Opportunities and Challenges for the Chemical Industry Brought About by Shale and Hydrocarbon Resources

A perspective from the American Chemistry Council Working Group on Catalysis

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Rob Hart, Shepherd Chemical
Owen Kean, American Chemistry Council
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Eric Stangland, Dow Chemical
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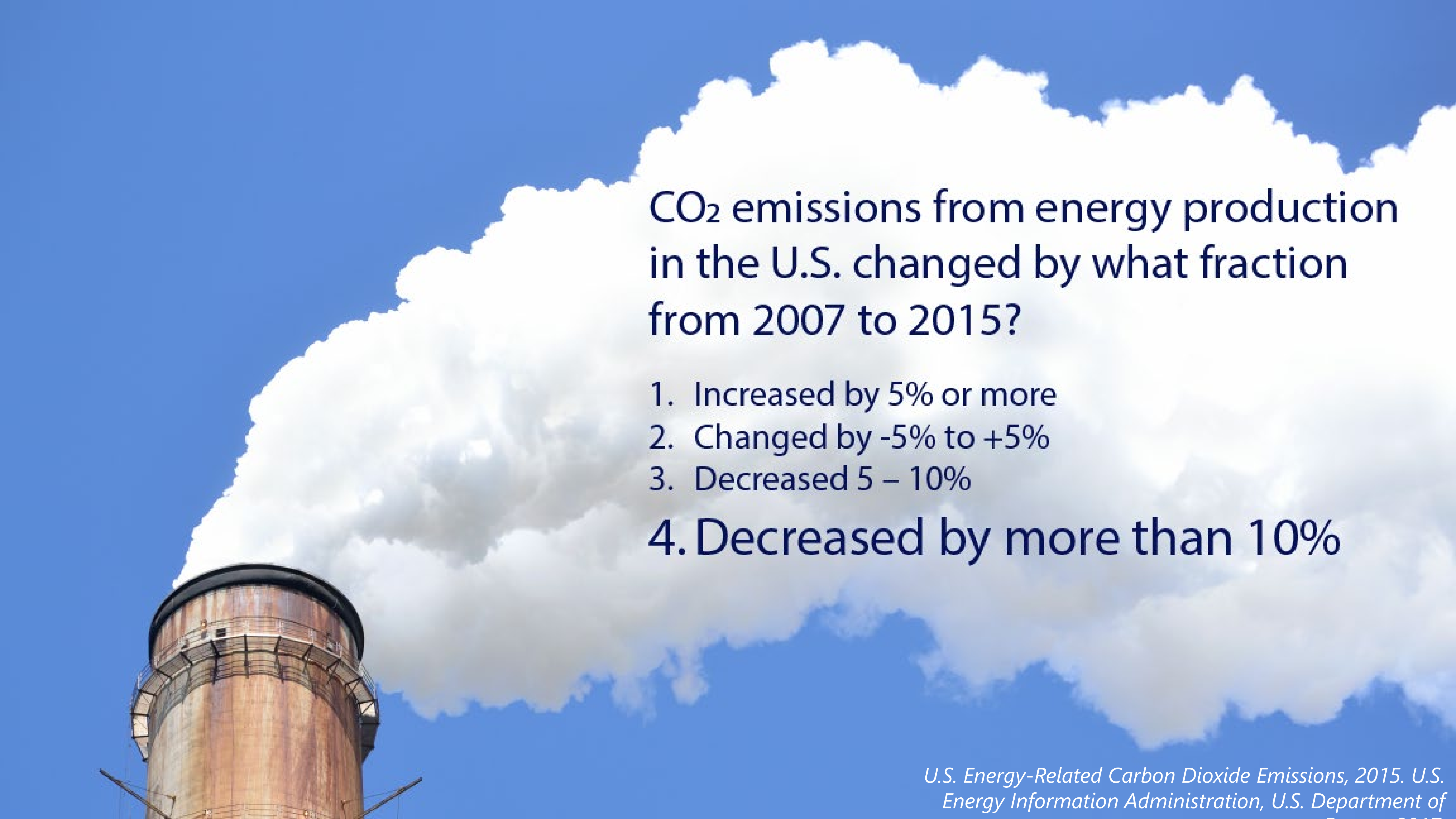
CO_2 emissions from energy production in the U.S. changed by what fraction from 2007 to 2015?

1. Increased by 5% or more
2. Changed by -5% to +5%
3. Decreased 5 – 10%
4. Decreased by more than 10%



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U.S. Energy-Related Carbon Dioxide Emissions, 2015. U.S. Energy Information Administration, U.S. Department of

By 2030, the world will need 45% more energy, while reducing greenhouse gas (GHG) emissions.

2013 — IEA Technology Roadmap

2014 — ACC Working Group on Catalysis

2015 — Catalytic Chemical Processes Roundtable

2016 — Changing Landscape Nat'l Academies Workshop

2017 — Hydrocarbon Conversion Booklet

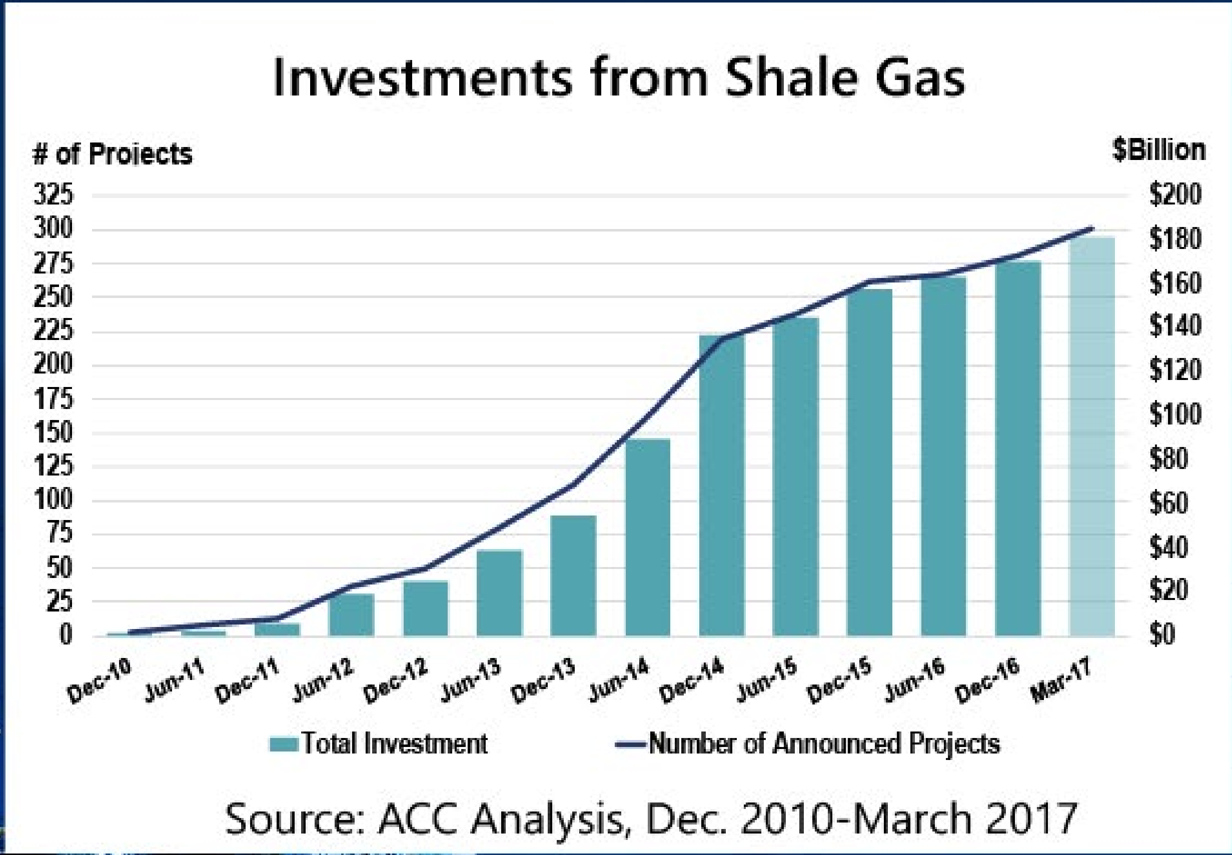
American Chemistry Council

Working Group on Catalysis

Objective: To elevate public and private sector interest in advancing R&D associated with improving the top energy consuming catalytic processes.

