Dow Olefins, Aromatics and Alternatives

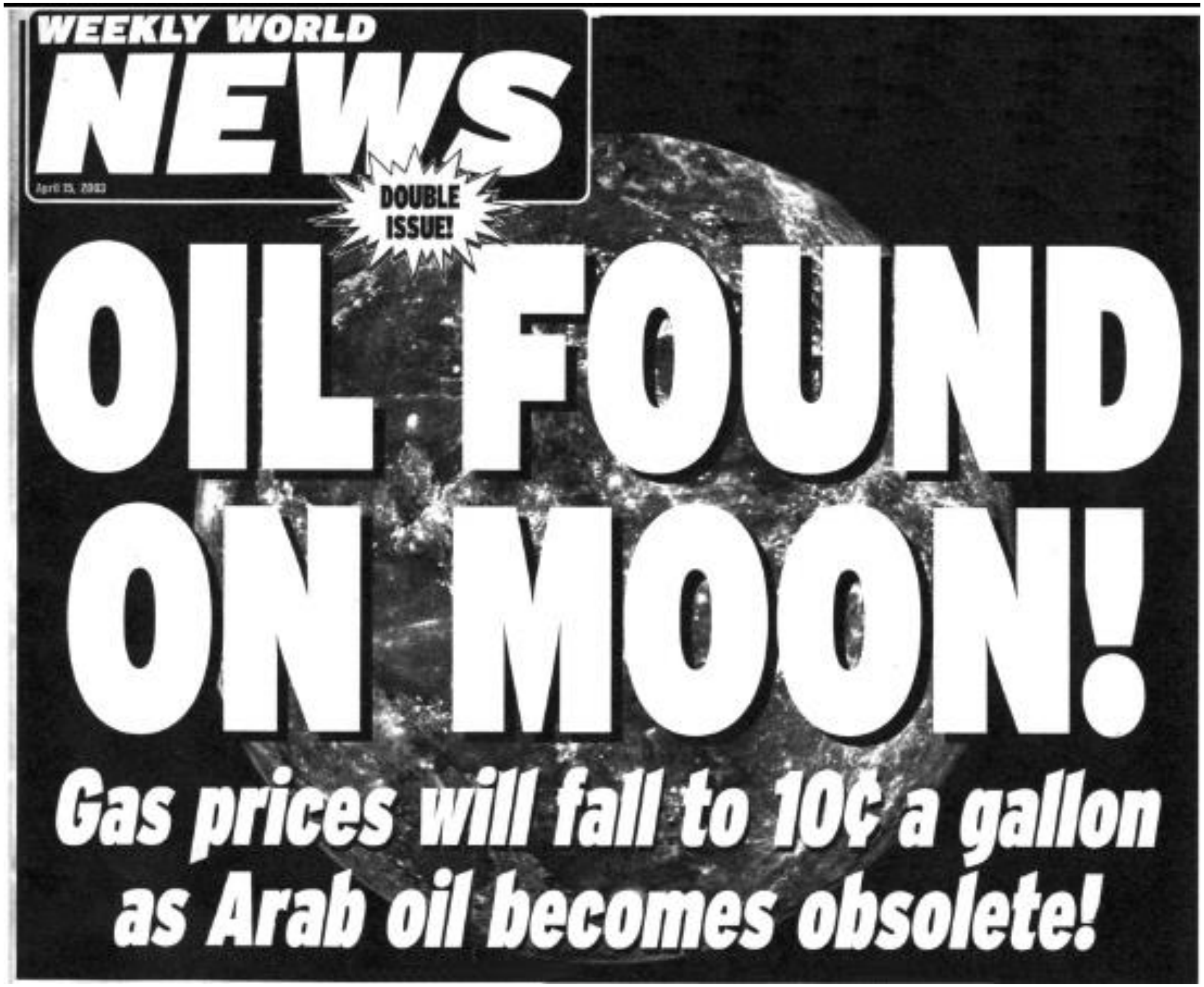
# Implementation Challenges and Risk Mitigation for New Technology

