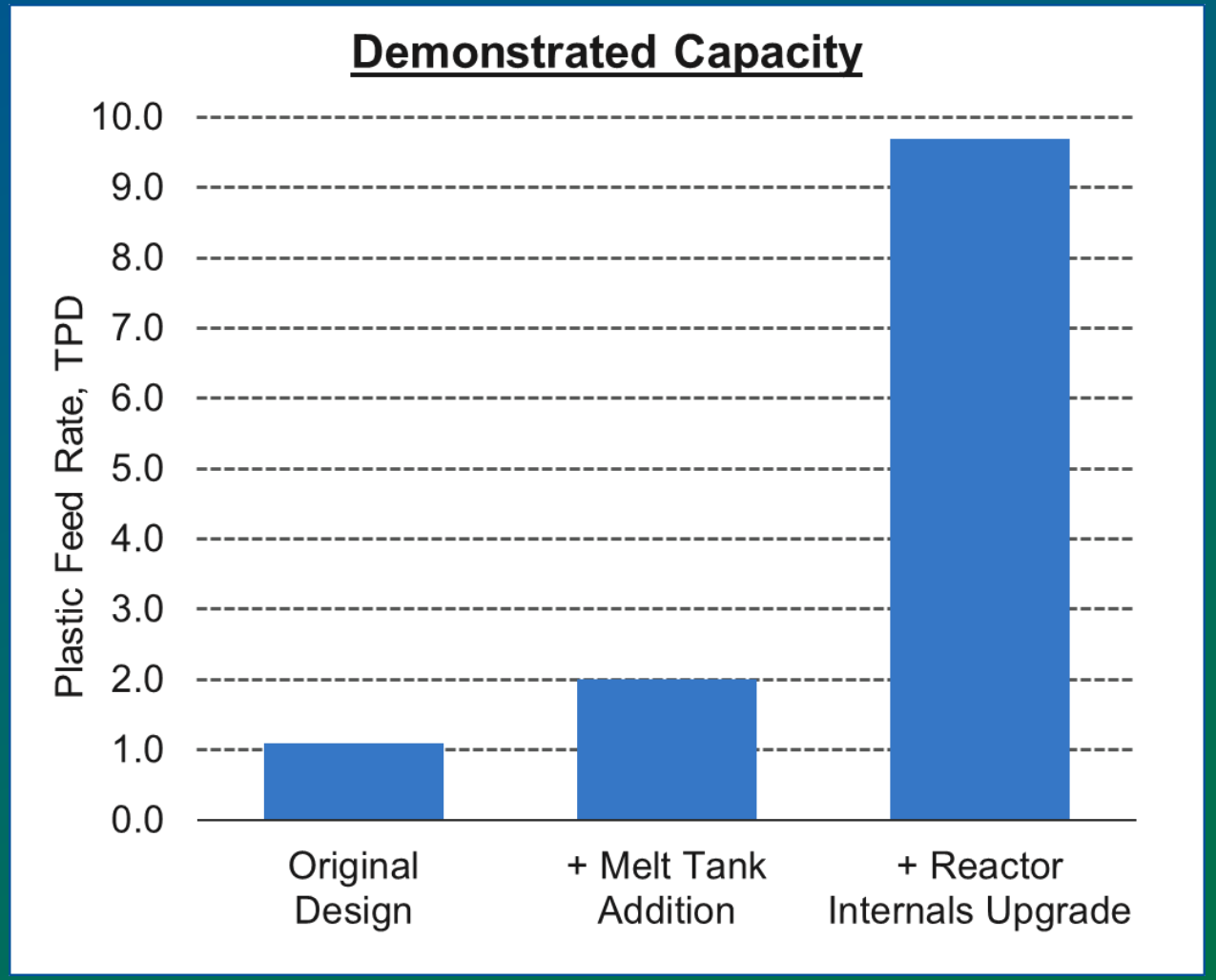
Designed Py Gas Recovery system to recover valuable C3 - C5 product

