Low-Energy, Low Cost Production of Ethylene by Low Temperature Oxidative Coupling of Methane

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Siluria Technologies (Lead) / RTI International (Partner)
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Project Objective

- **Overall Objective:** To develop a new catalytic process for distributed production of ethylene via low-temperature oxidative coupling of methane using the advanced OCM catalyst developed by Siluria Technologies.

- Distributed small-scale production of ethylene enables on-demand ethylene applications such as on-site generation of high-value derivatives with the potential to reshape and condense the national manufacturing value chain, from raw material to finished goods.

- The current design developed and commercialized by Siluria shows excellent scalability between 100 and 1000 KTA (KiloTons per Annum). However, the specific operating and capital costs sharply increase for smaller capacities.

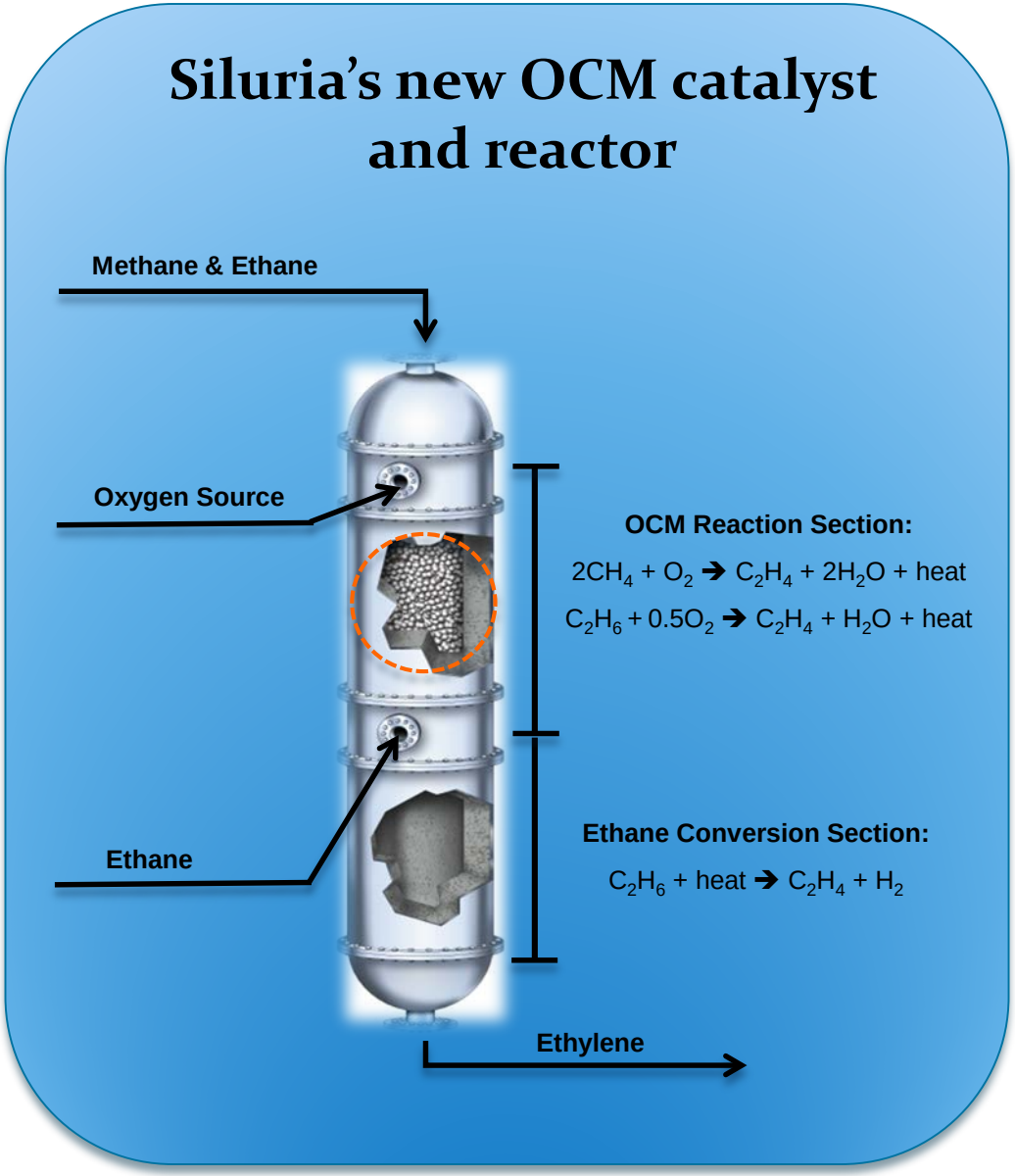
- Reasons for poor scalability at smaller scale:
  - Product recovery and purification train - utilizes typical cryogenic separation systems that show poor scalabilities at small-scale.
  - Technical limitations and minimum capital expenditures.
  - Separation section (and other process areas to a lesser extent) hit baseline costs and are cost challenged at capacities below 100 KTA.