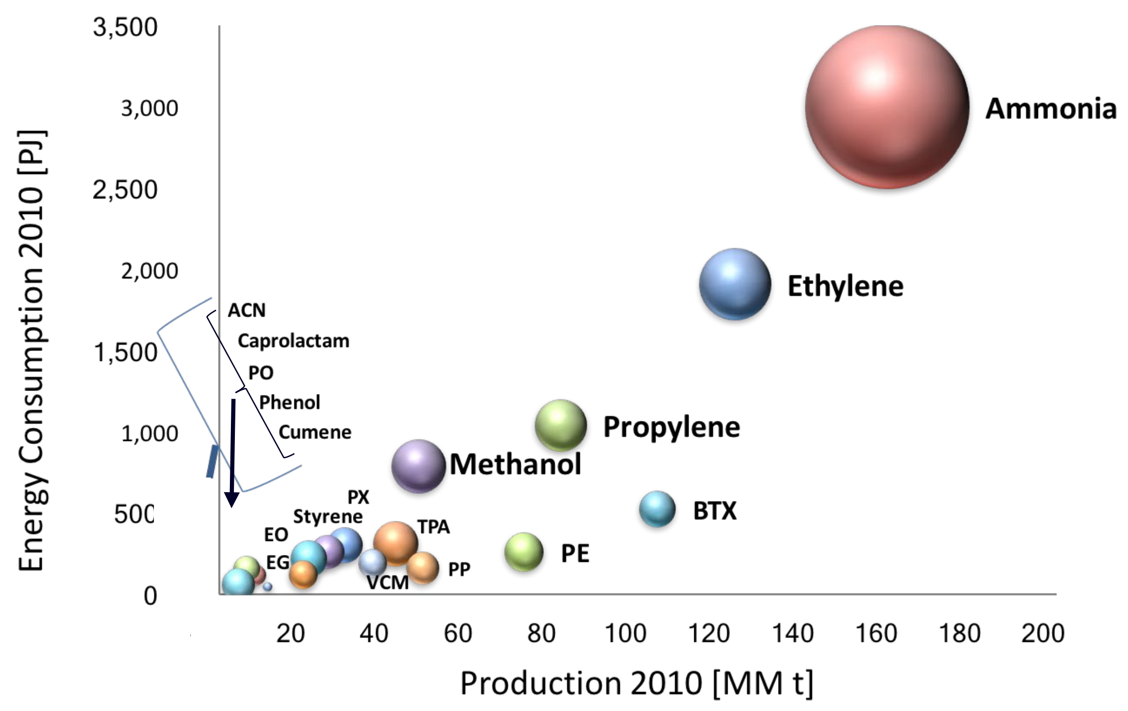
Goal: To promote exchange of ideas on ways to increase opportunities for R&D in catalysis and address barriers to such activities.

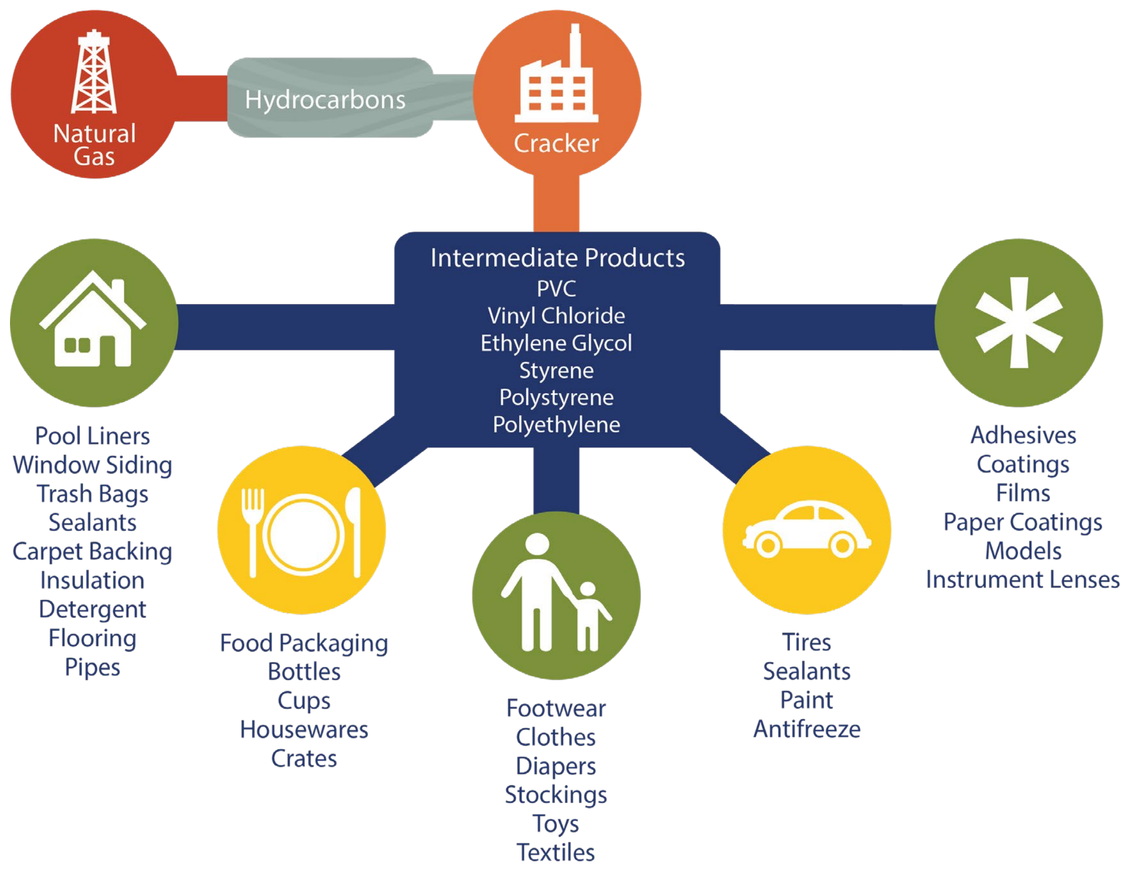
The shale gas boom transformed the competitive position of U.S. chemical manufacturers.



