# Presentation for US NASEM Committee on $CO_2$ Utilization Markets and Infrastructure

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# Thank You for Your Work and The Opportunity to Share Input!


We believe a sustainable future is attainable, but only if we all come together to drive forward science- and technology-based solutions to address global challenges.

Thank you for your work and dedication to study challenges and opportunities in detail for carbon dioxide utilization markets and infrastructure.

We appreciate the opportunity to share viewpoints and collaborate in the larger ecosystem on acceleration of the sustainability transformation.

# List of Questions Posed by NASEM Committee for Dow Input

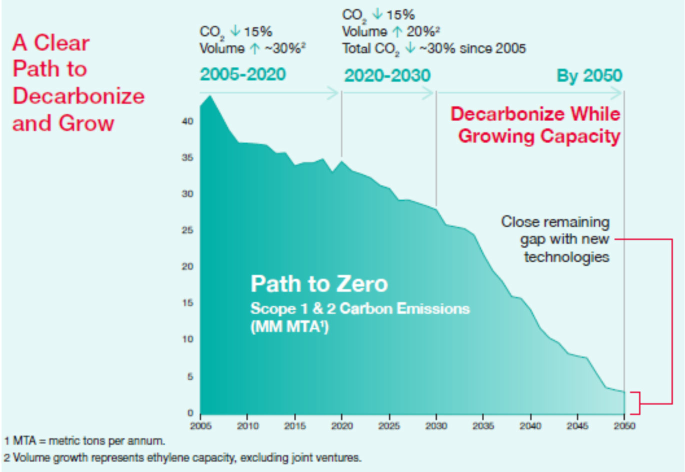
1. How does Dow see polymers in the circular economy more broadly?

2. What is Dow's vision and effort around $CO_2$ to polymers?

3. If Dow has activities/interest in $CO_2$ to polymers:
   - What is the current state of the art?
   - Where do you see this area going in 5-10 years?
   - What is stopping the field from advancing - are their technical, financial or regulatory hurdles that need to be overcome to make progress?
   - Is there a role for government research or other activity to mitigate risk or overcome technical barriers?

# DOW'S VISION OF SUSTAINABILITY AND THE CIRCULAR ECONOMY

- Dow's sustainability efforts are ***critical*** to our business, and we believe Dow can use our science, global reach, and partnerships to make an accelerating sustainability impact
- Dow's sustainability focus areas are Climate Protection, Circular Economy, Safer Materials
- In 2020, Dow introduced new targets for reducing carbon emissions and plastic waste:



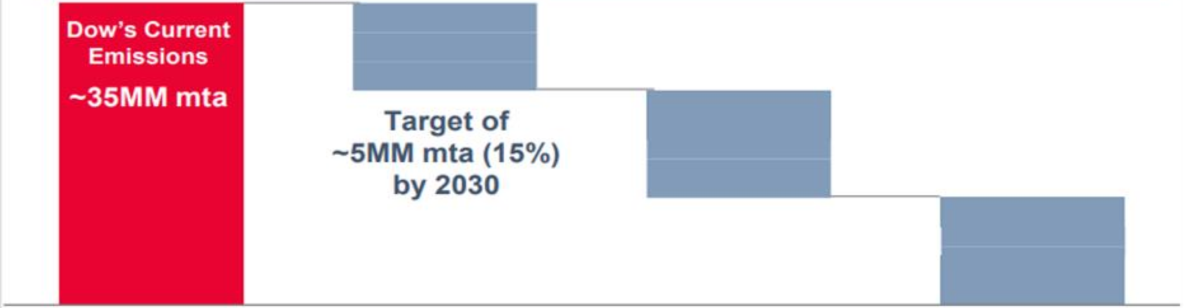

Protect the Climate: Accelerating our work with our suppliers, customers, and value chain partners to ***by 2030 reduce our net annual carbon emissions by 15% versus our 2020 baseline***, and to ***ensure Dow's ecosystem is carbon neutral by 2050 across Scope 1+2+3 plus product benefits***

