Chemical Catalysts as Growth Drivers of PGM

IPMI European Chapter 2017, Prague

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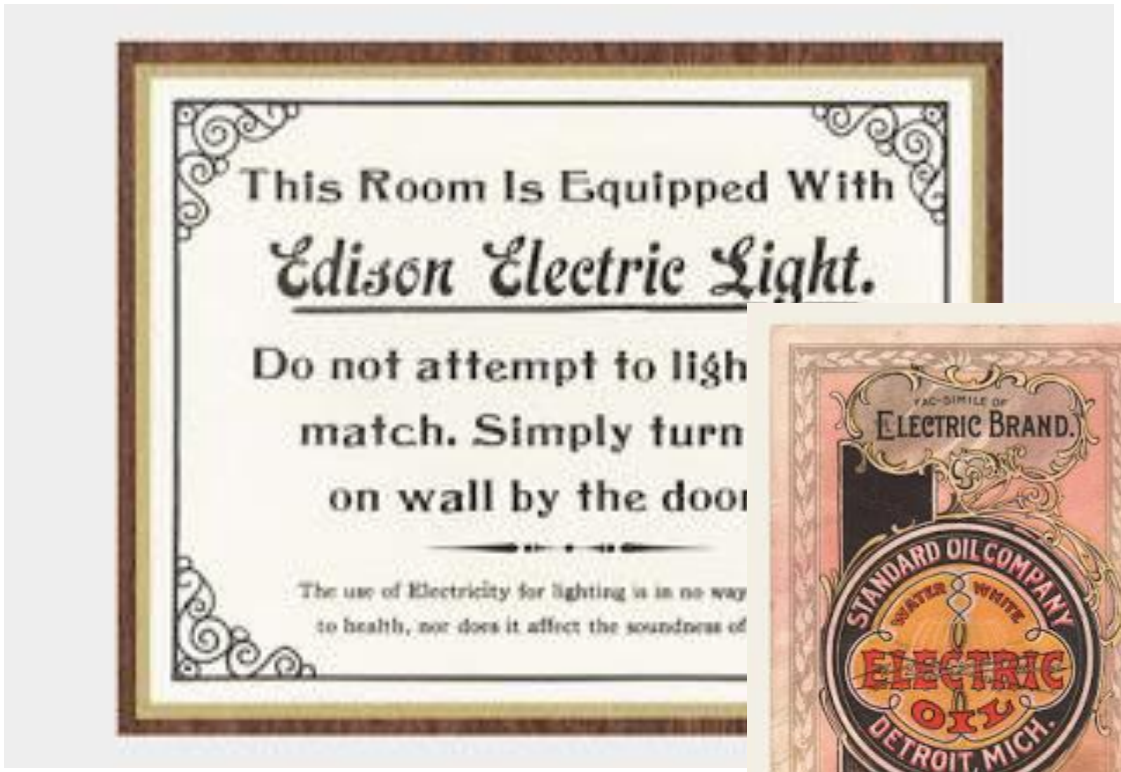
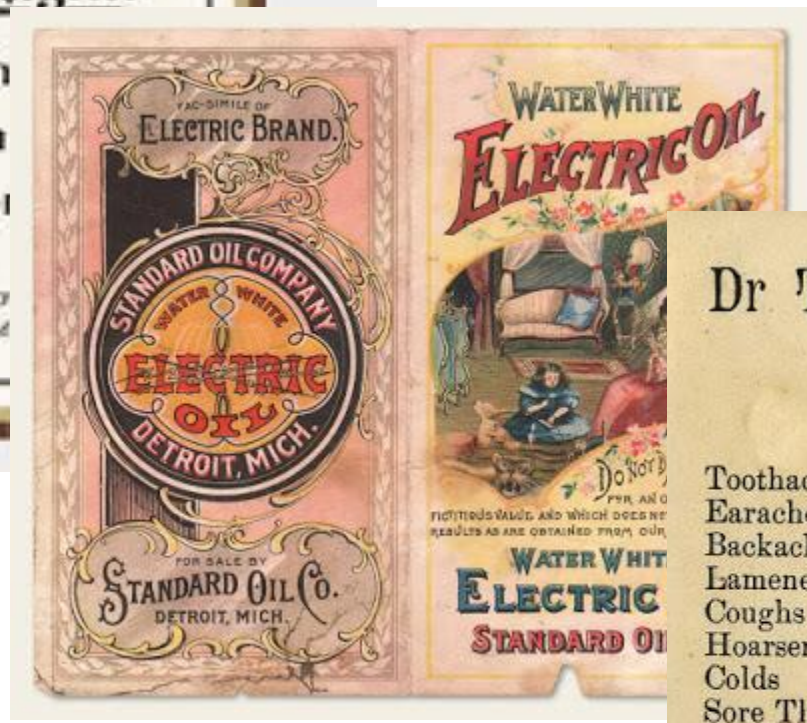




Dr Thomas' Eclectric Oil!

What it has Done.
What it will Do.

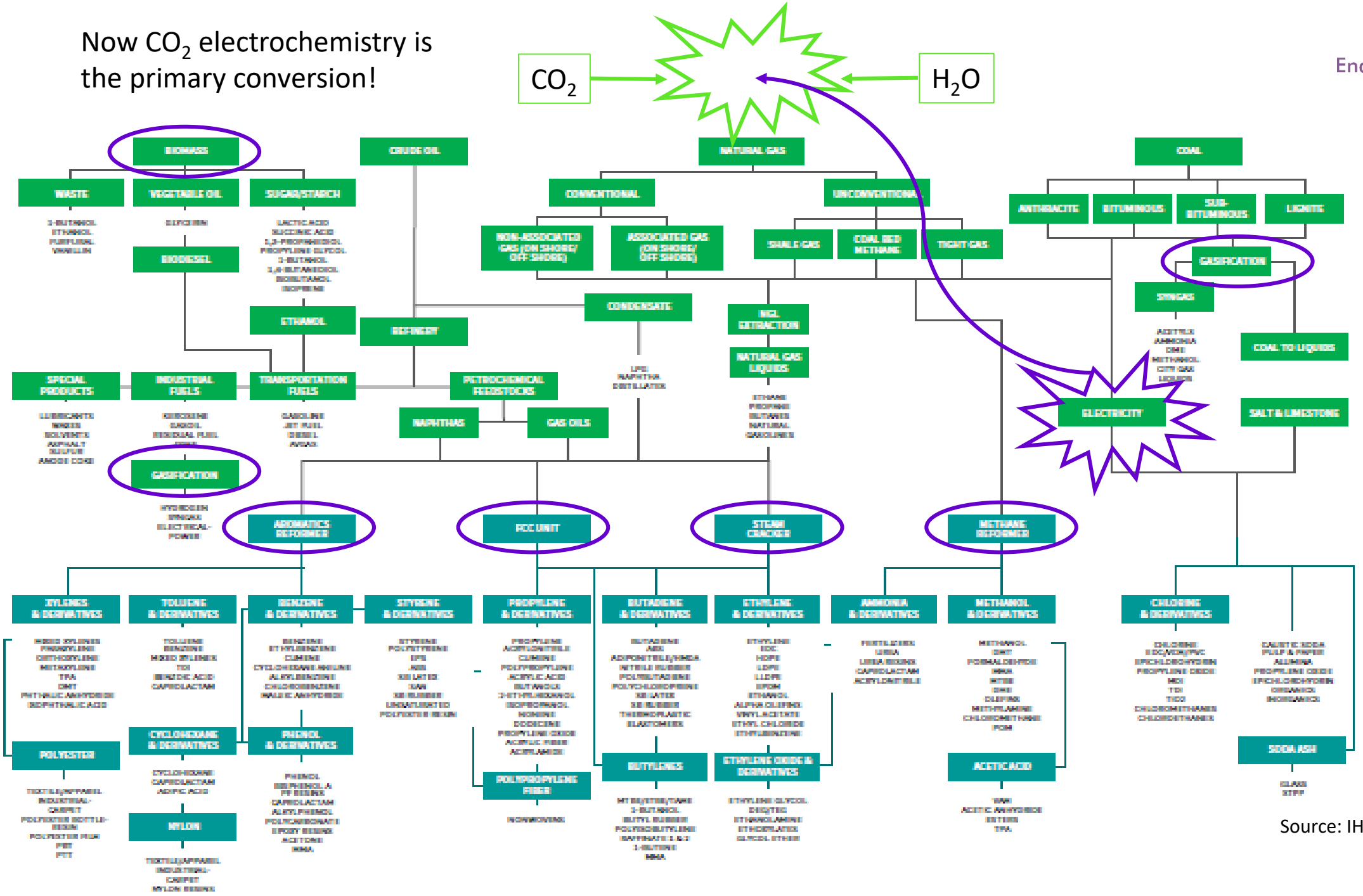
IT WILL POSITIVELY CURE

Toothache	in	5 Minutes
Earache	"	2 "
Backache	"	2 Hours
Lameness	"	2 Days
Coughs	"	20 Minutes
Hoarseness	"	1 Hour
Colds	"	24 Hours
Sore Throat	"	12 "
Deafness	"	2 Days
Pain of Burn	"	5 Minutes
" Scald	"	5 "

Croup it will ease in 5 minutes, and positively cure any case when used at the outset.