Brien Stears – Associate R&D Director

AICHE 2016 Natural Gas Utilization Conference, Morgantown WV, November 1-4, 2016

# Responding to Uncertainty

# A New Opportunity or Threat?



# Strategic Response

## Advantaged Positions Across the Globe

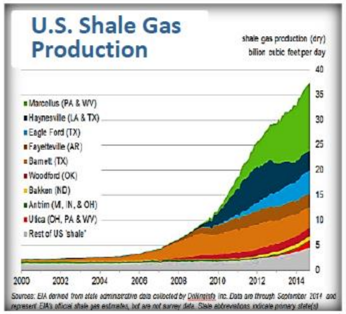
**USGC Investments**
- US shale

**Sadara**
- Low cost
- Access to Asia

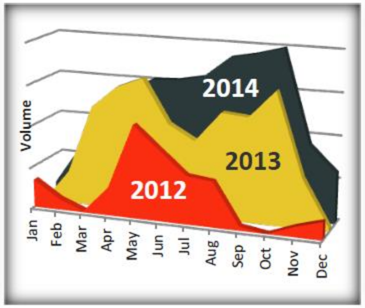
**Revamped Alberta Advantage**
- Alberta advantage

**European LPG**
- Extending US shale advantage
- Abundant LPG for Europe

**Established Key Alliances in Latin America**
- Growing ethane
- Next large shale development





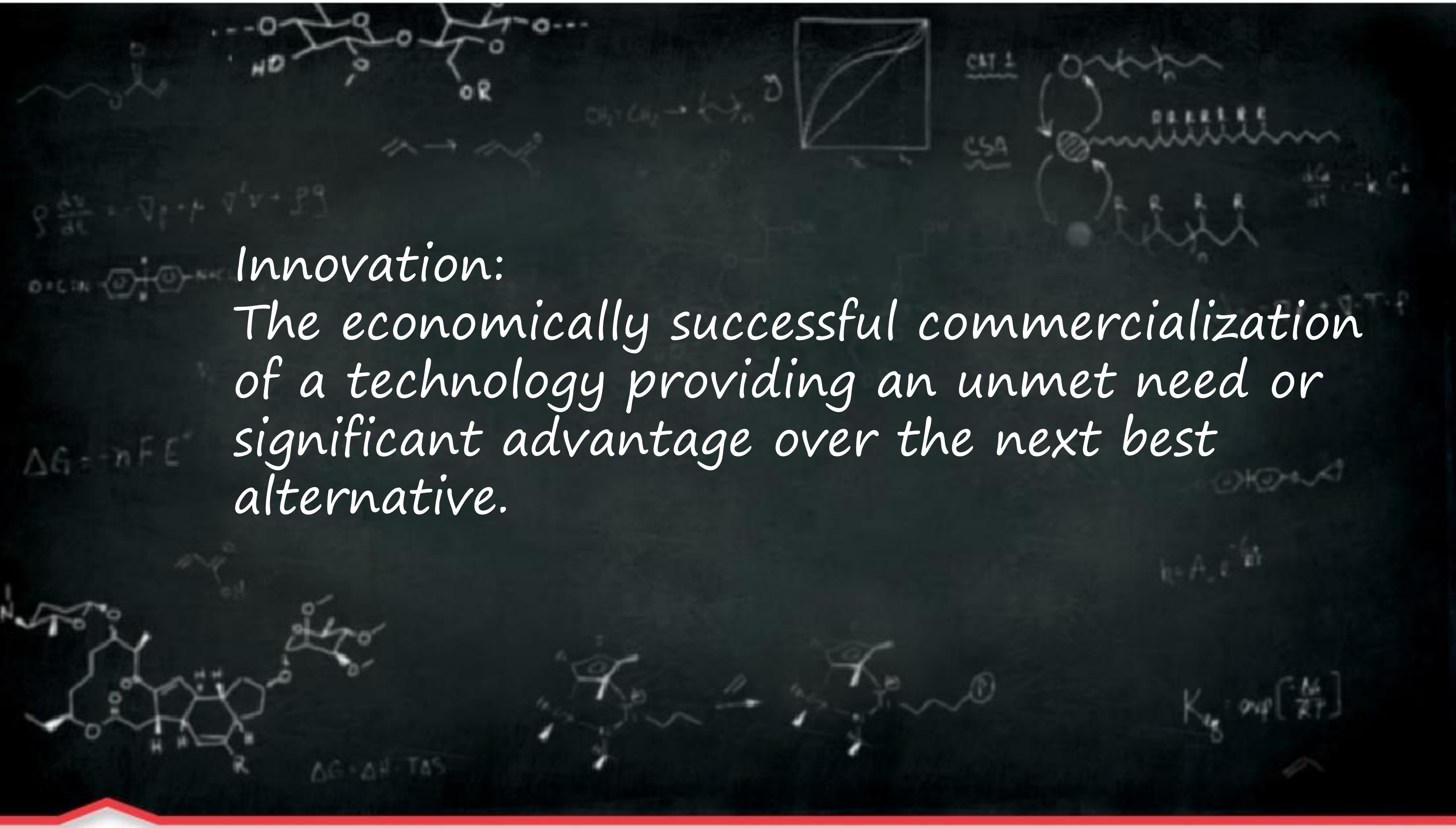




2014 Dow Investor Forum (http://www.dow.com/investors/)