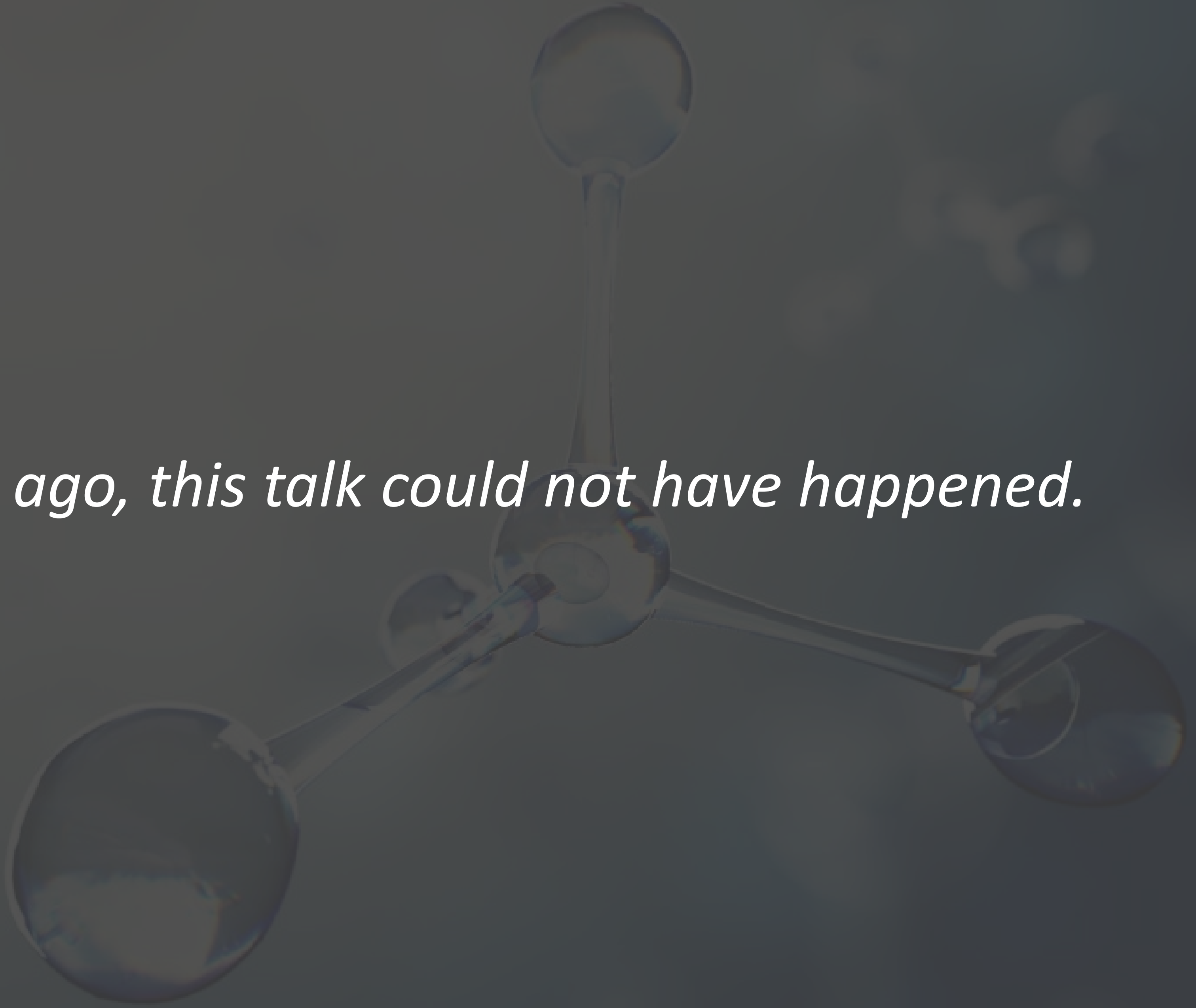
ACC. Shale Gas and New U.S. Chemical Industry Investment: $164 Billion and Counting. ***2016***.

Top Processes: Energy use vs. production volumes of 18 largest chemicals, 2010





IEA, ICCA, DECHEMA. Technology Roadmap: Energy and GHG Reductions in the Chemical Industry via Catalytic Processes. ***2013****.*

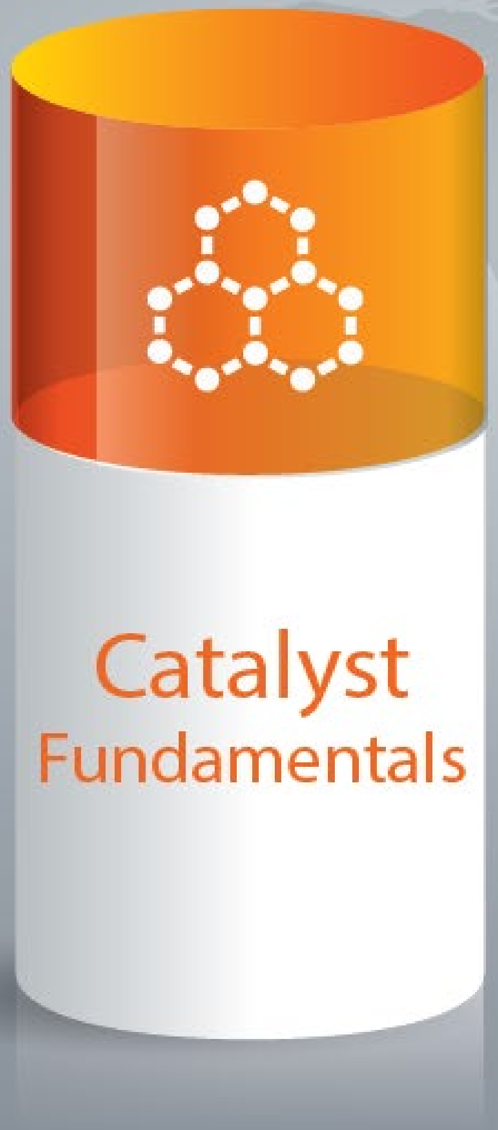


10 years ago, this talk could not have happened.

Four megatrends are converging and have altered the reward and risk ratio for research funding.

The Six Pillars of Hydrocarbon Technological Development


Catalyst
Fundamentals
Applied
Research
Scaling
Integrated
Design
Funding
Institute/
Hub
The Six Pillars of Hydrocarbon Technological Development