Remember that Dr. Thomas' Eclectric Oil is only 50 cents per bottle, and one bottle will go farther than half a dozen of an ordinary medicine.

Now CO_2 electrochemistry is the primary conversion!



Source: IHS Markit

Contents

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Summary of Research Approach

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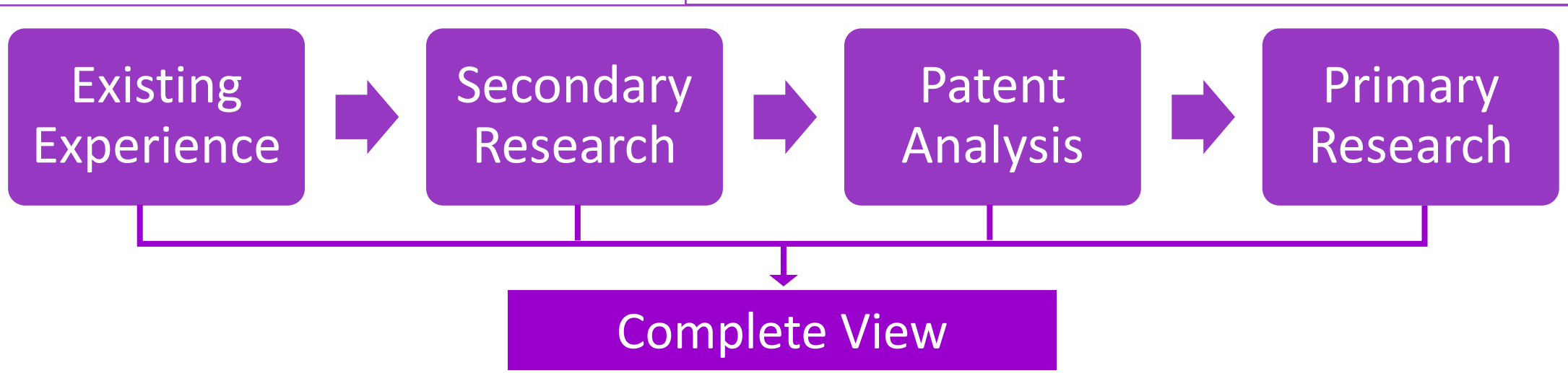
Optimising Technology Portfolios

5 Blocks of Experience:

- Catalyst Research and Development
- Catalyst and Chemicals Markets
- Platinum Group Metals (PGM) markets
- Information Science and Patent Analysis
- Chemicals and Materials Consulting



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Enabled Future Limited Products & Services

	Consulting	Training	Multi-Client Reports	Thought Leadership

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	Consulting	Training	Multi-Client Reports	Thought Leadership
Additive Manufacturing	●	●●	●●	●●

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	Consulting	Training	Multi-Client Reports	Thought Leadership
Additive Manufacturing	●	●●	●●	●●
Catalysts & Chemicals	●●●	●	●●●	●●●

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Enabled Future Limited Products & Services

	Consulting	Training	Multi-Client Reports	Thought Leadership
Additive Manufacturing	●	●●	●●	●●
Catalysts & Chemicals	●●●	●	●●●	●●●
Batteries	●	●	●	●

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	Consulting	Training	Multi-Client Reports	Thought Leadership
Additive Manufacturing	●	●●	●●	●●
Catalysts & Chemicals	●●●	●	●●●	●●●
Batteries	●	●	●	●
Nanotechnology	●	●	●	●

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Enabled Future Limited Products & Services

	Consulting	Training	Multi-Client Reports	Thought Leadership
Additive Manufacturing				
Catalysts & Chemicals				
Batteries				
Nanotechnology				

Advanced Manufacturing
Circular Economy
Industry 4.0

Electrification

- Electrification Roadmap
- Implications for Automotive PGM
- Opportunities for non-automotive PGM

The vast range and constant updating of EV forecasts is a supply chain planning nightmare

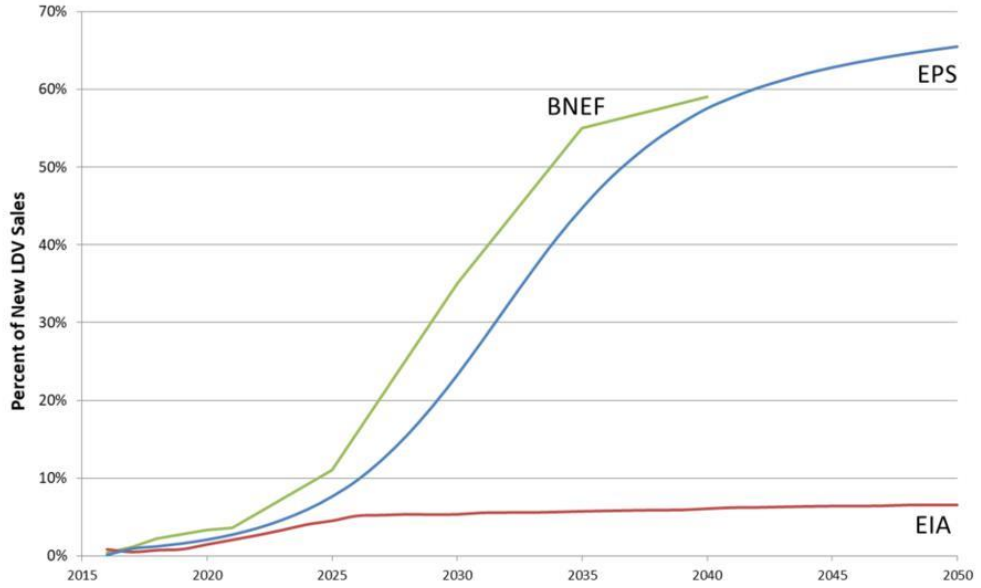

Figure 1. Projections of U.S. market share of EVs from three sources: the Energy Policy Simulator (EPS) 1.3.1 BAU case, the Energy Information Administration (EIA) Annual Energy Outlook 2017 "No Clean Power Plan" side case, and the Bloomberg New Energy Finance (BNEF) Electric Vehicle Outlook 2017.

Source: Forbes

- Forecasts range between <10% to >50% of new car sales globally by 2040.
- Figures are constantly being revised upwards.
- The IEA, EIA, Wood McKenzie and BP are sticking with up to 10% by 2035.
- This year Bloomberg upped their forecast from 35% in 2040 to 54%.
- The US Energy Innovation EPS model predicts 65-75% EV penetration by 2050.
- ING published figures suggesting Europe would be 100% electric (BEV) by 2035.
- The only thing that is certain is uncertainty.