- The project aims to overcome the above hurdles and enable economically attractive small scale OCM design.

Technical Innovation

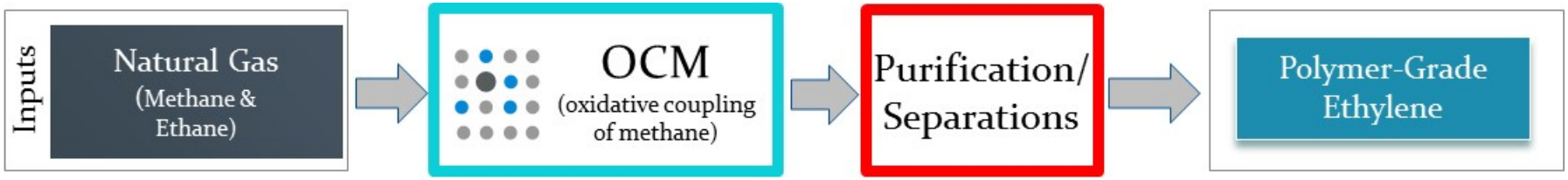
- **Ethylene Crackers:** Currently primarily produced by steam cracking of ethane, propane or naphtha
  - Utilizes mega scale crackers whose minimum efficiency scale is currently above 500 KTA.
  - Operate at very high temperatures and are extremely energy and capital intensive.

- **Siluria's New OCM Technology:**
  - Proprietary, revolutionary technology enables direct conversion of natural gas to higher value products.
  - Conversion accomplished through catalytic exothermic process.



Technical Innovation

Enabling small-scale production



- Simple design of the OCM reactor and overall process (as currently developed by Siluria) enables excellent scalability for a wider range of capacities than that currently available via steam cracking.

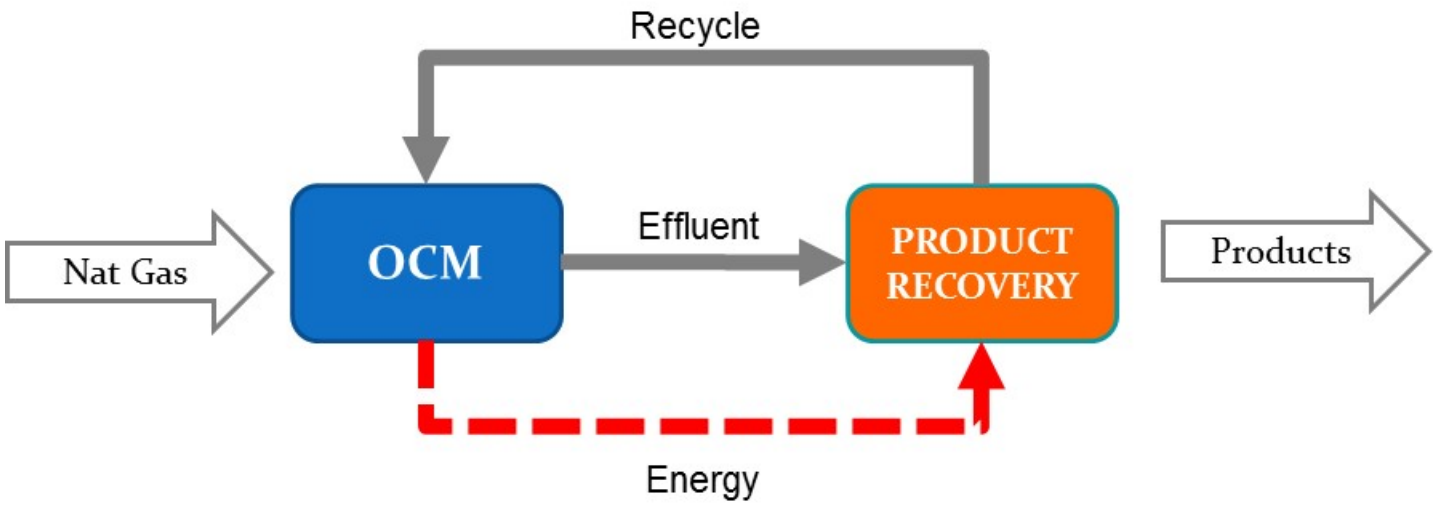
- Development of advanced olefin separation technologies (the main scope of this project) would further expand the scalability of the OCM process.