Chloride Reduction

Melt Tank vents HCl vapors which are captured and treated by caustic scrubber system to enable recovery

Capacity Scale-Up

1. Melt tank addition:
   - Resulted in 90% reactor capacity increase
2. Reactor internal modifications:
   - Resulted in further ~500% capacity increase (to ~10 tpd)
3. Performance confirms scale up to single reactor of 70 TPD capacity
   - Larger diameter and longer length for 20x heated surface area. Sized based on test run results



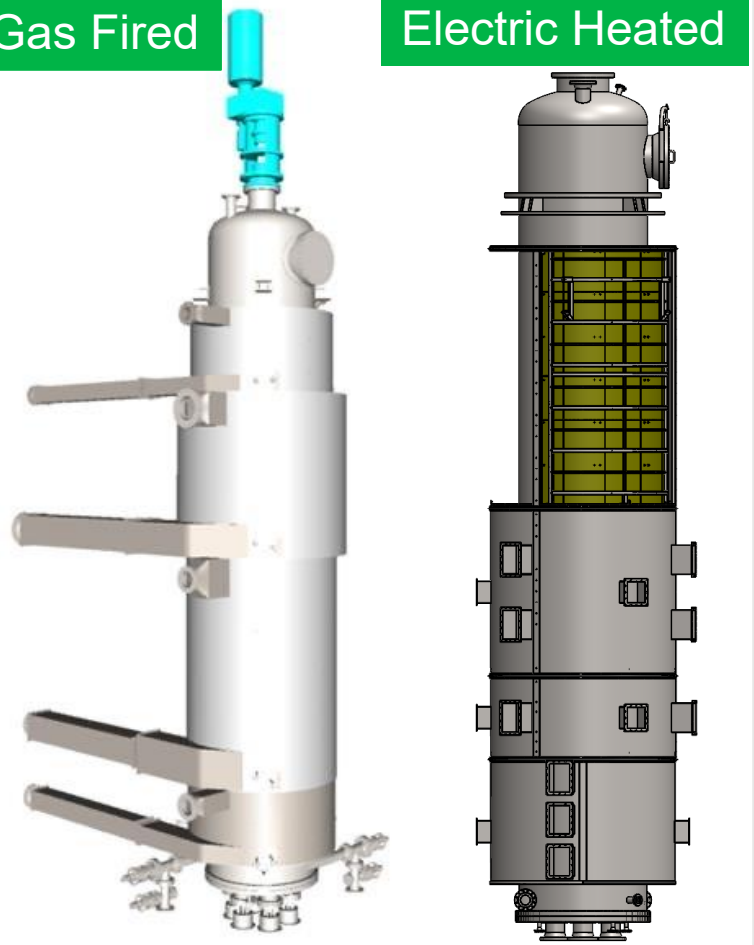
Advanced Pyrolysis Reactor Design

- High surface to volume design to maximize heat transfer
- Zone based modulation of heating rate and temperature control
- Optimized operating parameters for maximum light liquid yield
- Generation of liquid pitch instead of solid char
- Very low pressure operation for best pyrolysis reaction
- Fully electric design increases efficiency and reduces carbon footprint

Reactor 3D Model

Gas Fired

Electric Heated



Pyoil Upgrading Options

Pyoil yield depends on:

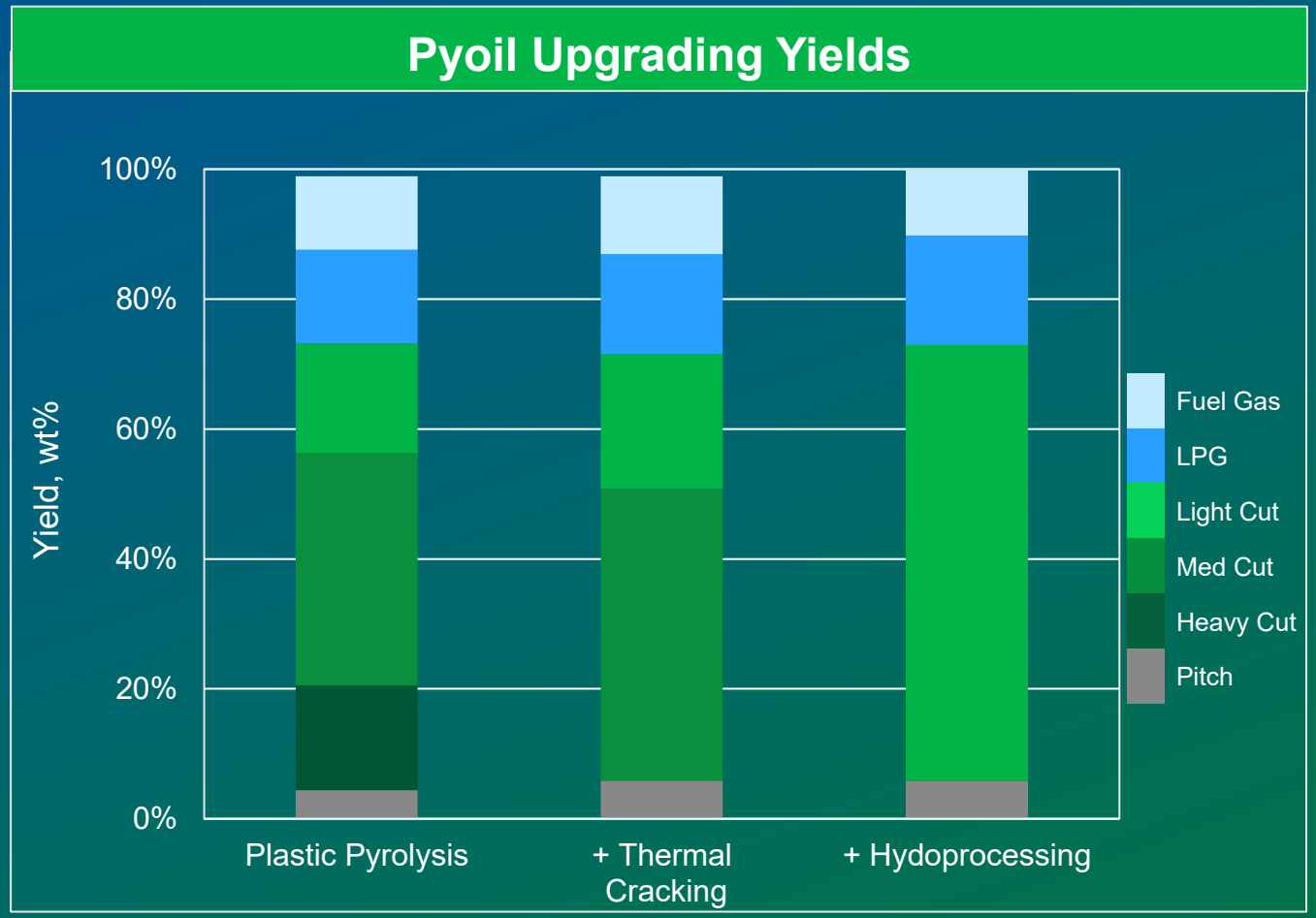
- Plastic feedstock characteristics
- Gas recovery configuration

Thermal Cracking eliminates heavy oil

- Increases potential cracker feed by 15-20%
- Slight increase in Pitch yield

Hydroprocessing maximizes cracker feedstock

- Up to 90% of products can be suitable cracker feed
- Lummus developed integrated design with CLG