The historic figures indicate rapid growth and there is no reason to suggest a slowdown

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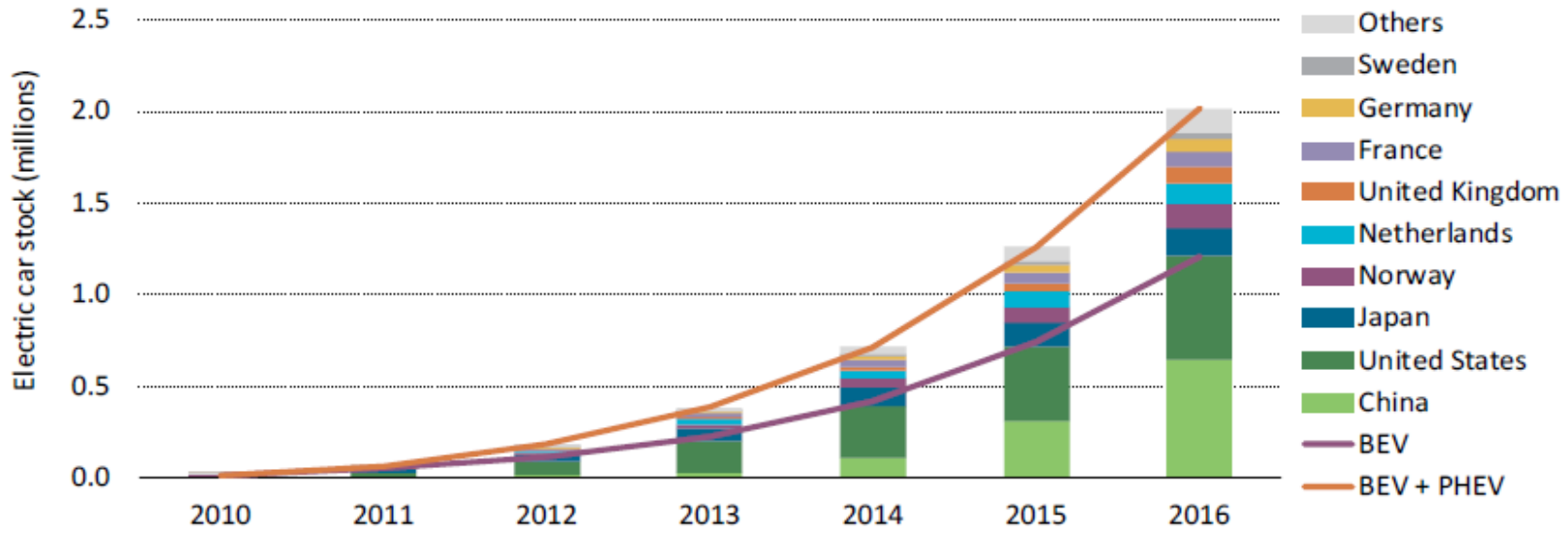

Source: International Energy Agency (IEA) Global EV Outlook 2017

- Past performance, while no prediction of future suggest no reason for a slow down in EV growth.
- In reality, even if the vehicle fleet is only 25% BEV by 2035-2040, this would have more than a profound effect on manufacturing supply chains including that of PGM. This needs to be understood, risks mitigated and opportunities maximised.

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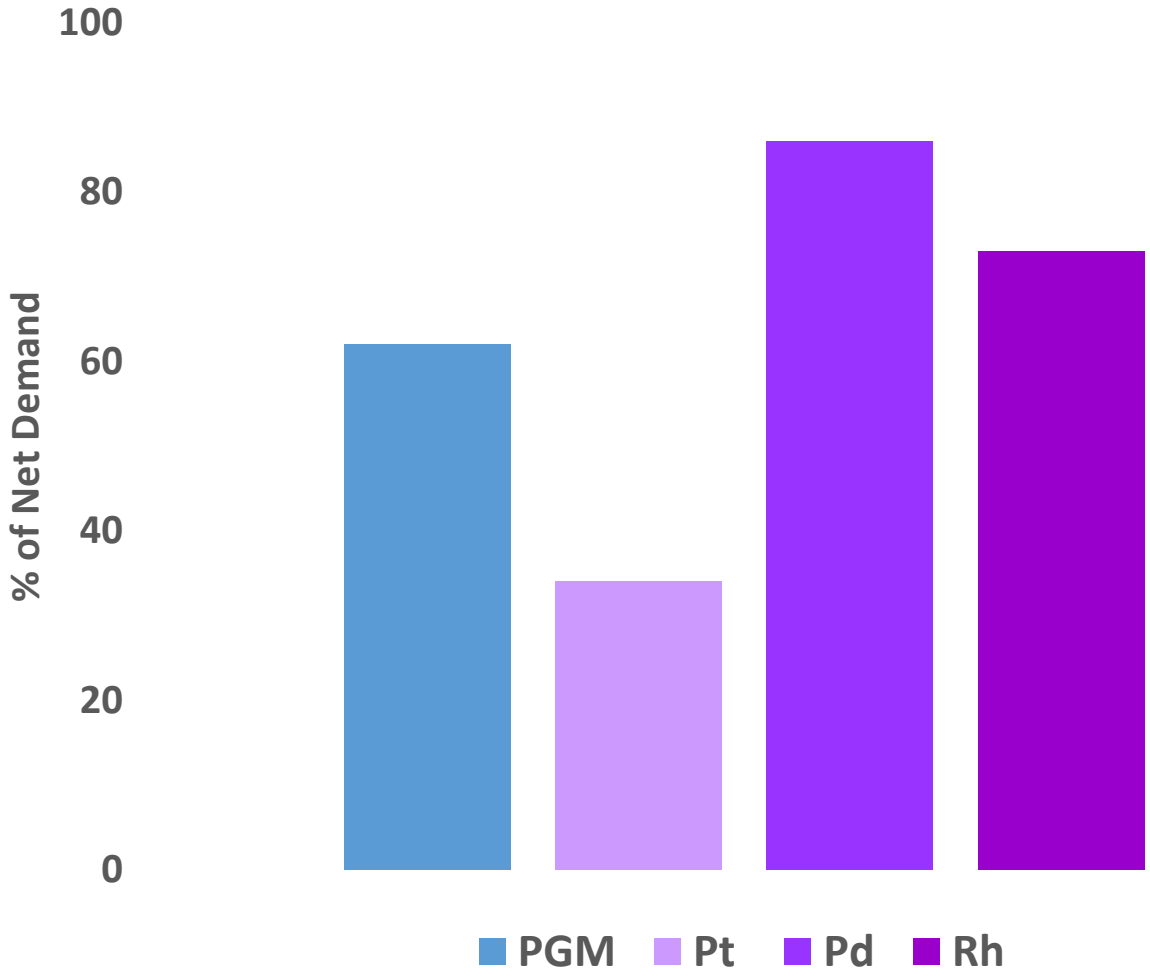
Automotive PGM consumption…potential for erosion and uncertain timing



Source figures: Johnson Matthey Platinum Book

- Over 60% of Net PGM demand is based on automotive consumption
- Automotive PGM demand is highly exposed to electrification
- There will be a ‘tipping point’ when rising auto sales can’t compensate for the % of new electric vehicles
- PGM returning from scrapped catalysts and declining gasoline demand will exacerbate the problem
- Can this PGM consumption be replaced?