- Availability of natural gas, attractive economics and flexibility in the new OCM process design opens concrete avenues towards
  - on-demand ethylene production
  - on-site conversion of ethylene to high value products and, possibly, finished goods

Technical Approach

Approach: Identify and resolve roadblocks to small-scale implementation of Siluria's OCM process by exploring out-of-the box and innovative solutions for olefin separations and other key process areas.

- Evaluate Siluria's current OCM ethylene design for small-scale deployments and identify critical bottlenecks to scalability.
- Research and develop alternative unit operations / process schemes addressing the bottlenecks.
- Investigate techno-economic viability of alternative designs.
- Experimental validation and final configuration design.



Technical Approach

Siluria's world class team:

Vision and competence to translate ideas into implementation

- State-of-the-art high throughput screening platform for catalyst discovery and development.
- R&D and pilot facilities specifically developed for OCM and incorporating new separation technologies.
- Extensive process engineering and technology development experience.
- Techno-economic analysis & commercialization expertise.
- First of a kind (world's largest) OCM unit co-located with Braskem operating polymer plant in La Porte, TX.

Materials and Process testing - RTI International (Partner)

- Material development and testing capabilities - (sorbent and membrane development for separation studies).
- Process development - strong competence in developing, designing and constructing separation systems for novel applications.