Process Emissions

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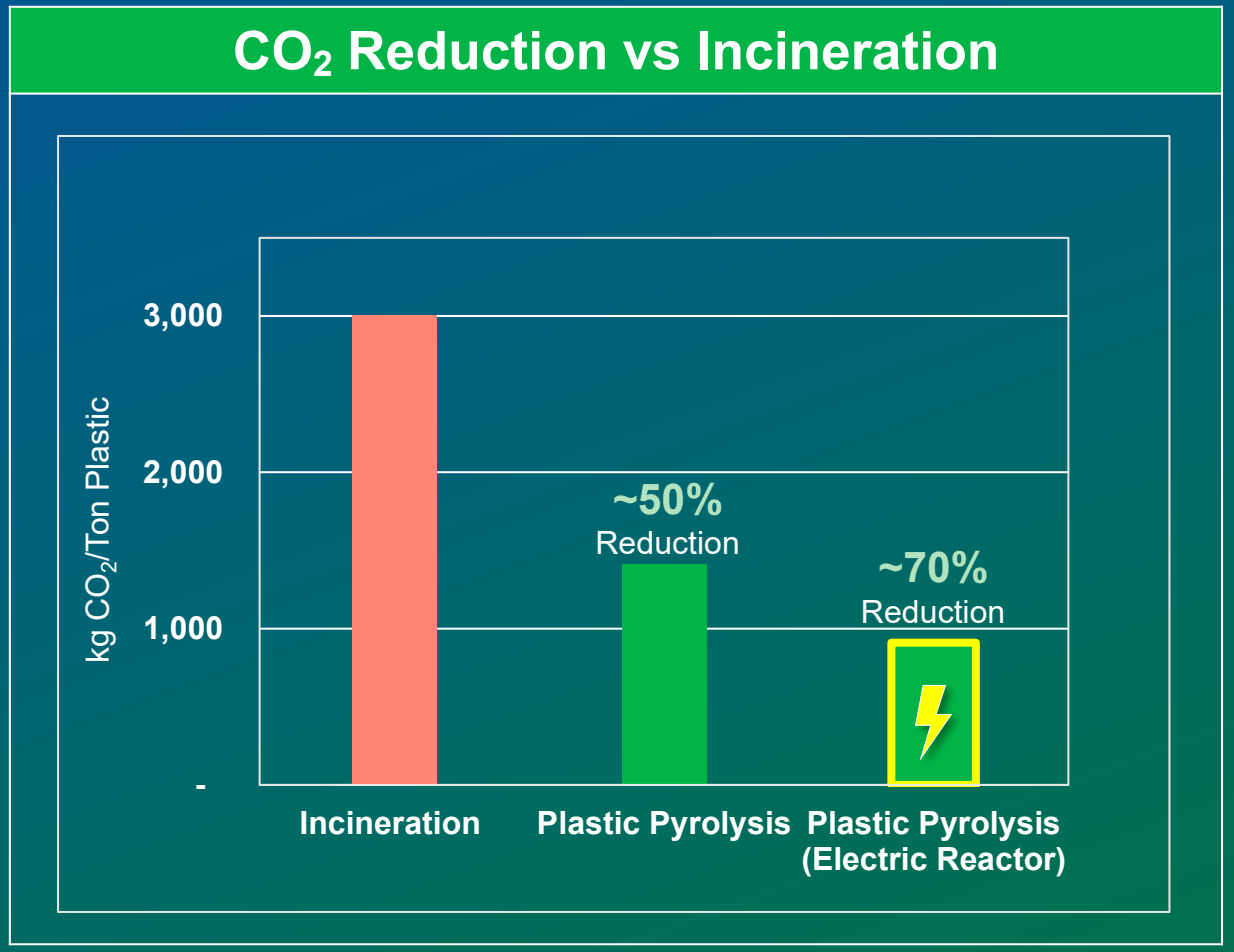
Significant CO_2 Reduction vs Incineration

Plastic Incineration

- Produces **~3,000** kg CO_2/Ton Plastic

Plastic Pyrolysis

- Every plastic pyrolysis configuration is a net CO_2 reduction compared to incineration
- Gas recovery with excess lights used as fuel results in maximum CO_2 reduction
- Electrifying reactor can reduce CO_2 by an additional 15-20%