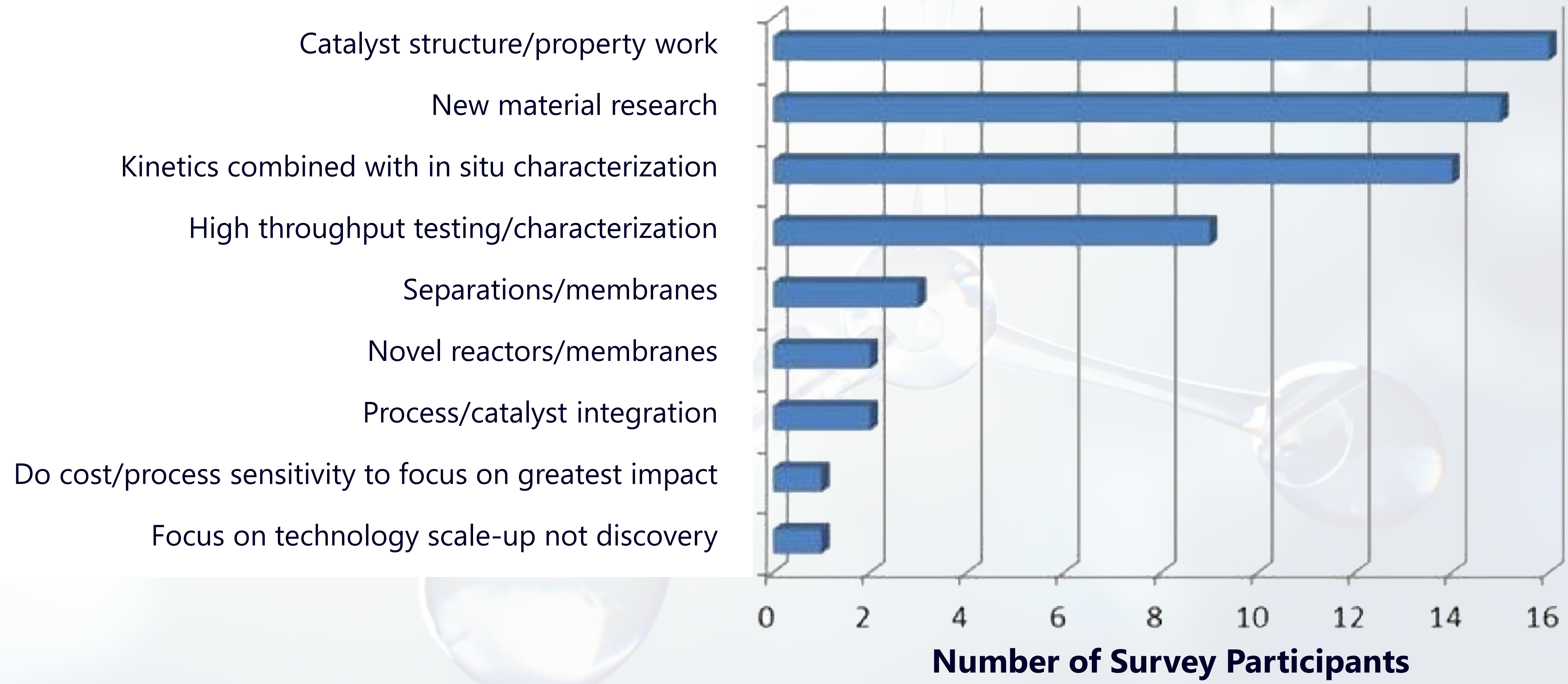
Active site design

In silico formulation and performance evaluation

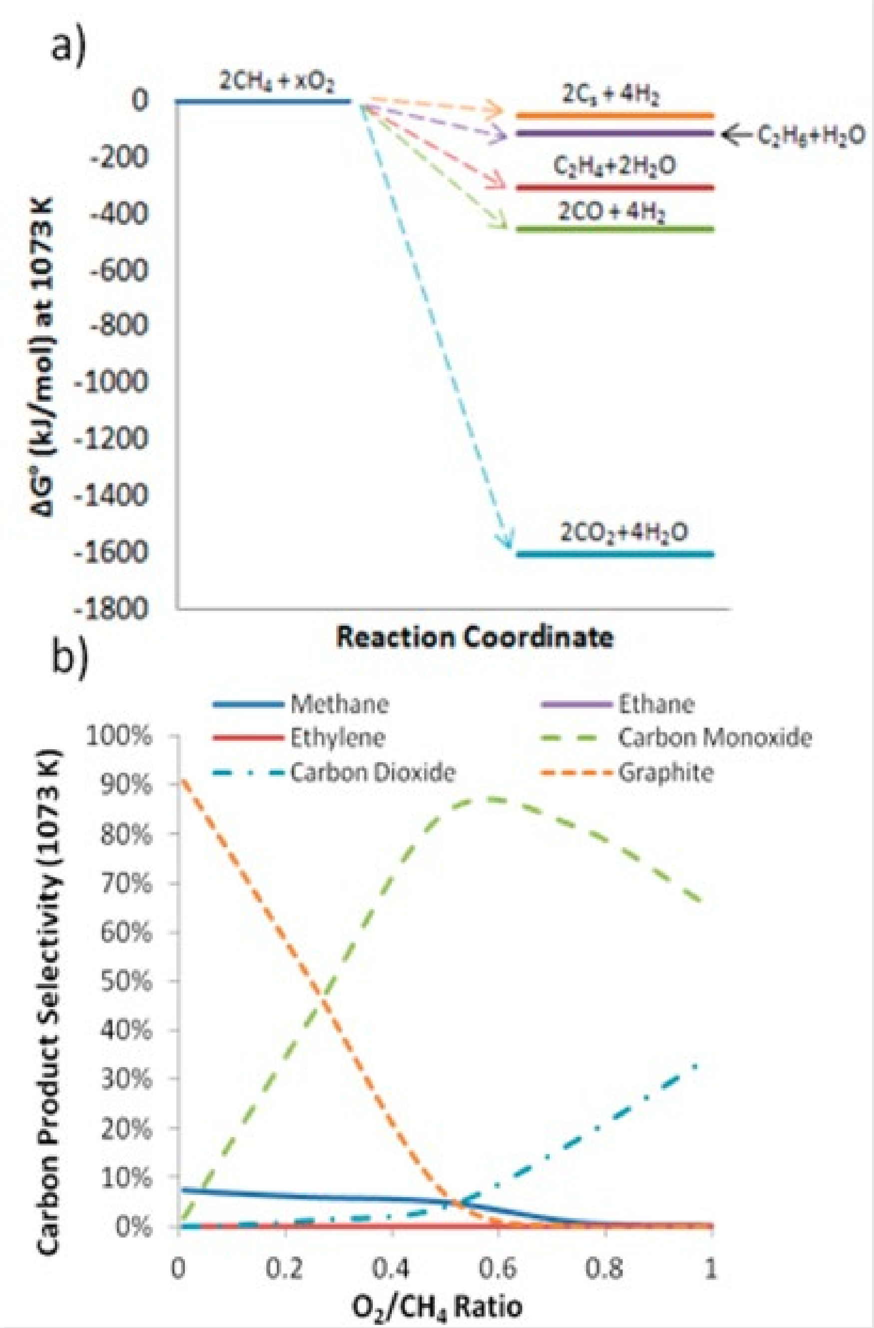
Thermodynamics

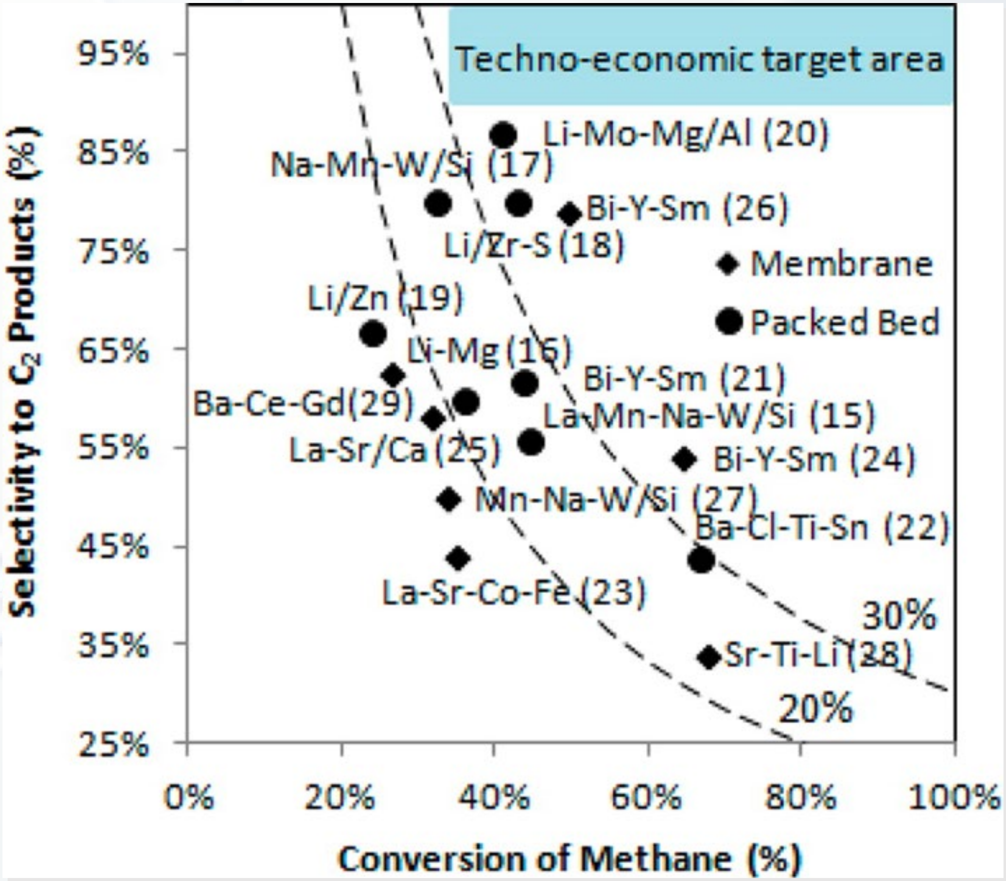
Selectivity optimization

Which areas of R&D would be most important for reducing barriers/gaps?



A.C.C. Advancing Energy and Sustainability Goal (2016), Washington DC.





Farrell, B.L., A Viewpoint on Direct Methane Conversion to Ethane and Ethylene Using Oxidative Coupling on Solid Catalysts. ChemInform. ***2016****; 47(37), 4340-4346.*