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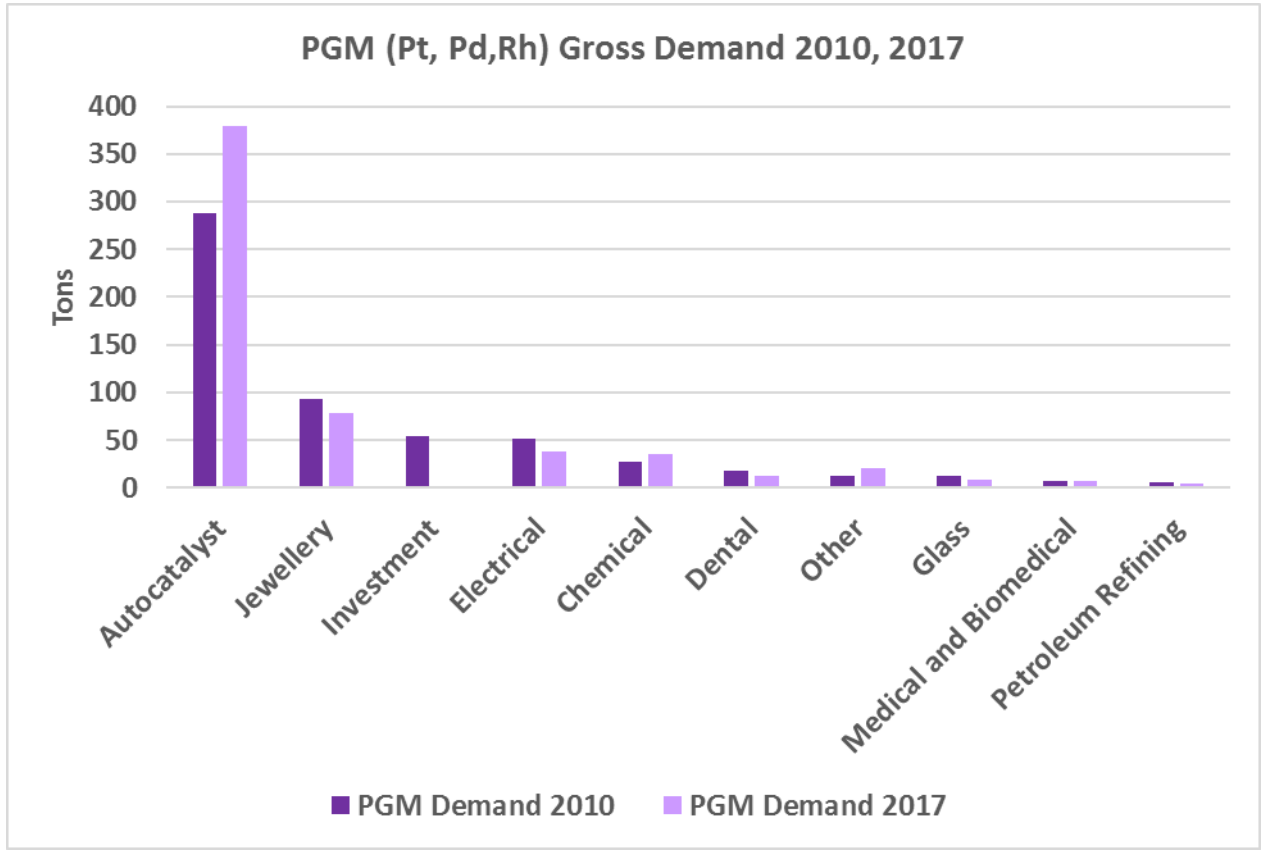
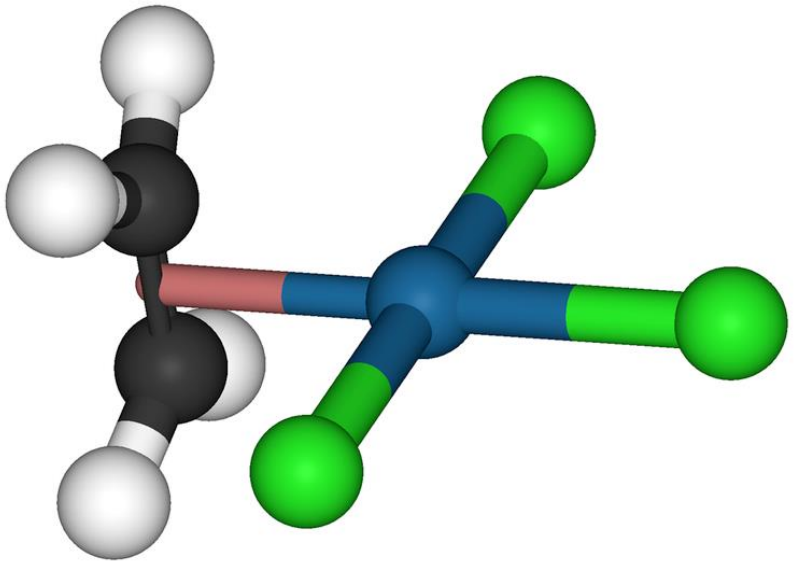
Almost all PGM growth is for automotive



Source figures: Johnson Matthey Platinum Book

- Between 2010-2017 automotive PGM accounts for 90% of new gross major PGM demand.
- Besides auto, only chemical and niche “other” apps showed any positive change.
- New capacity represents the best growth for chemicals (losses are not ideal anyway).
- What % of carbon is converted using a PGM catalyst? Do we have a target?

PGM Chemical Catalysts – Current Feedstocks



- Opportunities by feedstock
- Future process landscape

New uses of PGM but no “gamechangers”

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New uses of PGM but no “gamechangers”

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Feedstock	Opportunity	PGM	TRL	Potential for Success
Natural Gas	C1- DHA, OCM,	Pd	Demo/Pilot	++ Makes use of cheap, plentiful feedstock -- Currently limited by techno-economics
	Modular F-T	Pt, Pd, Rh	Early Commercial	++Several PGM catalysts required; -- Requires specific feedstock advantages
	PDH	Pt	Commercial	+++ High growth forecast out to 2030; significant PGM for new builds - Competes with non-PGM processes

New uses of PGM but no “gamechangers”

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Feedstock	Opportunity	PGM	TRL	Potential for Success
Natural Gas	C1- OCM, DHA	Pd	Demo (OCM)	++ Makes use of cheap, plentiful feedstock -- Currently limited by techno-economics
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	ODH	Pt	Commercial	+++ High growth forecast out to 2030; significant PGM for new builds - Competes with non-PGM processes
Oil/NGL	Direct Cracking Crude	Pt, Pd	Early Commercial	++ Several processes developed --- PGM catalysts not central to the flowscheme (but can be integrated) -- Requires specific feedstock advantages
	Heavy Upgrading	Pt, Pd	Pilot Scale	++ Attractive to valorise heavy fractions + PGM may be needed downstream of main cracker -- Constrained by techno-economics

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Coal	Coal-to-MEG	Pd	Commercial	++ PGM requirement seen over the last several years. -- Techno-economic difficulties, product quality not polymer grade
	Dimethyl Carbonate	Pd	Early Commercial	++ New PGM requirement -- Competes with other DMC processes; yet to be proven at scale

New uses of PGM but no “gamechangers”

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Biomass	Platform Chemicals	Pt, Pd	Early Commercial	+++ High growth rates, supported by techno-economics, several PGM catalyst processes -- Competition from biocatalytic systems
	Modular F-T	Pt, Pd, Rh	Early Commercial	++Several PGM catalysts required; -- Requires specific feedstock advantages
	HVO/Drop-in-Diesel	Pt, Pd	Commercial	++ Proven , simple, high PGM requirement for new plants -- Electrification of vehicles, non-PGM catalysts also employed

A bright spot for PGM is in biobased Chemicals

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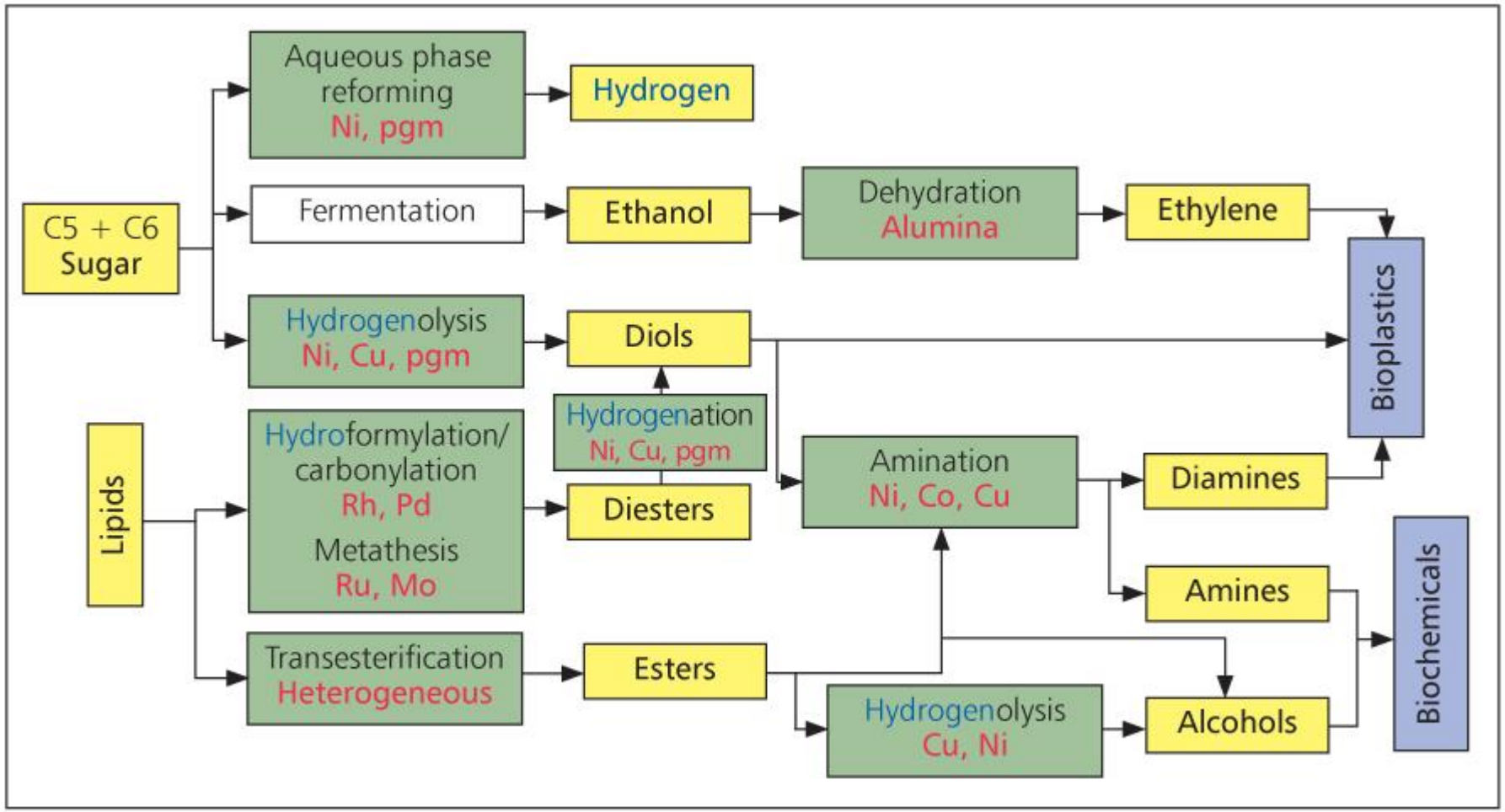

Source: Andrew D. Heavers* and Michael J. Watson; *Platinum Metals Rev.*, 2013, **57**, (4), 322

Time for a new lens

- What does the future hold for new process chemistries and catalysts?