- Incineration emissions calculated based on carbon content of HDPE/LDPE/PP plastic feed
- Plastic pyrolysis emissions include feedstock sorting and shredding

Designed to be Scalable

~50 kta per Train

Melt and Pyrolysis Train:

(2) Feed Injectors
(1) Melt Tank
(2) Pyrolysis Reactors

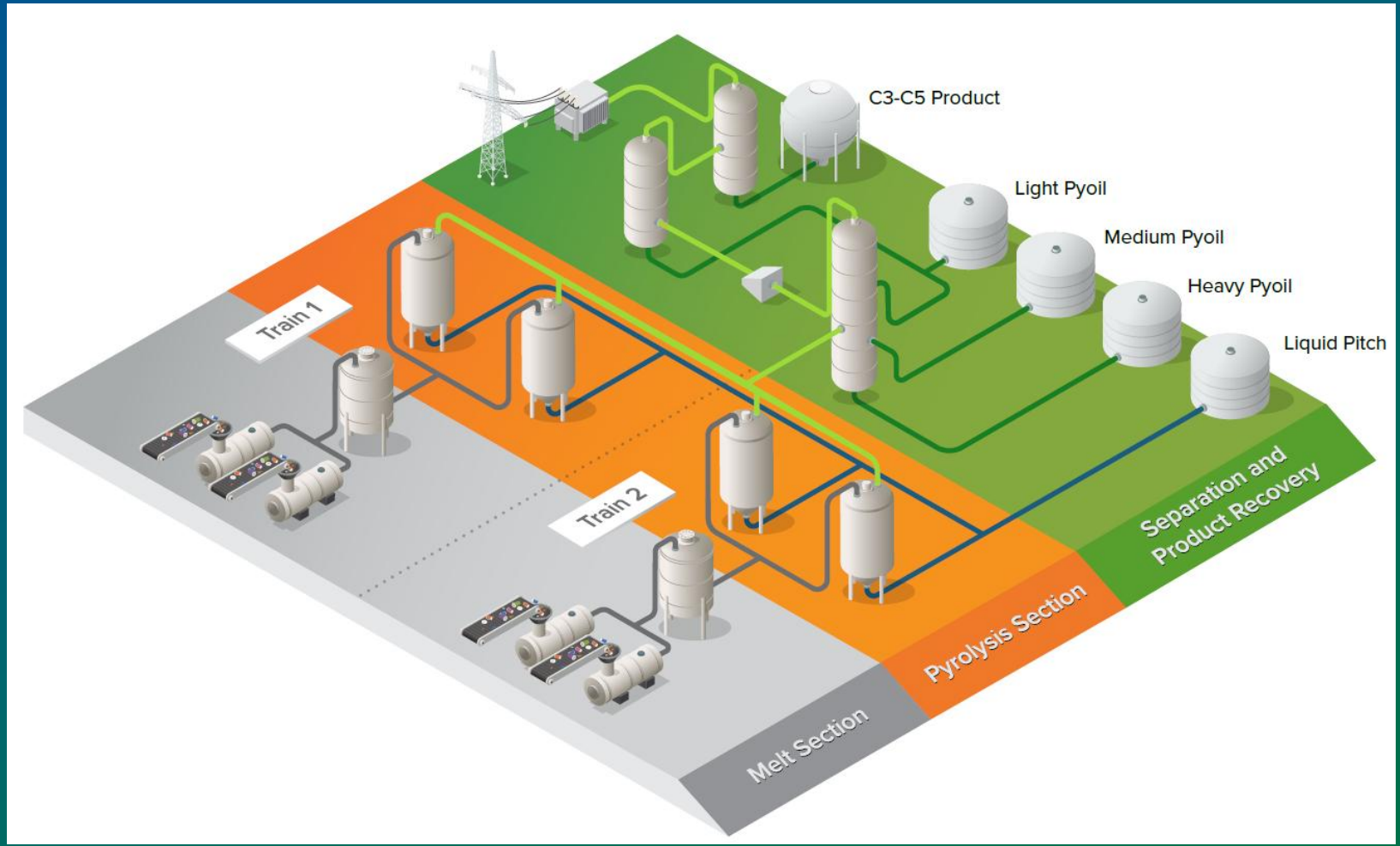
Common Separation Section:

- ✓ Multiple separation scheme designs depending on desired product slate

Py Gas Recovery:

- ✓ Separate C6+, C3-C5, and C1-C2 streams
  - ➢ Gas can be used as fuel or to generate power

Typical Two-Train Configuration



Typical Properties of Some Analyzed Light PyOil

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Cut point < 350°C and from different feedstocks

Specific Gravity	0.75-0.82
Paraffins, wt%	24-45
Olefins, wt%	26-58
Naphthenes, wt%	6-12
Aromatics, wt%	5-25
Iso/Normal Ratio	0.1-2.2

- PyOil is rich in olefins and paraffin content
- Full vaporization in the convection section is important
- Aromatics are mainly Mono and Di, very low Di+

Product Quality-Py Gas

	Offgas	C_3-C_5
Property	Mole %	Wt %
Nitrogen	2.16	0.00
Hydrogen	11.20	0.00
Water	0.18	0.02
Carbon Monoxide	0.92	0.00
Carbon Dioxide	1.32	0.04
Methane	24.53	0.00
Ethane	26.50	5.36
Ethylene	22.51	1.47
Propane	3.97	21.07
Propylene	6.05	21.29
Butane	0.07	15.36
C4 Olefins	0.10	21.69
1,3-Butadiene	0.01	2.35
Pentane	0.01	2.09
Hexane	0.07	4.11
C7 – 200°C (PHN)	0.39	5.14

Py Gas contains high amount of C2-C4 olefins

The gas is clean and can be recovered via steam cracker or FCC gas recovery section

For standalone pyrolysis plants the gas can be used as fuel for the process or recovered via liquifaction

Any excess gas can be used to generate electricity for the facility

Product Quality-Liquids

		Light Cut	Medium Cut	Heavy Cut	Pitch
Property	Unit				
Liquid Std Density	kg/m^3	735	821	876	987
Kinematic Viscosity	cSt	0.6 @ 42°C	1.5 @ 42°C	7.5 @ 80°C	151.5 @ 200°C
Diene (MAV)	mg/gm	2.5	1.2	0.5	
Cetane Index			52		
Br No		65	42	29	
Chloride	ppm	20	50	100	
Sulfur	ppm	80	110	150	250
Nitrogen	ppm	100	150	550	1000
Si	ppm	50	80	110	1100
ASTM D86 (LV)				**HT Simdist (WT)**	**HT Simdist (WT)**
IBP	°C	73	180	173	309
50%	°C	161	247	432	687
95%	°C	175	332	577	807
EBP	°C	196	358	640	820