The Six Pillars of Hydrocarbon Technological Development

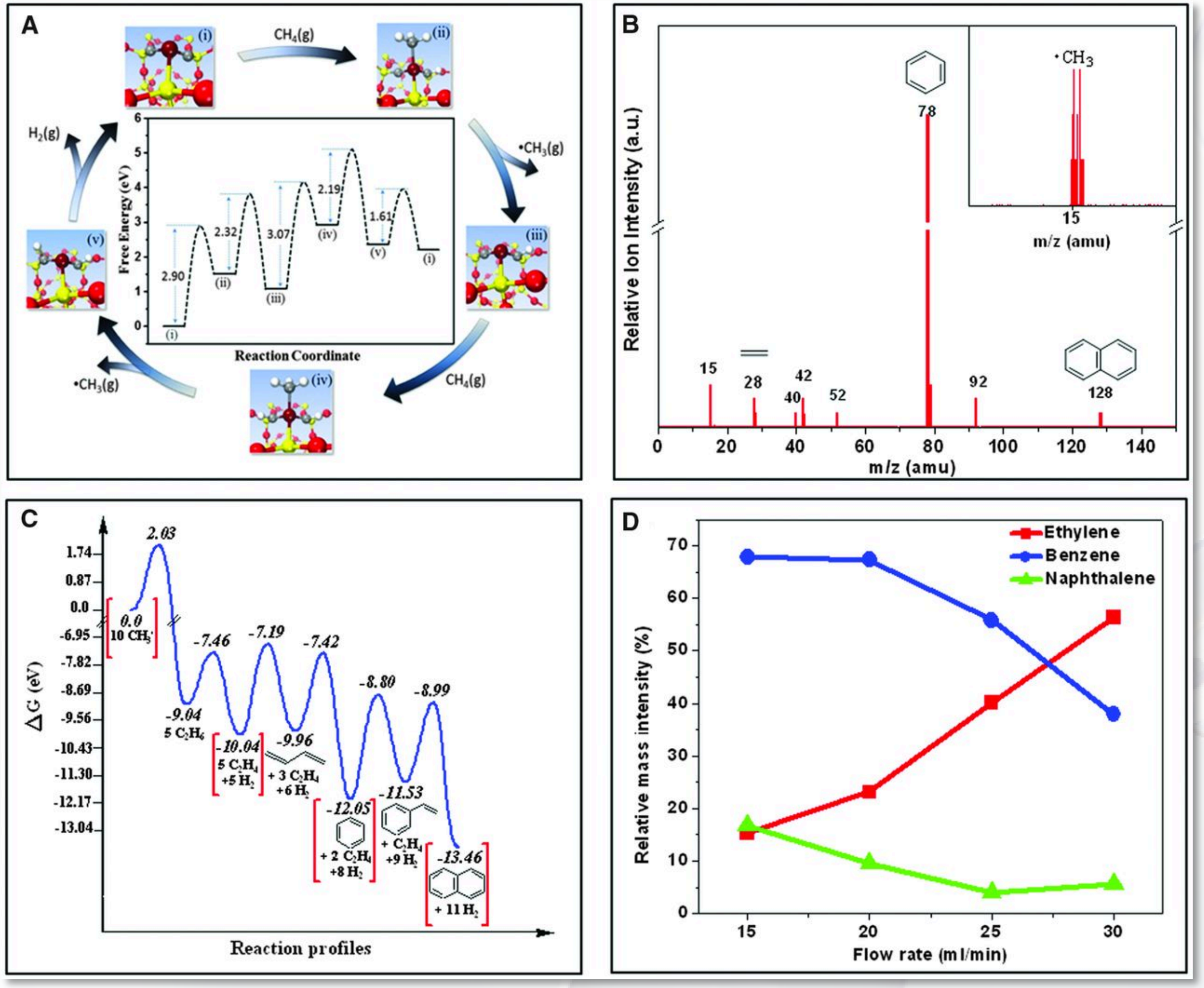
Applied Research

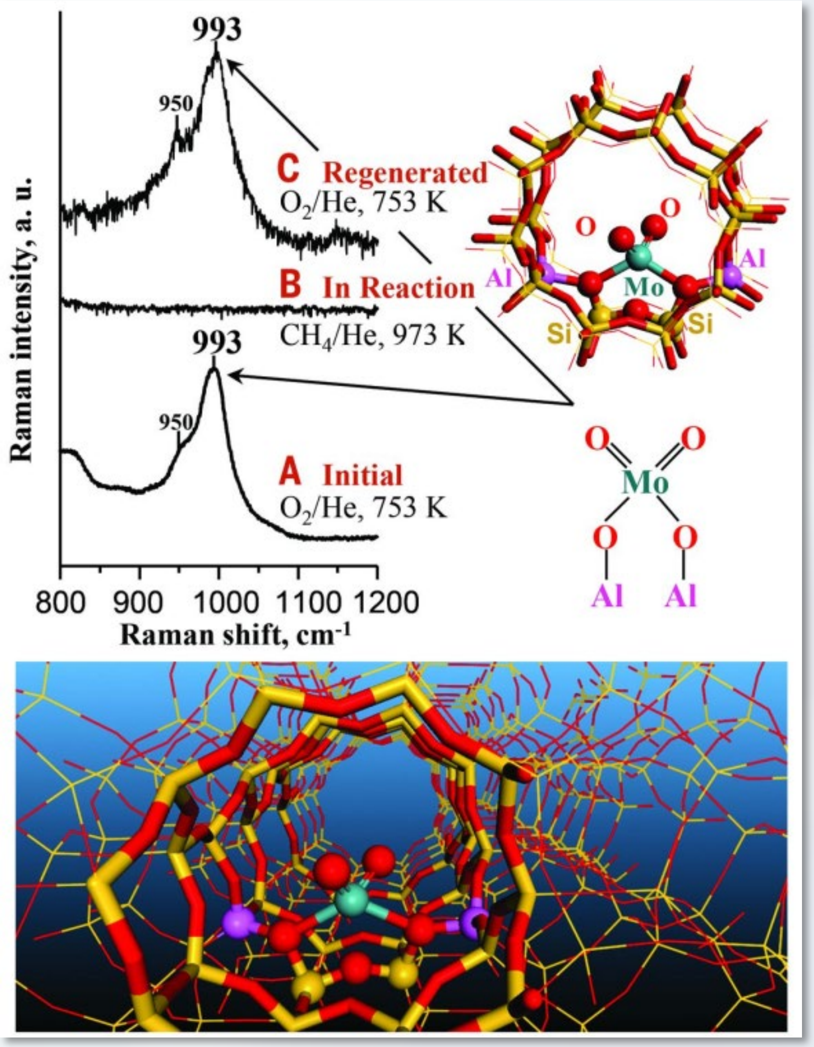
Kinetics

Parametric product distribution studies

In operando characterization

Physical and mechanical testing and improvement





Gao, J., Catalysis. Identification of Molybdenum Oxide Nanostructures on Zeolites for Natural Gas Conversion. Science. ***2015,*** *348, 686-690.*

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The Six Pillars of Hydrocarbon Technological Development

Scaling

Multi-scale simulation

Flexible and accessible test beds

Research on scaling principles for cross-cutting impact

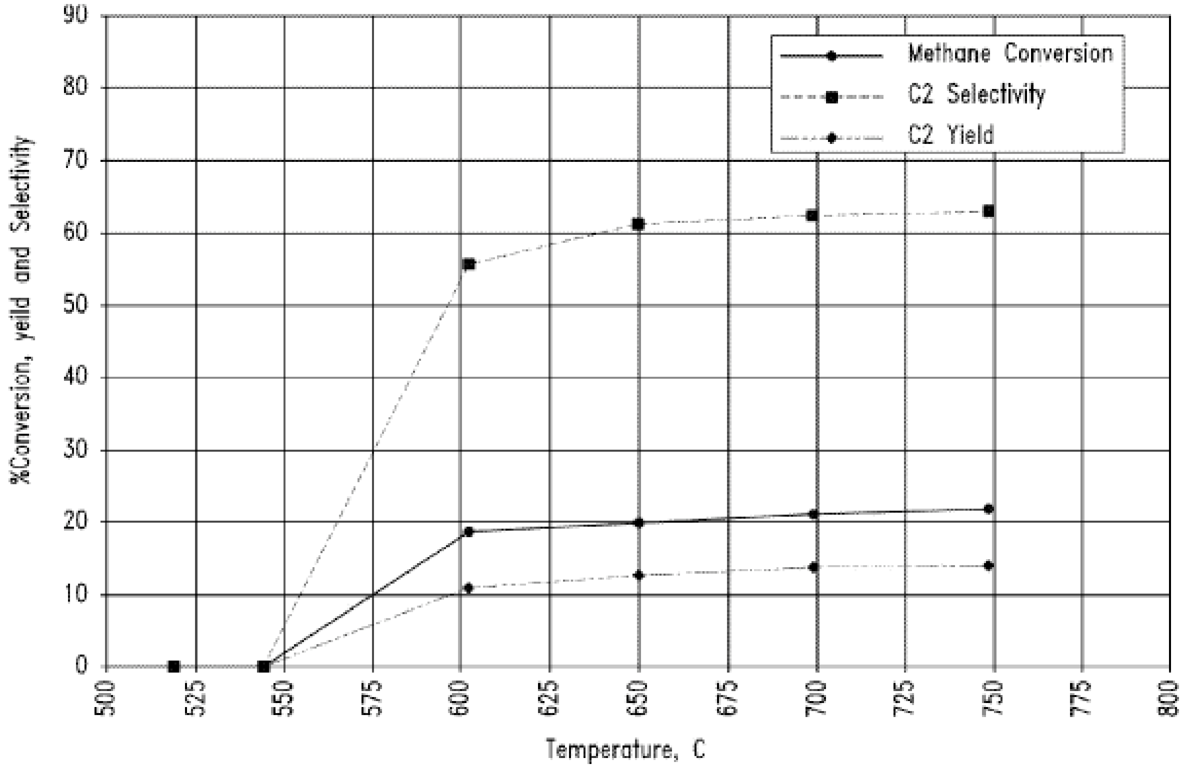


FIG. 23

Zurcher, F.R., Nanowire Catalysts and Methods for their Use and Preparation. US Pat. 8,962,517, February 24, 2015.