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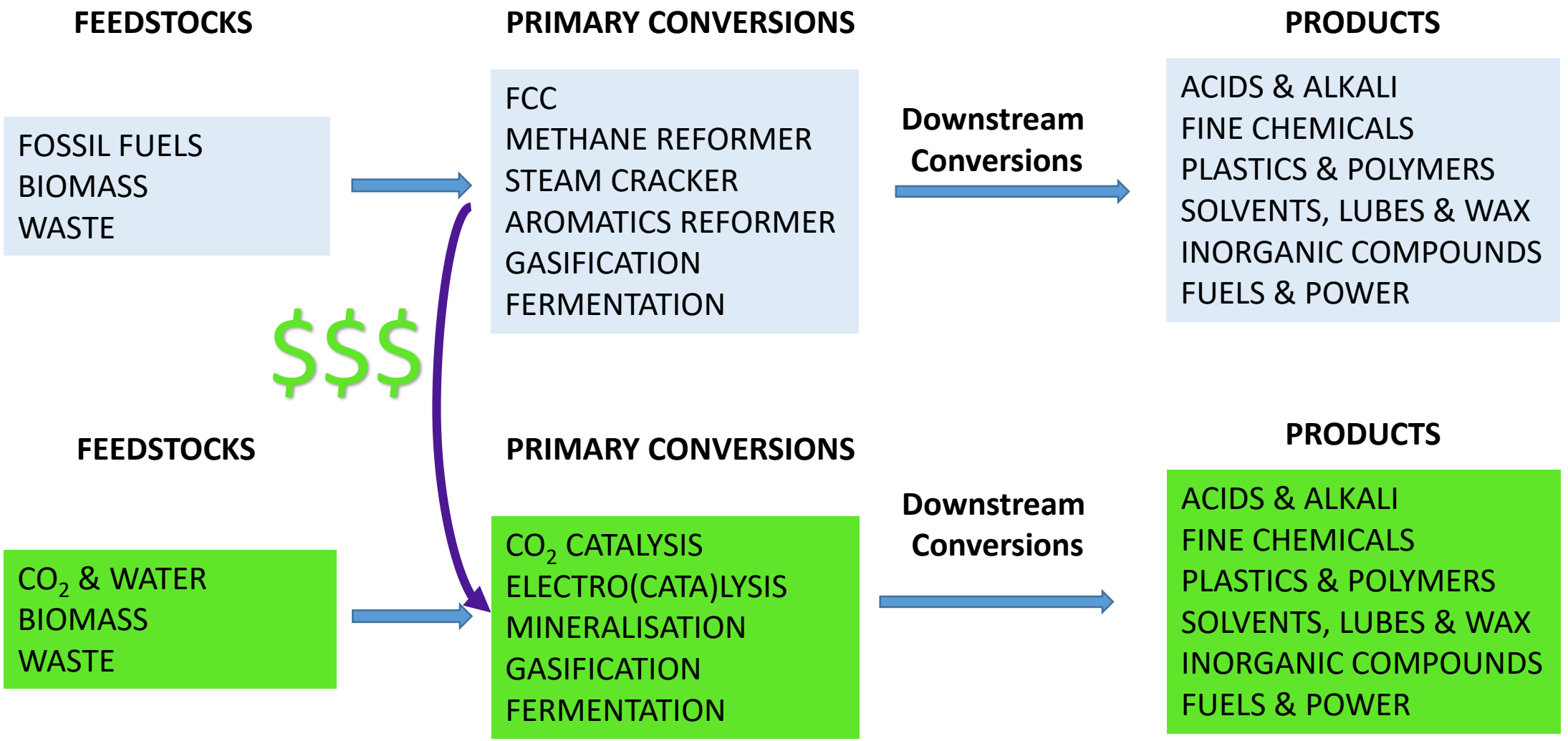
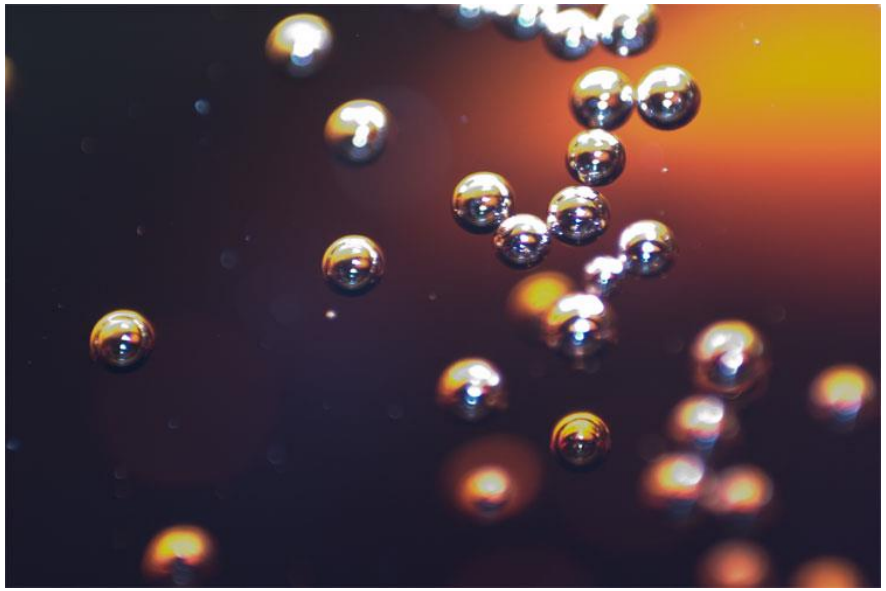
Real gamechangers come from shifts in feedstocks and process chemistry