Transform the Waste: Building industrial ecosystems to collect, reuse or recycle plastic waste and address waste management gaps - Dow committed to ***commercializing 3 million MT/y of circular and renewable solutions by 2030***

Intersections, Dow 2022 Progress Report,
[Dow 2022 Progress Report | A Year of Improvement]

# DOW'S PATH TO ZERO-$CO_2$ EMISSIONS INCLUDE SCOPE 1, 2, AND 3 ACTIONS

## Roadmap to Reduce >90% of Scope 1 & 2 Carbon Emissions




### Details & Target

- Scope 1 & 2 emissions mostly from power & steam generation and olefins production
- Target reducing these emissions by >90% by 2050 while enabling business growth

### Through 2030

- Site efficiency improvements and renewable power
- On-purpose circular-hydrogen; carbon capture & sequestration
- Implement Alberta project and Terneuzen site carbon emissions reduction plans with government support

### 2030 – 2050

- Optimize $H_2$ allocation & production
- Additional carbon capture and storage capabilities
- Retrofit turbines for $H_2$ fueling or electrical drivers
- New cracking technologies
- Leverage most competitive clean $H_2$ and zero-carbon emissions e-cracking technologies
- Connect to $H_2$ infrastructure

***Plans for >60% sites to be $H_2$-ready by ~2040[1]***

## Scope 3 Emissions Reduction

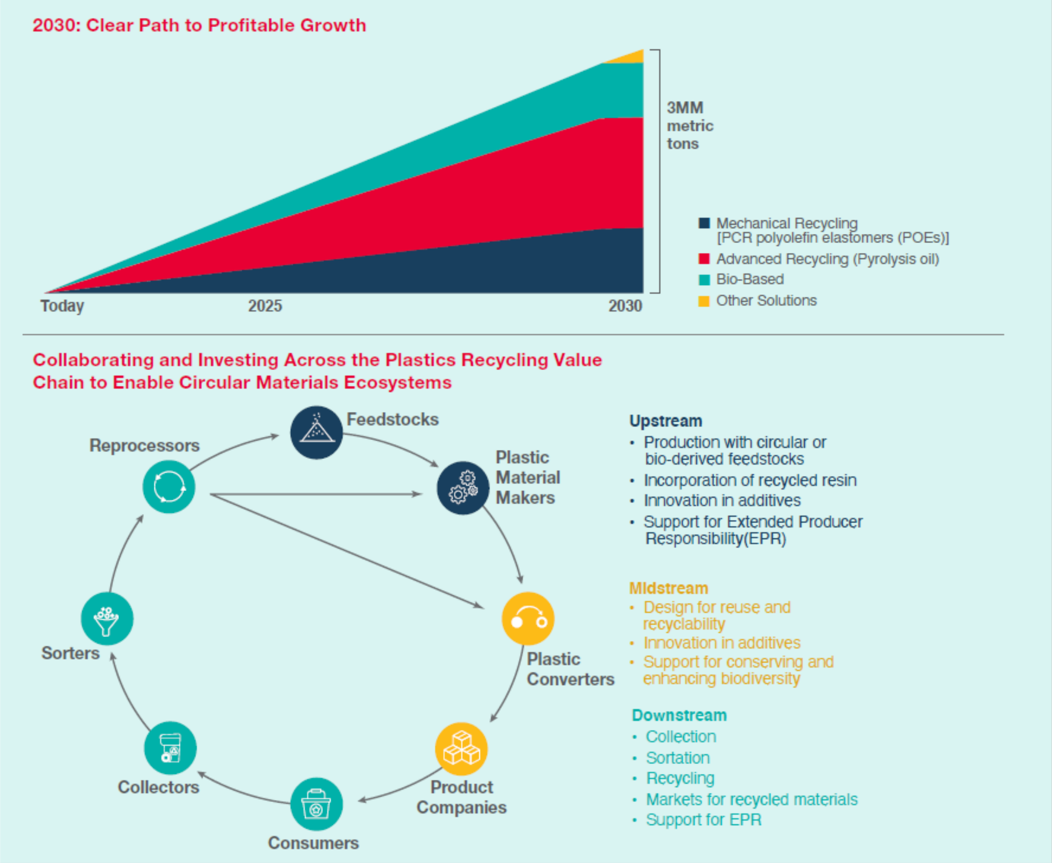
- Working with suppliers on upstream decarbonization opportunities, aligned with our Supplier Code of Conduct
- Enabling customers to reduce emissions, amplifying our impact through design for recyclability, light-weighting, downgauging, and lower carbon footprint delivery
- Collaborating with Columbia University to better identify opportunities to value carbon savings from product benefits