Catalyst Fundamentals
Applied Research
Scaling
Integrated Design
Funding
Institute/ Hub
The Six Pillars of Hydrocarbon Technological Development

Integrated Design

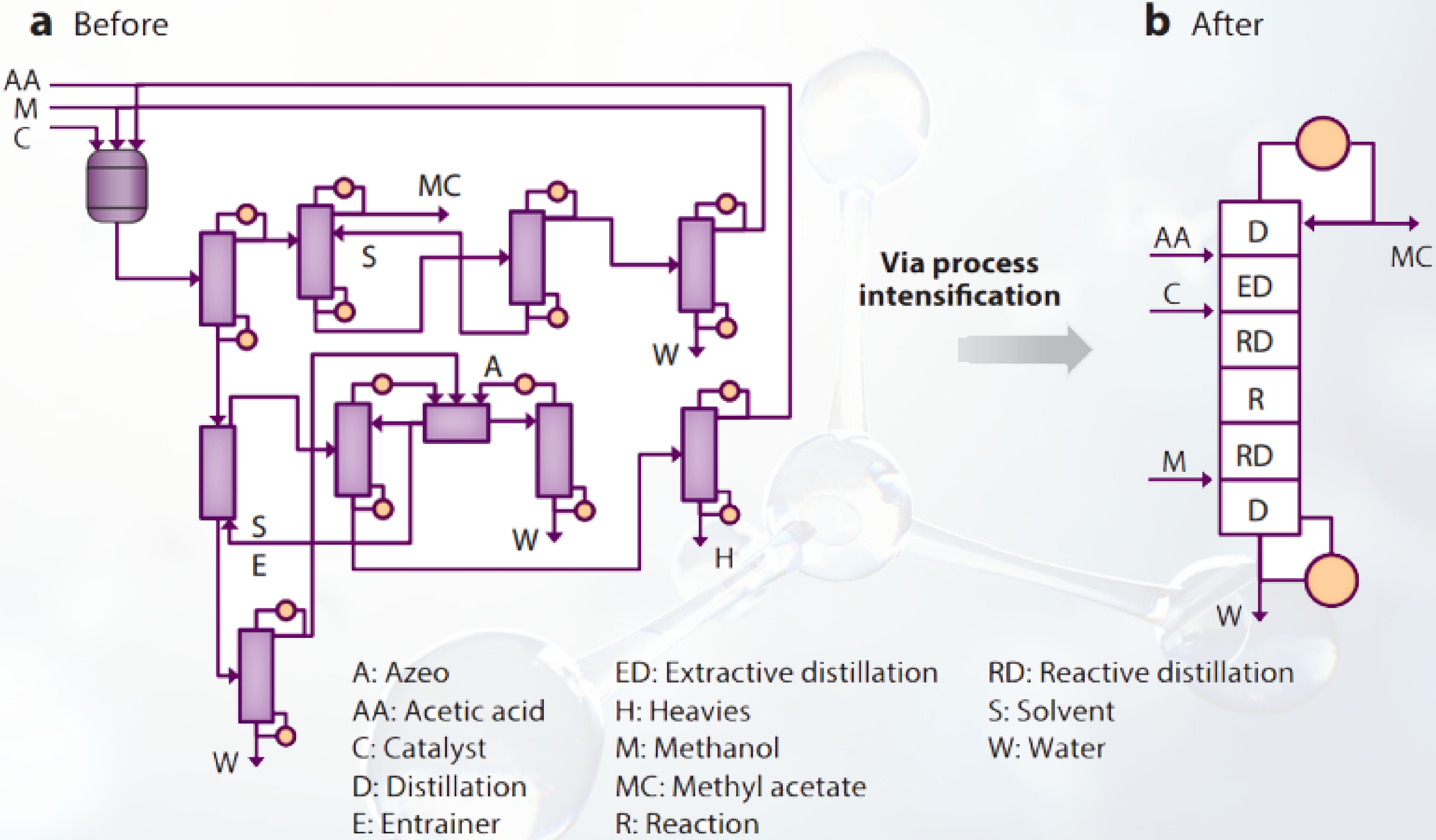
Process intensification

Reactors

Power plants

Heat and mass transport

Separations

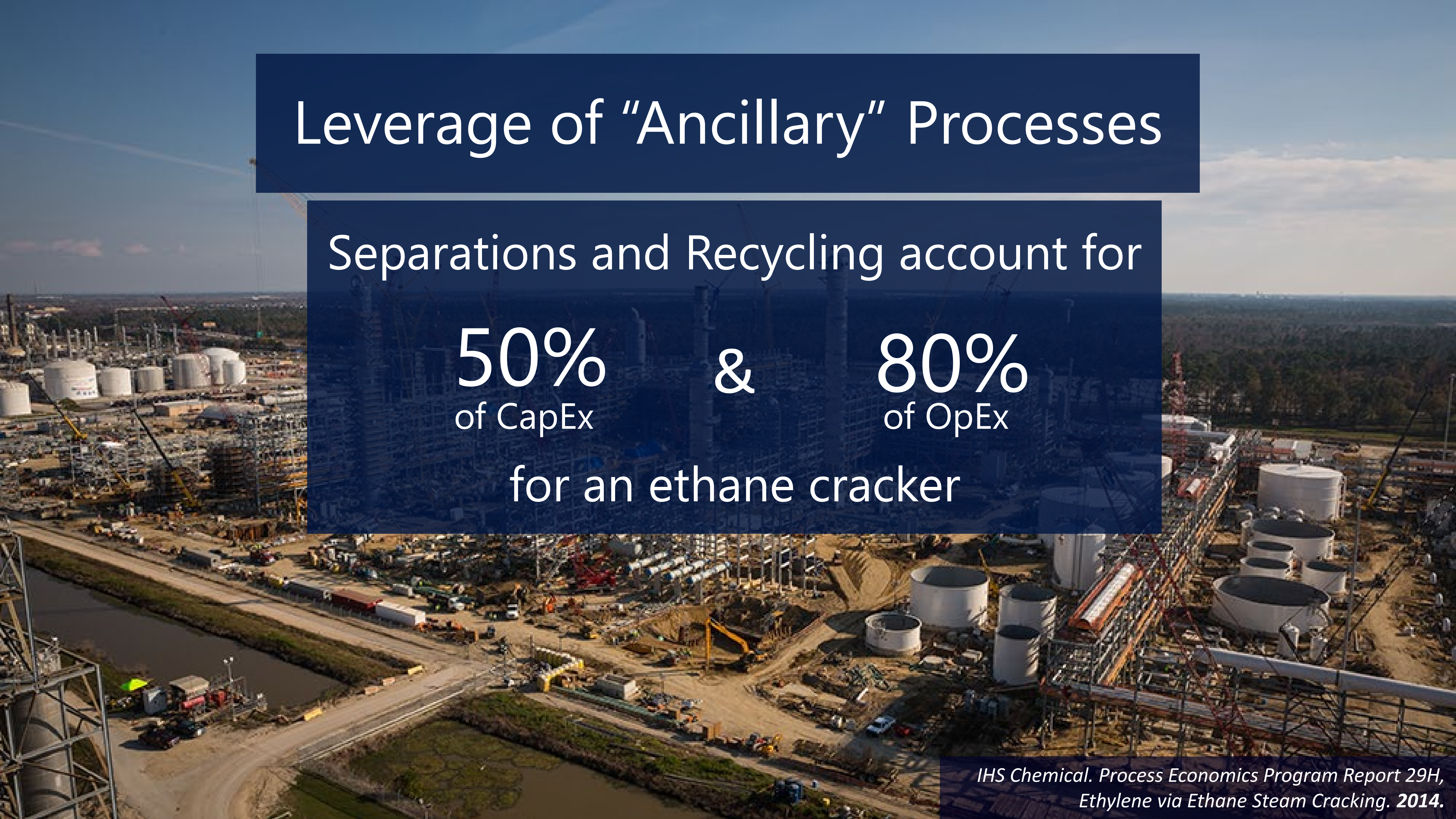


*Kim, Y., et al. Modular Chemical Process Intensification: A Review. Annu. Rev. Chem. Biomol. Eng. **2017**. 8, 16.1–16.22.*

“Almost every advance in petrochemical processes came about because of the invention of a new material.”