Transition and Deployment

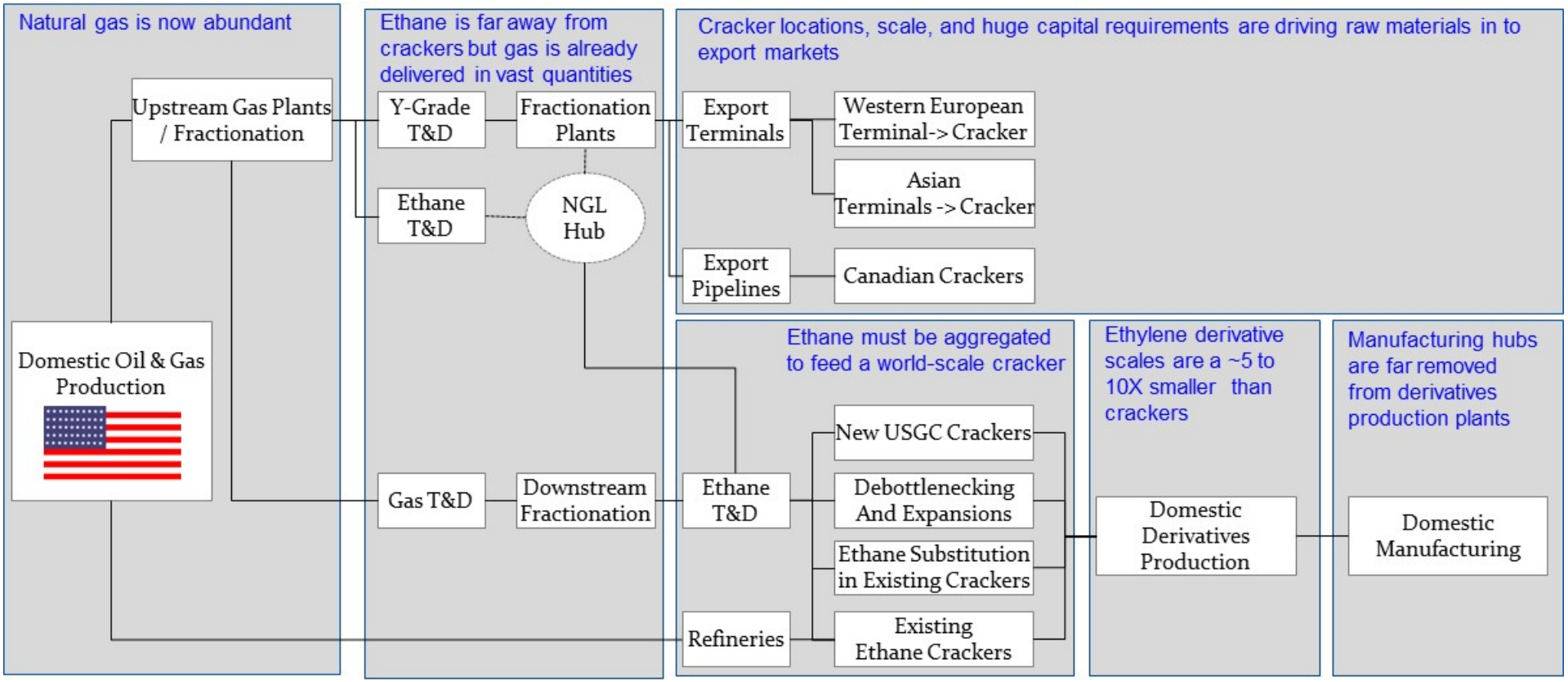
Mega Trends in the US Ethylene Market

Scale, location, and infrastructure

- American natural gas and ethane is being produced in growing quantities, in geographies far removed from petrochemical hub in the US Gulf Coast (infrastructure constrained)
- Scale of ethane crackers requires 60 to 80 MBPD of ethane to be delivered to each US Gulf Coast cracker
- Scale of ethane crackers dwarfs ethylene derivatives facilities
- These drivers are pushing raw materials like natural gas and ethane to export, rather than adding value domestically through manufacturing