***Actions targeted to incentivize innovation and infrastructure to decarbonize the value chain***

Investor Events & Presentations | Dow Investor Relations
2021 Dow Investor Day

# Dow's Acceleration of the Transform the Waste Roadmap

- To support this expanded target, Dow formed a new business platform, Circular & Renewable Solutions[1].
- This also enables increased accountability and robust decision-making around transforming our plastics franchise.
- Dow has exploratory interest in $CO_2$ to chemicals/materials pathway today – this pathway has high energy and $H_2$ demands




[1] Intersections, Dow 2022 Progress Report,
[Dow 2022 Progress Report | A Year of Improvement]

# Recent Dow Investments and Collaborations

| | |
|---|---|
| **Flyability** | Flyability has implemented a collision tolerant drone. The drone is used to reduce operator exposure for confined spaces |
| **MURA Technology Ltd.** | Hydro-PRS technology for the conversion of plastic waste to synthetic naphtha |
| **Mr Green Africa** | Coordinates the collection, sorting, cleaning and mechanical recycling of plastic waste in Nairobi, Kenya. |
| **Plastogaz SA** | Advanced recycling of waste plastic to clean synthetic naphtha |
| **Valoregen SA** | Integrated mechanical and feedstock recycling process |
| **The MOST** | Device and consumables for treatment of under served market of curly, kinky hair |
| **X-Energy** | Technology for small advanced modular nuclear fission reactors for the provision of heat and power |
| **The Ocean Fund by Circulate Capital** | Social and environmental impact fund to reduce pollution and ocean plastic in SE Asia |
| **Closed Loop Plastic Waste Fund** | Impact fund to finance the development of infrastructure to source, process, and return to supply chains hard-to-recycle plastics in the United States and Canada |

# How Does Dow See Polymers in The Circular Economy?

- To maximize society's sustainable use of resources and carbon, we need conventional polymers to be recyclable where possible
- The vision is to offer a long lifetime of use, cascading from closed loop recycling to open loop recycling to advanced recycling
- For products that are not collectible, the aim is to reduce environmental impact with products that return to base components that already exist in the natural environment after their useful life
- Dow has committed to commercializing 3 million MT/y of circular and renewable solutions by 2030, aligned with our Transform the Waste goal, and with building industrial ecosystems to collect, reuse or recycle plastic waste and address waste management gaps

# Thermodynamic Challenge of $CO_2$ Utilization

- Comparing energy for ethylene production via naphtha steam cracking to $CO_2$ Utilization, steam cracking is at least 3x more energy efficient