– Jeff Bricker, UOP Honeywell, *Changing Landscape Report*

- Haber Process Enabled by High-Strength Steel
- Fluid Cracking Enabled by Zeolites
- Ceramics for High-Temperature Applications
- Fluoropolymers and Glass for Aggressive Chemicals



Leverage of "Ancillary" Processes

Separations and Recycling account for

50% of CapEx & **80%** of OpEx

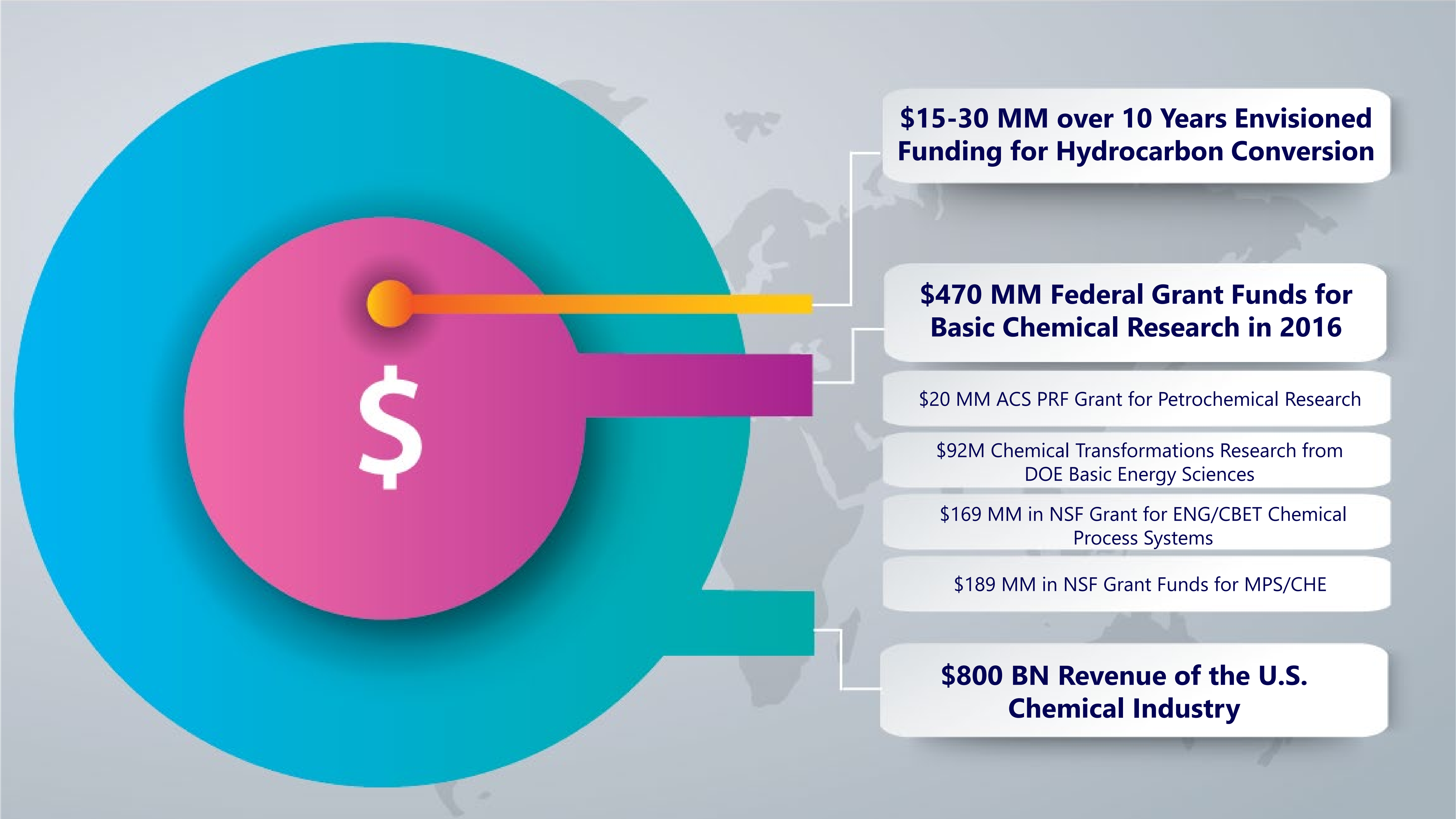
for an ethane cracker

IHS Chemical. Process Economics Program Report 29H, Ethylene via Ethane Steam Cracking. ***2014.***

The Six Pillars of Hydrocarbon Technological Development

National
priority level

Sustained
public and private
commitments


$15-30 MM over 10 Years Envisioned Funding for Hydrocarbon Conversion
$470 MM Federal Grant Funds for Basic Chemical Research in 2016
$20 MM ACS PRF Grant for Petrochemical Research
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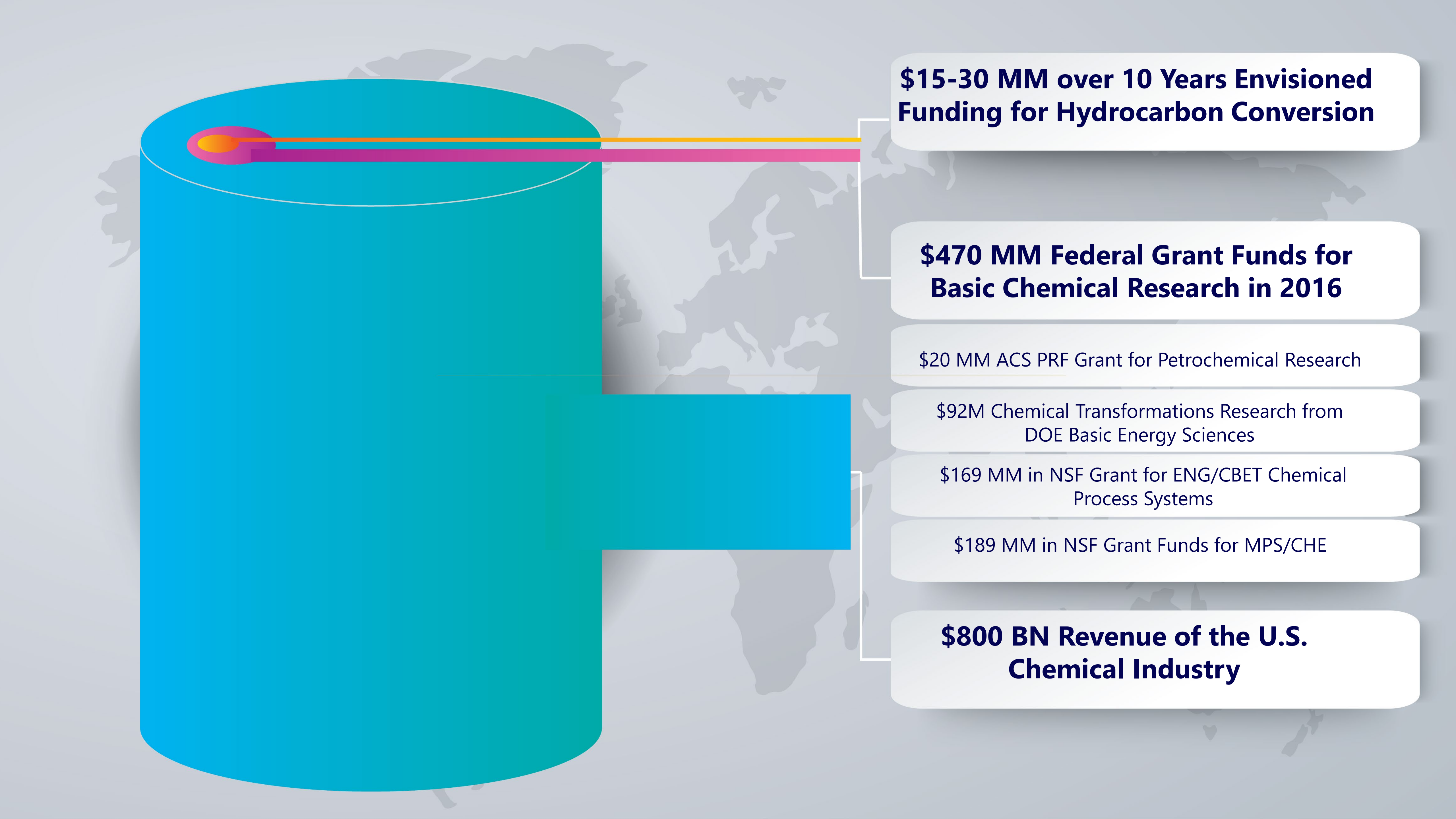
$169 MM in NSF Grant for ENG/CBET Chemical Process Systems
$189 MM in NSF Grant Funds for MPS/CHE
$800 BN Revenue of the U.S. Chemical Industry
$