Light and Medium cut can be blended with regular steam cracker feed

Heavy cut is suitable for FCC to produce more olefins

All products are high on hydrogen content. Low on MCRT and Aromatics

Pitch is suitable as binder for asphalt, fuel for cement plant

Contaminant Removal

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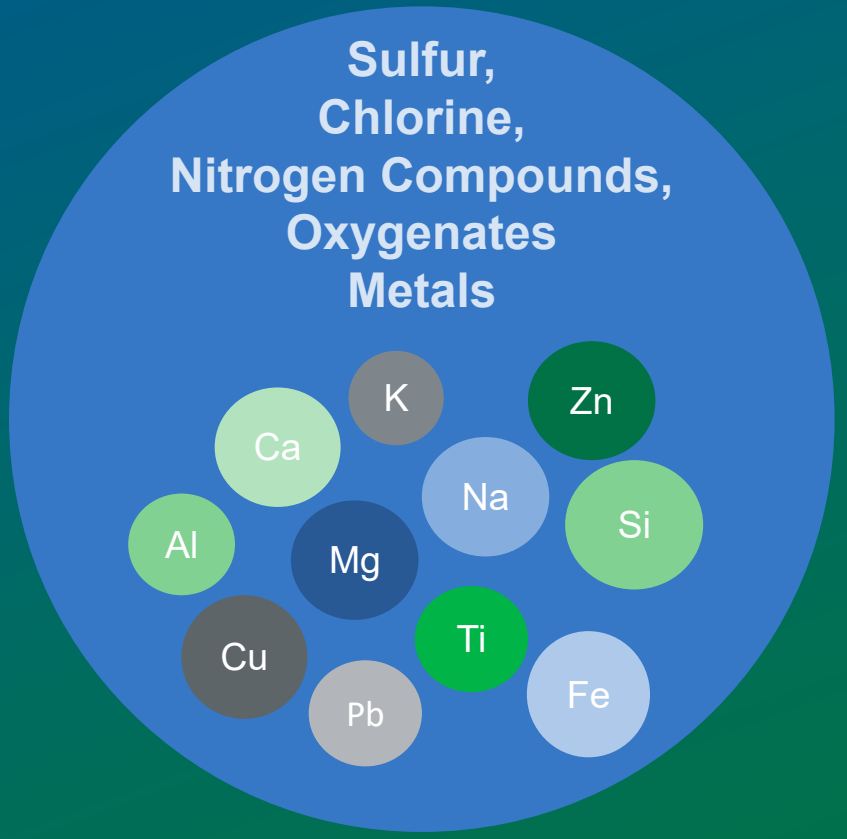
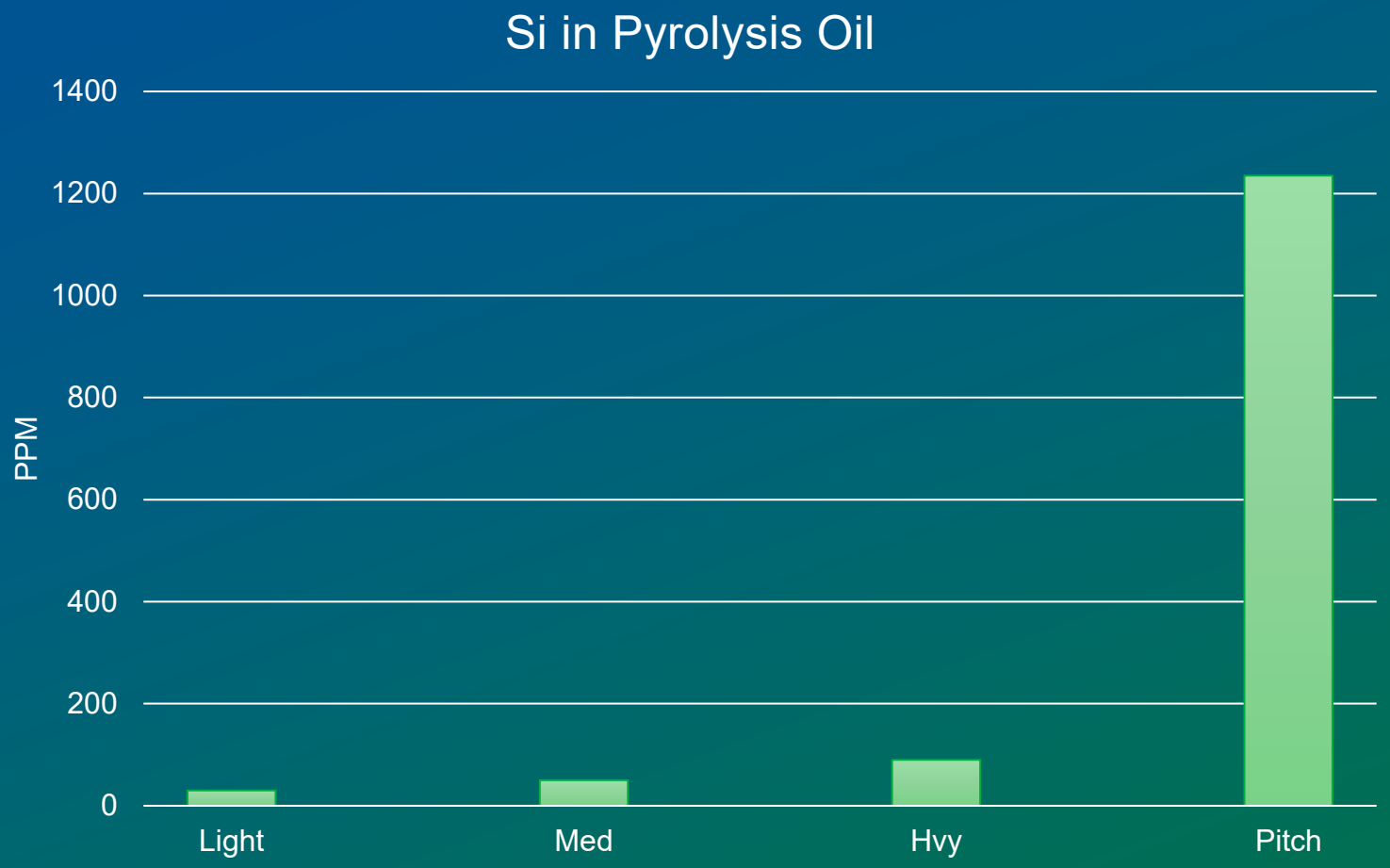
High quality pyrolysis product