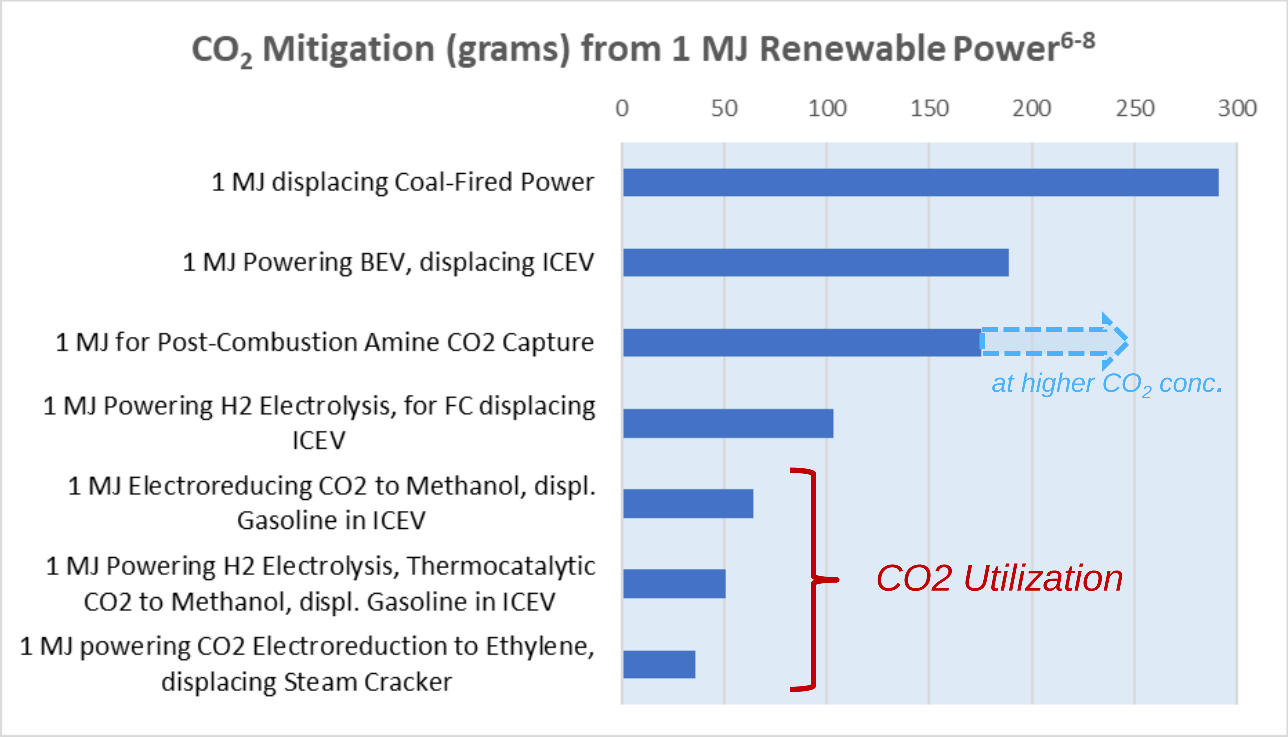
| Reaction | Energy Type | Energy (GJ/ton ethylene) |
|---|---|---|
| Naphtha Steam Cracking[1,2] | Total Energy | 17-19[6] |
| $H_2$ from electrolysis, then $CO_2$ hydrogenation to methanol, then methanol-to-olefins[3] | Total Energy | 96 |
| Electrochemical[4,5] $2CO_2 + 2H_2O \rightarrow C_2H_4 + 3O_2$ | Standard Gibbs Free Energy | 48 |

- The first priority for Dow is to decarbonize the emissions from energy/steam generation that drive processes; in parallel, recycling of polymers is accelerated and implemented


[1] Ren et al., *Energy* **2006**, 31 (4), 425-451
[2] Eryazici et al, *MRS Bulletin*, **2021**, 46, 1197-1204
[3]https://dechema.de/dechema_media/Downloads/Positionspapiere/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry.pdf
[4] NIST Chemistry WebBook, SRD 69
[5] Gao et al., *ACS Catalysis* **2019**, 9, 8592-8621
[6] GJ/ton of valuable olefin product