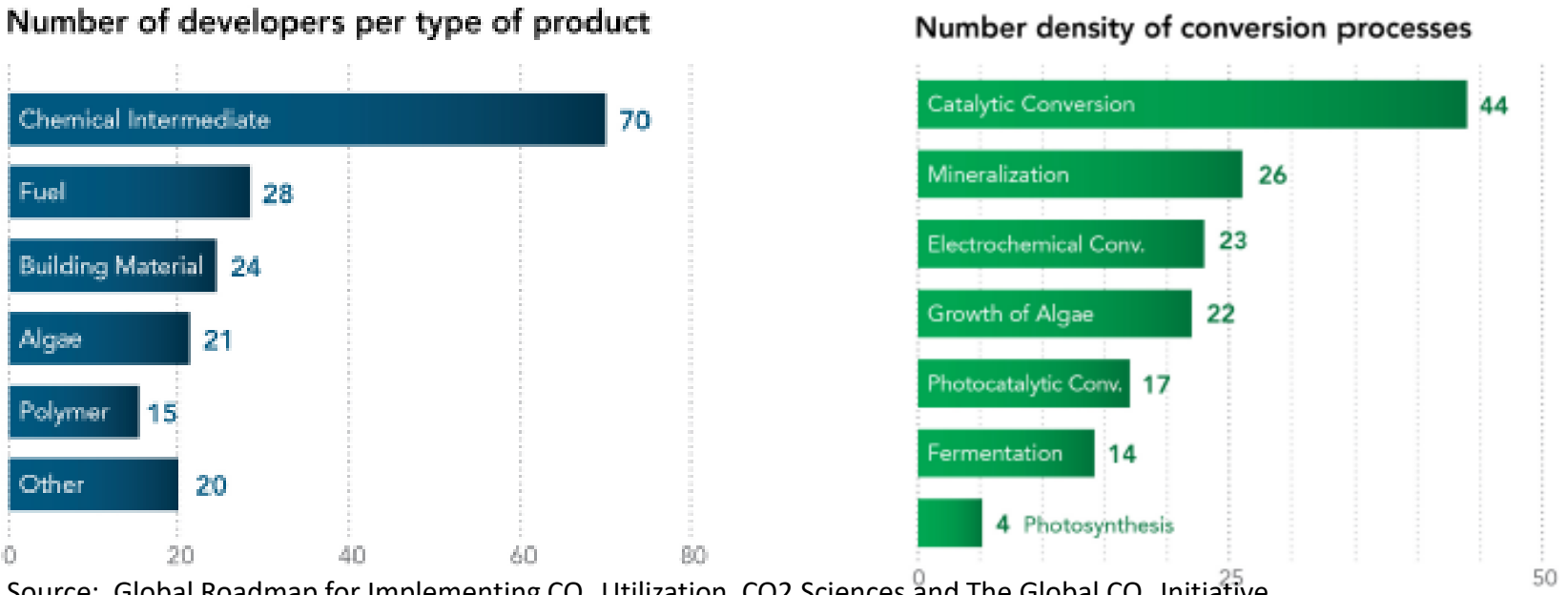


PGM Chemical Catalysts – CO2U



- Intro to CO2U
- Market for CO2U
- CO2U Value Chain
- Enabling technologies
- PGM for CO2U

What is CO2U and why is it important?



Source: Global Roadmap for Implementing CO_2 Utilization, CO2 Sciences and The Global CO_2 Initiative

- Carbon Dioxide Utilisation (CO2U), also referred to as Carbon Capture and Utilisation (CCU), is a fast growing market that converts CO_2 into a range of useful chemicals, fuels and products.
- CO2U has the potential to reduce anthropogenic CO_2 emissions by up to 7 gigaton of CO_2 equivalent per year (7 $GTCO_2eq$) which is 15% of the current total.
- Over 130 separate developers working in chemicals, fuels and polymers. At least half use catalysts. Ideal time to engineer in PGM to the new processes is now.

CO2U is a success story waiting to happen

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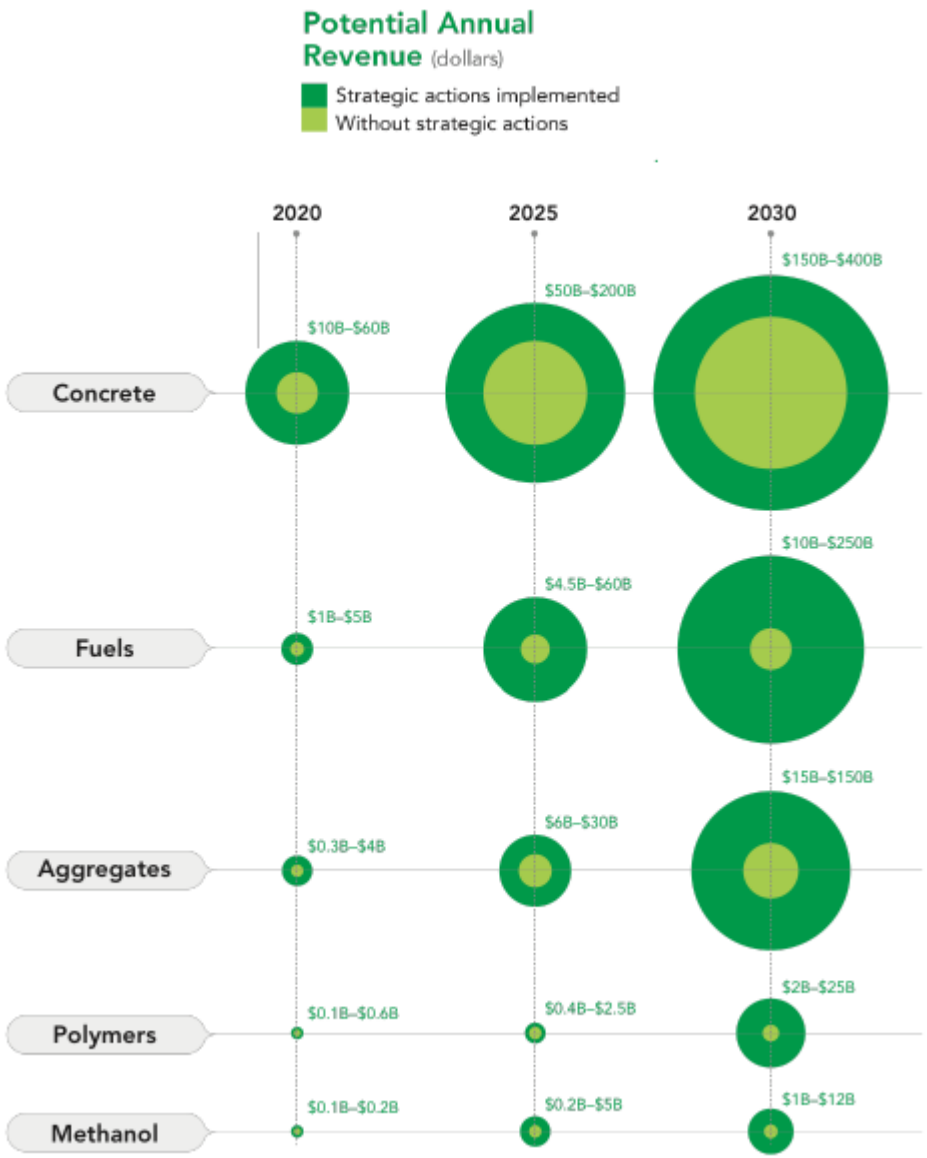

- CO_2 Utilisation is already commercial within the aggregates and concrete sectors and generating $10 bn in revenue.
- It is fast growing for a range of chemicals, intermediates, polymers and fuels. Revenues already forecast at $1.2 bn in 2020 and set to reach $13 bn by 2030 without policy intervention. (CAGR = 56%)
- CO2U has the potential to be the anathema PGM demand needs to plug the gap left by reduced automotive consumption.

Source: Global Roadmap for Implementing CO_2 Utilization, CO2 Sciences and The Global CO_2 Initiative