Feed Injector	• Maximizes film type plastic intake • Removes moisture • Heats plastic
Melt Tank	• Chloride/biogenic removal • Recycle streams stabilize viscosity fluctuations and improve heat transfer
Alkaline chemical	• Neutralizes organic chloride, reducing concentration in Light and Medium PyOil to <50 ppm
Pitch	• Continuous removal prevents coke build up inside reactor • Removes Si and heavy metals

Possible Feedstock Contaminants



Contaminants removal within Lummus Plastic Pyrolysis Process



PyOil Decontamination and Stabilization

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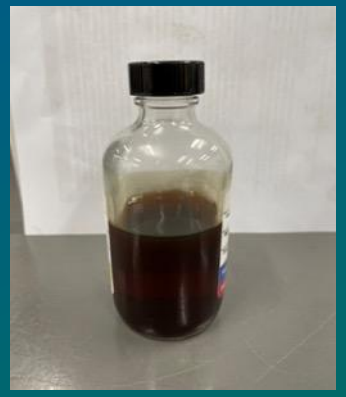
Antioxidant

Full Range Pyrolysis Oil
TAN 5-8
N 125-150 ppm
S 10-30 ppm
Chloride ~50 ppm
Si : ~100 ppm



Purification Process

Removal Efficiency
Chloride 98%,
Si 92%;
Fe 98%;
Zn 100%

Reduced Oxygenates,
Nitrogen, Sulfur, Fines,
TAN <1
Improved Color
Removes Diolefin

Storage & Transport

- **Developed jointly by Chevron and Lummus**
- **No hydrogen, non catalytic process**
- **Removes main contaminants from full range pyrolysis oil**

Key Takeaways

- Strong growth and maturation of plastic recycling market expected – driven by government regulation and brand pledges
- Lummus' Plastic Pyrolysis technology is commercially demonstrated
  - Produces superior quality PyOil product that can be sent directly to steam cracker as a blend or after purification
  - Significantly reduces CO_2 compared to incineration
  - Optional configurations allow for greater flexibility and product upgrading
  - Continuous process for maximum efficiency
  - Novel purification process to remove major contaminants
- Technology is being licensed at a large scale

Thank You

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