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User facility

Shared access model

Public/private Partnerships

RAPID's Industry-Led Vision

RAPID Transforming Process Industries

A dynamic network of partners who collectively build a sustainable ***ecosystem*** *that:*

… researches, develops and broadly commercializes new technology for modular chemical process intensification

… delivers dramatic reductions in energy, greenhouse gas, capital and operating cost

… makes U.S. Manufacturing and our workforce more competitive

RAPID's Ecosystem

Industry leaders, researchers, educators, engineers, operators and facilities

Our Mandate

RAPID Transforming Process Industries

- Research, develop and demonstrate high-impact modular chemical process intensification solutions for U.S. Manufacturing.
- Actively build RAPID membership.
- Leverage $70 million of DOE funding with member cost share.
- Benefit a wide range of stakeholders.
- Enable access to process intensification resources, tools, expertise & facilities.
- Establish a technical education and workforce development program.

"The goal for these Institutes is to revitalize American manufacturing and support domestic manufacturing competitiveness."

— U.S. DOE

Potential Benefits

- Accelerated economic growth and innovation
- New high-paying STEM jobs and a resurgence in chemical manufacturing
- Energy efficiency improvement and lower emissions
- Enhanced living standards and communities
- Lower barriers to the adoption of new technologies
- Building scientific capital in chemistry, a field that's vital to our nation

Potential Losses

- Weakened global competitiveness of U.S. companies
- Slower economic growth
- Higher labor costs and erosion in skill levels
- Stagnation in resource efficiency and optimization of materials
- Capital inefficiencies through project overruns, opportunity expenses, and failed commissioning

The Perennial Question: What Does Industry Want?

20% improvement in Figures of Merit (FOM)

Bridge over industrial “valley of death” to commercialization

Develop public partnerships for workforce & technological development

Leverage chemical industry’s global competitiveness

Achieve economic growth and reduce commodity costs

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NAS

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Jennifer Scott, ACC


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ACTION
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Opportunities
Elevate
Interest
Connect
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References

- ACC. *Catalysis Helps Society Do More with Less.* https://www.americanchemistry.com/Policy/Energy/Energy-Efficiency/Catalysis-Infographic.pdf (accessed on June 1, 2017).
- ACC. *Shale Gas and New U.S. Chemical Industry Investment: $164 Billion and Counting*. **2016**. https://www.slideshare.net/MarcellusDN/acc-shale-gas-and-new-us-chemical-industry-investment-164-billion-and-counting (accessed on June 2, 2017).
- Alper, J. The Changing Landscape of Hydrocarbon Feedstocks for Chemical Production: Implications for Catalysis: Proceedings of a Workshop. National Academies Press, **2016**. http://www.nap.edu/23555.
- Brown, M. J. Progress in the Partial Oxidation of Methane to Methanol and Formaldehyde. *Catalysis Today*. **1991.** Volume 8(3), 305-335.
- Cavani, F., N. Oxidative Dehydrogenation of Ethane and Propane: How Far from Commercial Implementation? *Catalysis Today*. **2007**. 127(1-4), 113-131.
- DeRosa, S. E. Impact of Natural Gas and Natural Gas Liquids Supplies on the United States Chemical Manufacturing Industry: Production Cost Effects and Identification of Bottleneck Intermediates. *ACS Sustainable Chem. Eng*. **2015**. 3(3), 451-459.
- Farrell, B.L., A Viewpoint on Direct Methane Conversion to Ethane and Ethylene Using Oxidative Coupling on Solid Catalysts. *ChemInform*. **2016**; 47(37), 4340-4346.
- *FY 2017 Congressional Budget Justification*. Department of Energy. 2017. https://science.energy.gov/~/media/budget/pdf/sc-budget-request-to-congress/fy-2017/FY_2017_SC_BES_Cong_Budget.pdf.
- Gao, J., Catalysis. Identification of Molybdenum Oxide Nanostructures on Zeolites for Natural Gas Conversion. *Science*. **2015,** 348, 686-690.
- Gao, J., Y. Structure of Mo_2C_x and Mo_4C_x molybdenum carbide nanoparticles and their anchoring sites on ZSM-5 zeolites. *J. Phys. Chem. C*. **2014.** 118(9), 4670-4679.
- Gärtner, C. A. Oxidative Dehydrogenation of Ethane on Dynamically Rearranging Supported Chloride Catalysts. *J. Am. Chem. Soc.* **2014**. 136(36), 12691-12701.
- Gärtner, C. A. Oxidative Dehydrogenation of Ethane: Common Principles and Mechanistic Aspects. *ChemCatChem*. **2013.** 5(11), 3196-3217.
- Gaspar, N. J. H2S Promoted Oxidative Dehydrogenation of Hydrocarbons in Molten Media. *Can. J. of Chem. Eng*. **1974**. 52(6), 793-797.
- Guo X., Direct, Nonoxidative Conversion of Methane to Ethylene, Aromatics, and Hydrogen. *Science.* **2014**, 344, 616-619.
- Hristov, I. H. The Possible Role of SO3 as an Oxidizing Agent in Methane Functionalization by the Catalytica Process. A density functional theory study. *Organometallics*. **2003**. 22(8), 1668-1674.
- IEA, ICCA, DECHEMA. *Technology Roadmap: Energy and GHG Reductions in the Chemical Industry via Catalytic Processes*. **2013**. https://www.iea.org/publications/freepublications/publication/Chemical_Roadmap_2013_Final_WEB.pdf.
- Kim, Y., et al. Modular Chemical Process Intensification: A Review. *Annu. Rev. Chem. Biomol. Eng*. **2017**. 8, 16.1–16.22.
- NSF CBET Awards. https://www.nsf.gov/awards/award_visualization.jsp?org=CBET#showAwardDollars=true (accessed June 1, 2017).
- NSF CHE Awards. https://www.nsf.gov/awards/award_visualization.jsp?org=CHE#showAwardDollars=true (accessed June 1, 2017).
- Siluria Technologies. Demonstration Plant. http://siluria.com/Technology/Demonstration_Plant (accessed May 25, 2017).
- *U.S. Energy-Related Carbon Dioxide Emissions, 2015.* U.S. Energy Information Administration, U.S. Department of Energy. **2017**. https://www.eia.gov/environment/emissions/carbon/.
- Zurcher, F.R., Nanowire Catalysts and Methods for their Use and Preparation. US Pat. 8,962,517, February 24, 2015.