CO_2 start-ups have been working hard on CO2U for a range of chemicals

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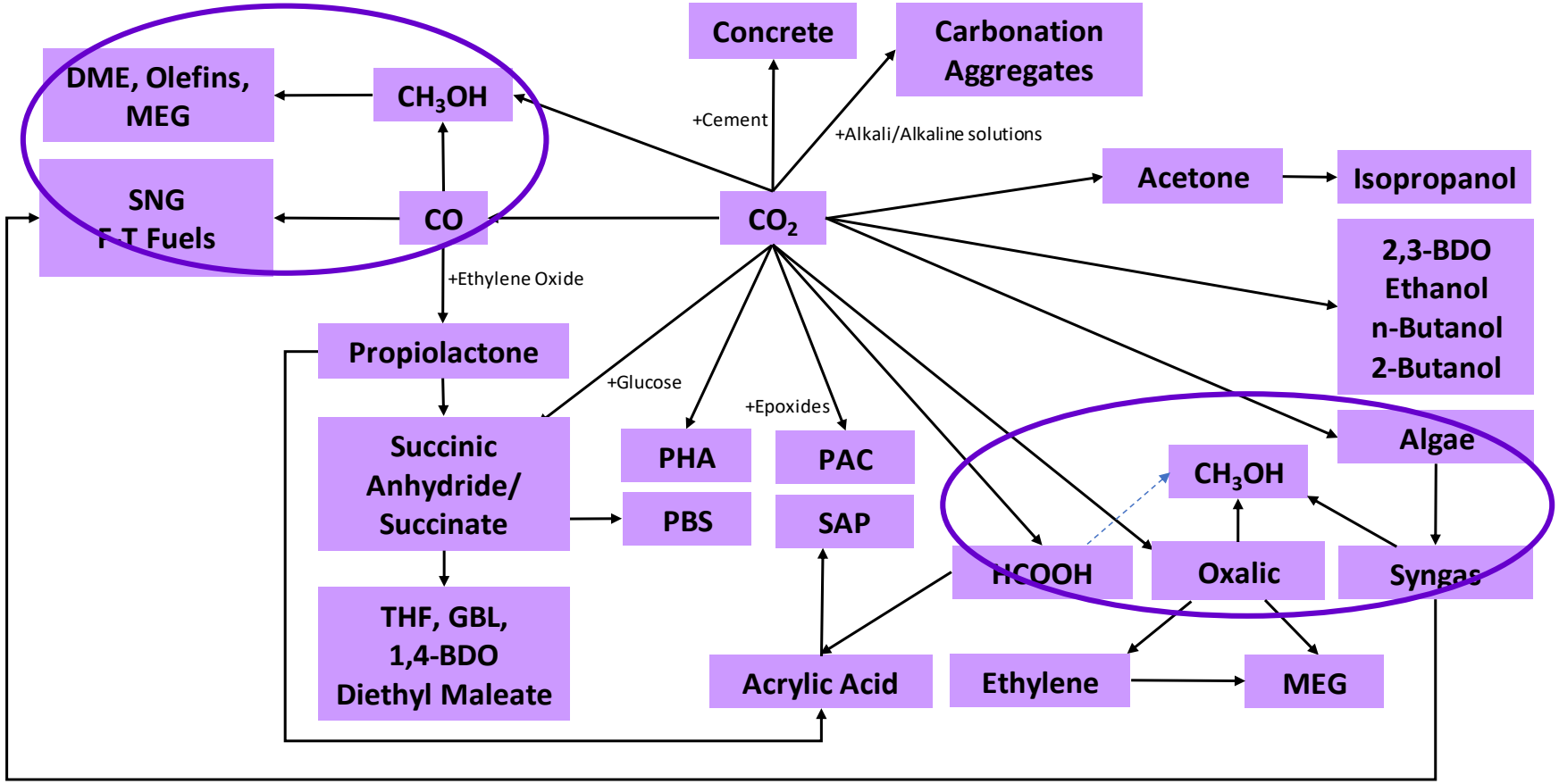
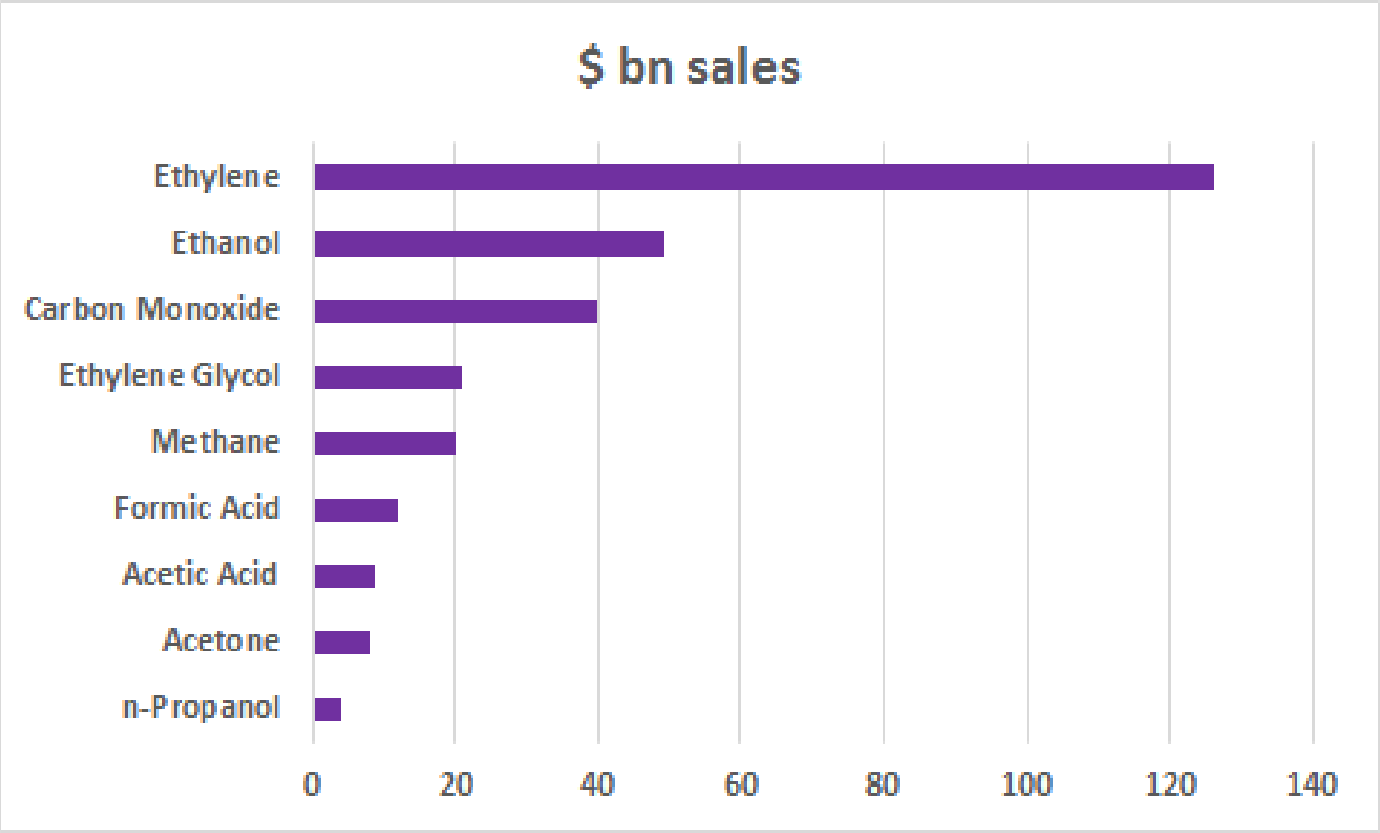


BDO = Butanediol, DME = Dimethyl Ether, GBL = Gamma-Butyrolactone, MEG = Monoethylene Glycol,

THF = Tetrahydrofuran, PAC = Polyalkylenecarbonates, PHA = Polyhydroxyalkanoate, SNG = Substitute Natural Gas

Source: CO2 Startups for Venture Capital, The Catalyst Group, 2017

Electrochemical Approaches



Source: Opus12

- Key start-ups with technology:
  - Carbon Electrocatalytic Recycling
  - Catalytic Innovations
  - Dioxide Materials
  - Electrochaea
  - Ineratec
  - Liquid Light (Avantium)
  - Mantra Energy
  - Opus 12
  - Sunfire

Possible opportunities for PGM in CO_2 electrocatalysis – Dioxide Materials

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- Dioxide Materials is a start-up founded in 2009 by Professor Richard Masel of the University of Illinois
- Dioxide Materials system process consists of:

  Reaction at Silver Anode: $CO_2 + 2H+ + 2\ e- \rightarrow CO + H_2O$

  Reaction at Tin Anode: $CO_2 + 2H+ + 2\ e- \rightarrow HCOOH$
- The company's patents cite PGM based "Catalytically Active Element and Ethyl-3-methylimidazolium-boron tetrafluoride (EMIM-BF4) ionic liquid co-catalyst
- The co-catalyst successfully overcomes the issues of selectivity and overpotential required for activating CO_2.