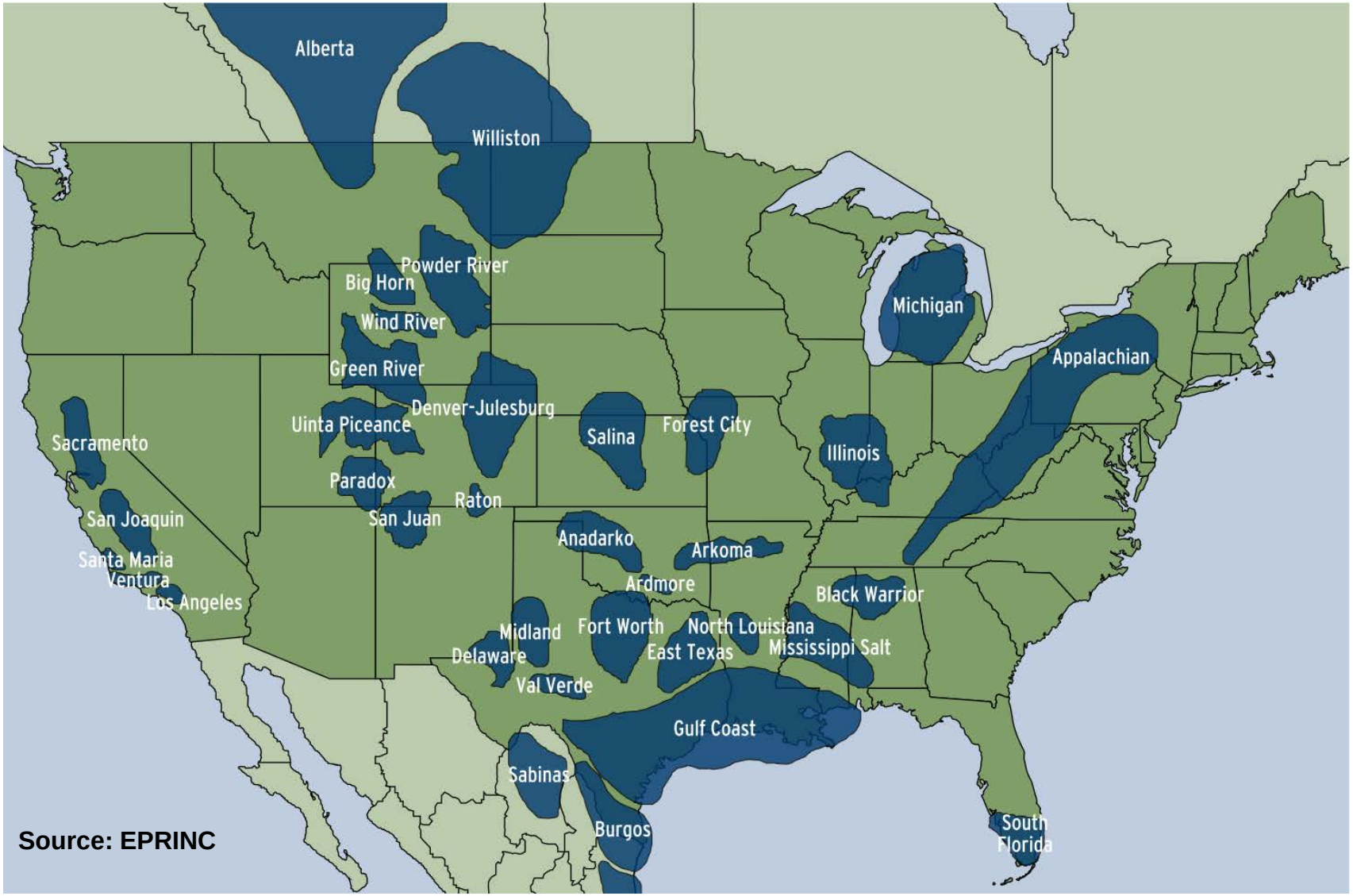
Transition and Deployment

US NG and Ethylene Value Chain is Constrained by Huge Cracker Scales and Concentrated Location