# $CO_2$ MITIGATION IMPACT BY PROCESS CHANGE

- 1 MJ renewable energy has highest $CO_2$ mitigation impact when used for direct energy replacement followed by carbon capture; $CO_2$ utilization delivers less $CO_2$ mitigation




[6] Ravikumar et al., *Applied Energy*, 2020, 279, 115770
[7] Lattner, *Current Opinion in Chemical Engineering* **2022,** 29, 51-58
[8] Pappijn et al., *Frontiers in Energy Research*, **2020**, 8, 557466, 1-12

BEV = Battery Electrical Vehicle
ICEV = Internal Combustion Engine Vehicle
FC = Fuel Cell

# Direct $CO_2$ Utilization Connection To Dow's Products

- **Thermochemical** pathway to feedstocks and chemical intermediates:
  - Syngas to C2+, olefins, methanol, …
  - Urea/fertilizer
  - Fuel

- **Thermochemical** pathway to downstream materials:
  - Polymers
  - Carbon-Based Additives/Fillers
  - Mineralization into Concrete or Aggregate Components*

- **Biological, electrochemical, or other novel** pathways:
  - Feedstocks
  - Chemical Intermediates
  - Polymers

Note: Indirect $CO_2$ utilization (e.g., through bio-sourced materials) are strategic to Dow but not included here, per the definition of $CO_2$ Utilization in NASEM Report 1.

* Dow is interested in enabling CO2 utilization in construction materials through additives

# THERMOCHEMICAL $CO_2$ CONVERSION TO FEEDSTOCKS/INTERMEDIATES

- **Current Status:** Known commercial chemical conversion pathways from $CO_2$ and $H_2$
  - Direct hydrogenation to methanol, methanol to olefins/aromatics
  - Conversion to Syngas (via RWGS) followed by Fisher-Tropsch to fuels/C1 to chemicals
  - Dow is monitoring output of these process developments
- **Future Direction:** $CO_2$ conversion to e.g., syngas, C2+, offers flexibility to integrate with optimized downstream syntheses, but requires
  - Economic viability, incl. $CO_2$ valuation framework across value chains, markets and industries
  - High-purity supply of $CO_2$ to main manufacturing sites
  - Cost efficient energy and $H_2$ supply to manufacturing sites, transitioning to low carbon electricity
  - Improved syngas production yield/rates to be competitive with fossil fuel-based benchmarks, through catalyst innovations (CO yield/productivity, longer lifetime)
  - Improved syngas conversion to feedstocks with higher yields and production rates competitive to current benchmarks, and product distributions amenable to down-stream value
- **Needed:** Entire ecosystem collaboration to overcome regulatory, financial, and technical hurdles, starting with availability/low cost of low carbon energy and hydrogen

# THERMOCHEMICAL $CO_2$ CONVERSION TO DOWNSTREAM MATERIALS

- **Current Status:** Known commercial conversion pathway of $CO_2$ to materials/polymers
  - Alkyl carbonates; established electrolytes, lubricants, solvents
  - Poly-urethane materials via alkene carbonate polyols; specialty polyols with different balance of properties versus incumbents (high viscosity limiting $CO_2$ content, high modulus)
  - Poly-hydroxyurethanes via epoxidized fatty acid cyclic carbonates/amines; emerging, cost/performance balance being explored
  - Poly-alkene carbonates; e.g., sacrificial binders for ceramics and metal manufacturing applications
  - Dow is exploring some of these options

- **Future Direction:** $CO_2$ incorporation in materials can offer decade$^+$ carbon end-use storage. For polymers, many are new polymers with inherently long development timelines. If performance/cost balance can equal incumbents or meet new market needs, one also needs to consider entirely new circular loop impact on the environment.