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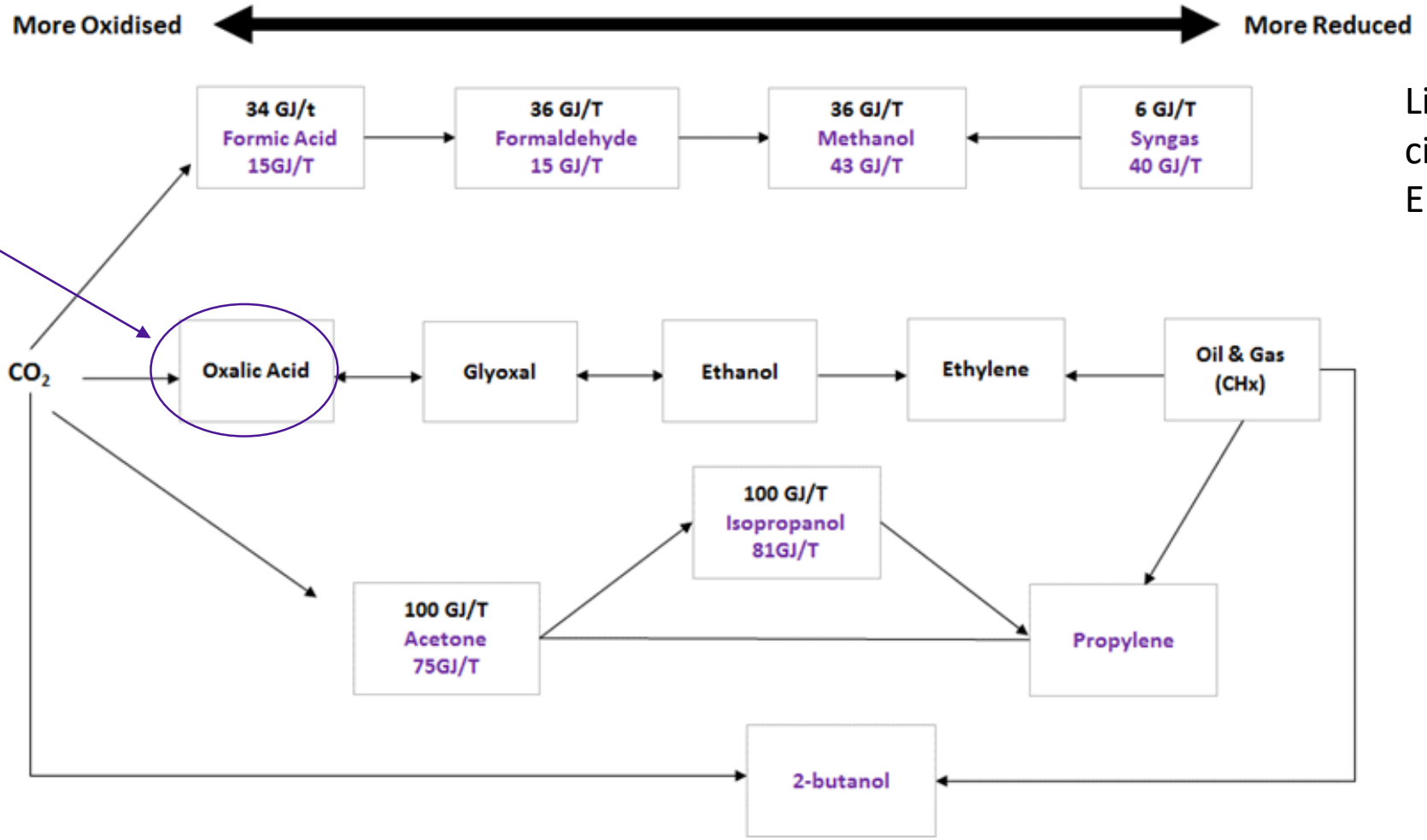
Liquid Light (now Avantium) has an extensive portfolio of CO_2 platform technologies



Conventional Hydrogenation to MEG

Liquid Light Patents cite PGM Gas Diffusion Electrodes (GDE)

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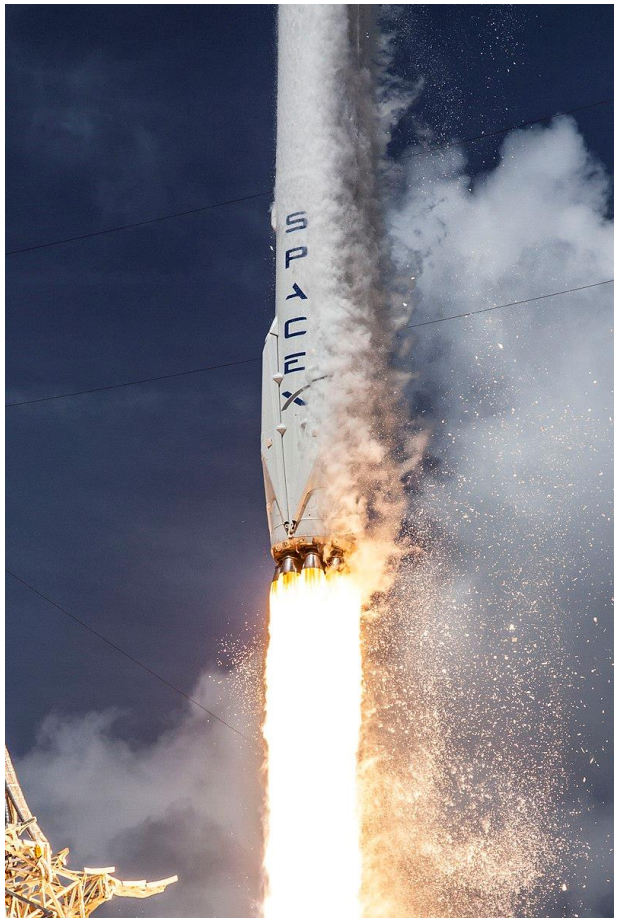
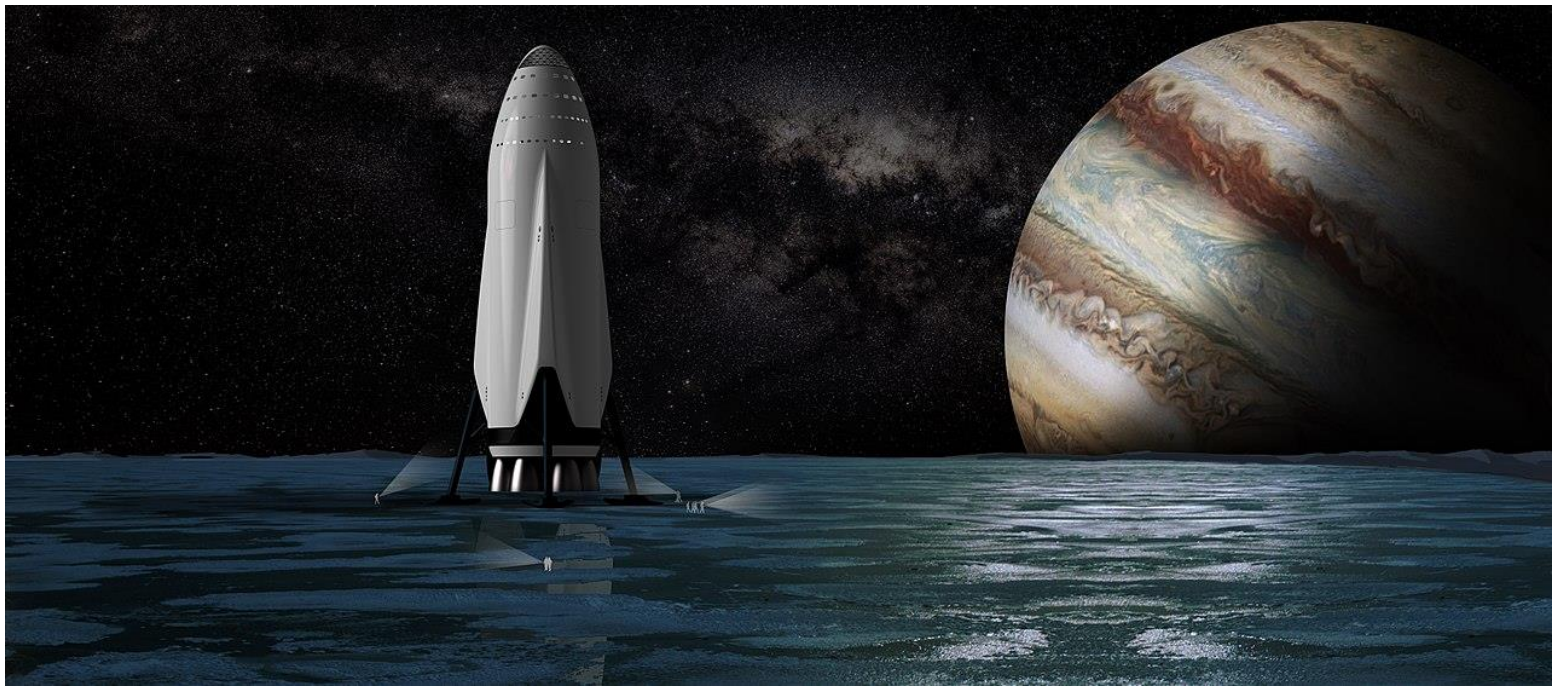
Summary of PGM Opportunities in Chemical Catalysts

- Near term – focus on chemicals from conventional feedstocks with high growth forecasts and new plant builds e.g. PDH.
- Medium term –
  - maximise opportunities in the bio-sector: platform chemicals taking off e.g. biosuccinic acid and downstream transformations.
  - Understand where CO2U interfaces with biobased and conventional platforms with existing PGM catalyst technologies.
- Long term – work with start-ups in innovative fields enabled by other macrotrends e.g. availability of renewable power and electrolysis for CO_2 and H_2O conversion. Develop new PGM catalysts
- Full scoping of each of these strategies is required to ensure longevity of PGM in chemical catalysts over the coming decades.

Time for SpaceX…



Source: SpaceX Wikipedia



- No need to worry about declining PGM…
- By 2040, 54% of us will be living on Mars and we can start building chemical plants all over again!

Thank you & Q's

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