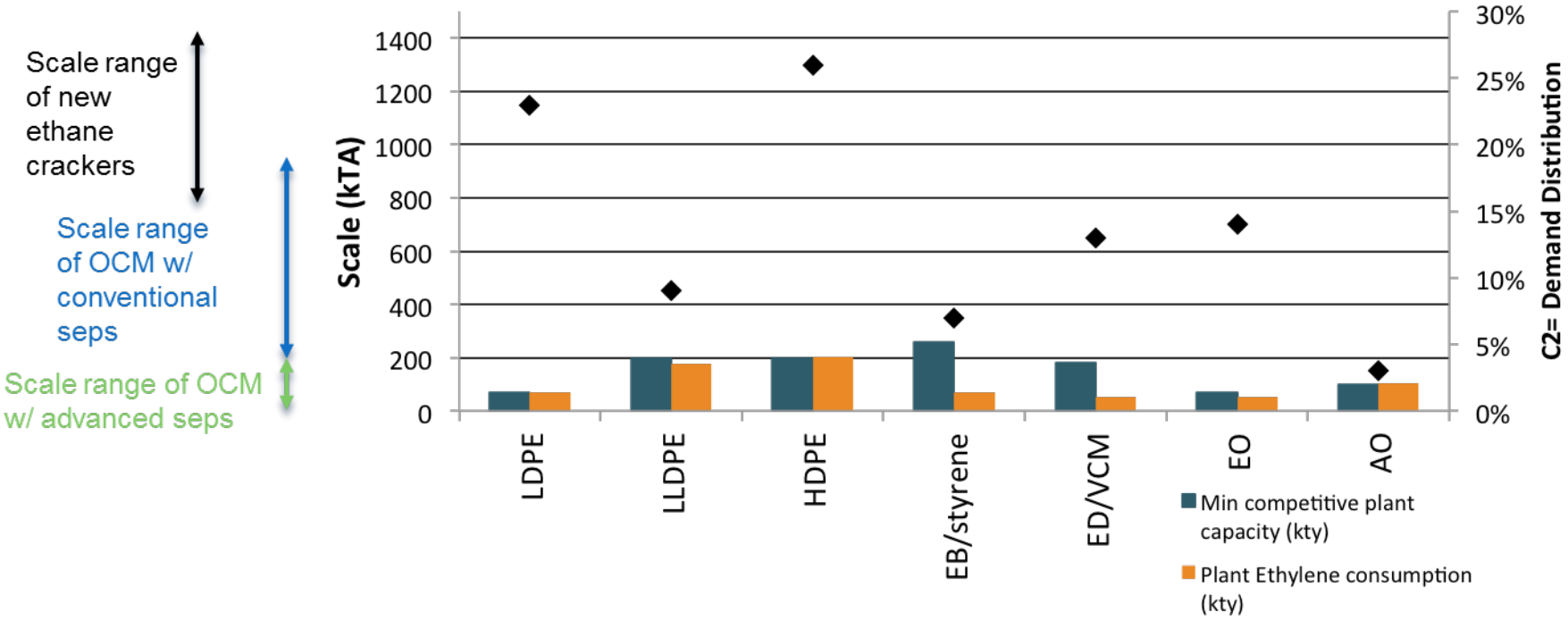
Transition and Deployment

NGL Supply Map- New Sources are Physically Removed from Demand



Measure of Success

Cracker / Derivatives Scale Mismatch



Siluria's OCM can enable distributed-scale production of high value products like polymers from ubiquitous natural gas, radically disrupting the resource-to-manufacturing value chain

Source: Internal Siluria, I H S Chemicals Commissioned Research

Project Management & Budget

- Project Duration: 18 months

Task	Description	Duration	Status
1.0	**Detailed Process Analysis** • **Milestone 1:** Target list of unit ops and/or process steps providing roadblocks to small scale implementation (Q1)	Q1	Complete
2.0	**Process Design and Development** • **Milestone 2:** Identify alternative process concepts (Q2) • **Milestone 3:** Preliminary alternative process concepts, validated w/experimental data (Q3) • **Milestone 4:** Refined alternative process concepts, validated w/experimental data (Q4)	Q2 to Q4	In Progress
3.0	**Refined Conceptual Design & Techno-Economic Modeling** • **Milestone 5:** One or more process concepts for small-scale OCM ethylene production (Q5)	Q3 to Q5	In Progress
	Internal Go/No-go Decision Point: Techno-economic analysis for one or more process concept for small-scale <20 MMBTu/ton ethylene	Q5	
4.0	**Project Management and Reporting** • **Milestone 6:** Draft final report (Q5) • **Milestone 7:** Submit final report (Q6)	Q1 to Q6	

Total Project Budget	
DOE Investment	$2,000,000
Cost Share	$500,923
Project Total	$2,500,923

Results and Accomplishments

- **Accomplishments:** Completed Milestones 1 and 2 (currently in Q3)
  - Identified roadblocks to small-scale OCM implementation via thorough technical and economic evaluation
    - Product recovery and separation section – critical roadblock
  - Alternative technologies for separation section along with other process areas were researched.

- **Current Work:**
  - Suite of advanced separation materials as well as commercial-off-the-shelf technologies being evaluated together with RTI International
    - Testing for potential membranes and adsorbents that can be utilized in a PSA/TSA environment currently underway
  - Initial results from tests to date indicate great potential for vastly enhanced scalability and lower costs of production

- **Schedule:**
  - Refined testing → Process integration, optimization for promising technology → Techno-econ analysis for final process configurations