- **Needed:** Primarily technical and end-use application evaluations of the performance/economic viability spectrum of $CO_2$ derived polymers

# Biological $CO_2$ Conversion to Feedstocks/Intermediates/Polymers

- **Current Status:** Known (commercial) fermentation pathways from $CO_2$ and $H_2$
  - $CO_2/H_2$ or Syngas to ethanol and other C1-C4 chemicals (e.g., C3/C4 alcohols, MEG)
  - $CO_2/CH_4$ to polymers, incl. poly-hydroxyalkanoates
  - Dow is interested in the progress of this research
- **Future Direction:** Feedstocks/intermediates from $CO_2$/syngas fueled fermentation processes could feed into established production pathways, however, require
  - Economic viability, incl. $CO_2$ valuation framework across value chains, markets and industries
  - Available supply/purity of $CO_2$ to fermentation companies
  - Cost efficient $H_2$ supply to fermentation companies transitioning to low carbon electricity derived $H_2$
  - Technical barriers to scale: production rates, pre-treatment/product recovery cost, physical footprint
  - Impact of water requirements and associated environmental footprint
  - Advances in microbial innovation to access a broader range of feedstocks/intermediates
- **Needed:** Primarily technical acceleration to assess economic viability of fermentation output at scale for variety of feedstocks/intermediates

# Electrochemical $CO_2$ Conversion to Feedstocks/Intermediates

- **Current Status:** Pilot scale to exploratory research into electrochemical $CO_2$ conversion
  - $CO_2 + H_2$ (from $H_2O$ electrolysis) to syngas (pilot scale)
  - $CO_2$ to C1, C2+ intermediates (lab to pilot scale)
  - Dow is interested in the progress of this research

- **Future Direction:** Electrochemical pathways (and low T potential) need to be studied in the portfolio of approaches to achieve the sustainability transition, however
  - Specifically for $CO_2$ conversion, electrochemical pathways need to be energy/cost benchmarked against the alternative of electrochemical water splitting to make $H_2$ for thermochemical reactions
  - Technical barriers to scale: Faradaic efficiency (separation and energy costs), current density (scale, production rates), overpotential (energy cost), cell lifetime
  - Advances in electrochemical catalysis required
  - Available supply required of $CO_2$ of high enough purity, and cheap low carbon energy
  - Impact of water requirements and associated environmental footprint

- **Needed:** Primarily technical acceleration to assess economic viability of electrochemical $CO_2$ conversion pathway compared to water electrolysis and RWGS reaction

# Novel $CO_2$ Conversion to Feedstocks/Intermediates

- **Current Status:** Exploratory research into novel $CO_2$ conversion pathways
  - Photocatalysis (some pilots planned)
  - Plasma catalyzed
  - Dow is monitoring progress in this research

- **Future Direction:** Electromagnetic conversion pathways need to overcome several significant barriers to be viable
  - Energy efficiency of combined conversion of electricity to EM radiation, and consequent conversion to chemical energy
  - Selectivity of reaction pathway, especially for higher Cx reaction products
  - Capital cost to achieve sufficient and homogeneous EM exposure to reaction media
  - Scale due to inherently modular nature of EM input
  - Low cost and wide availability of low carbon energy, and $H_2$

- **Needed:** Primarily technical acceleration to assess fundamental and economic viability of novel (EM) $CO_2$ conversion pathways

# SUMMARY

- Dow's sustainability efforts are ***critical*** to our business, and we believe Dow can use our science, global reach and partnerships to make an accelerating sustainability impact.
- Dow is focused on the use of low carbon hydrogen and low carbon energy sources, and has over 1GW of renewable power contracts.
- Thermodynamic barrier of pathway to $CO_2$ utilization won't change, but research can improve kinetics. Availability of low-cost low carbon energy and $H_2$, and an established carbon valuation framework are required.
- Entire eco-system (regulatory, financial, technical) collaboration is necessary to transition to carbon cycle options.
- If these conditions are met and are economically viable, for $CO_2$ utilization the highest potential for commercialization is via production of liquids and feedstocks/intermediates that can integrate with existing conventional (transitioning) polymer production processes.

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