## R&D evaluates, develops and deploys technology options for different scenarios

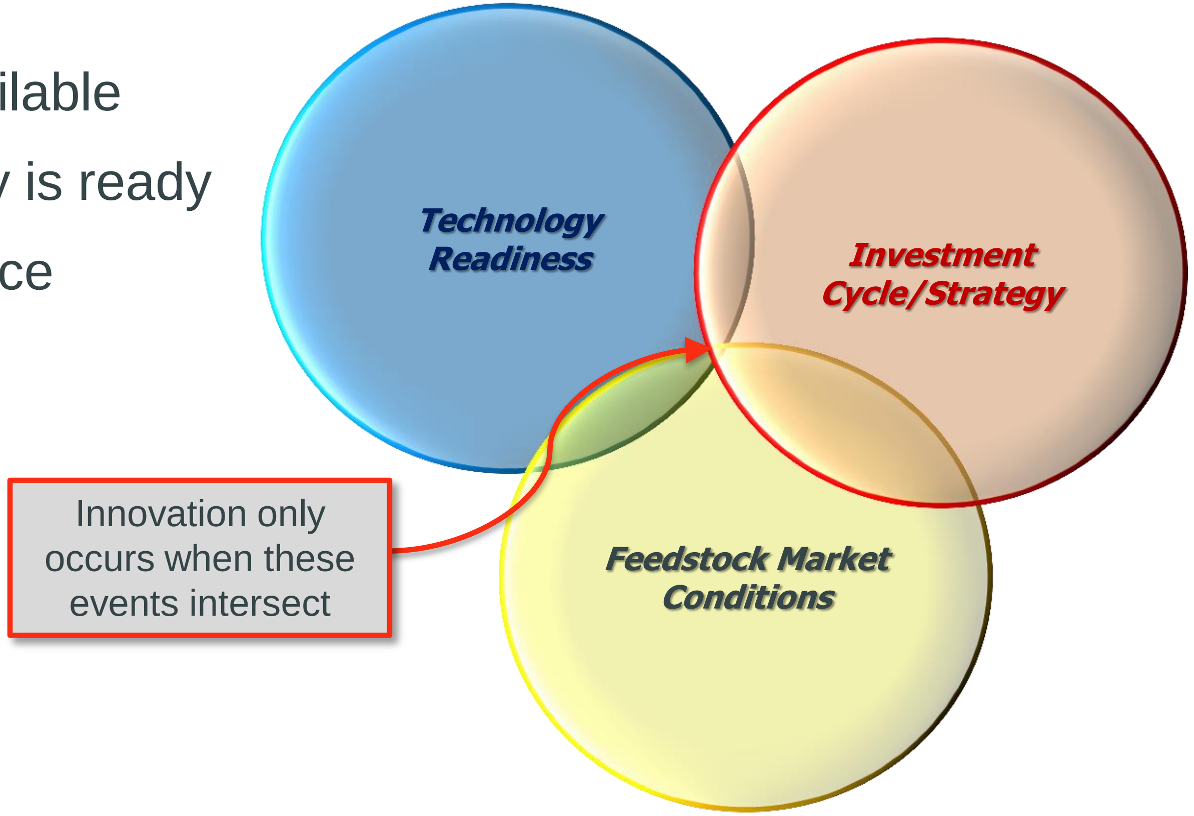
# Responding to Uncertainty with Innovation



Innovation:
The economically successful commercialization of a technology providing an unmet need or significant advantage over the next best alternative.

# Technology Innovation Requirements

1. Market opportunity is available
2. Need-meeting technology is ready
3. Investment support in place




*Technology and Commercialization Plan must be complete prior to alignment to insure quick and robust execution*

# Implementation Challenges

***Feedstock Market Conditions***

***Technology Readiness***

***Investment Cycle/Strategy***

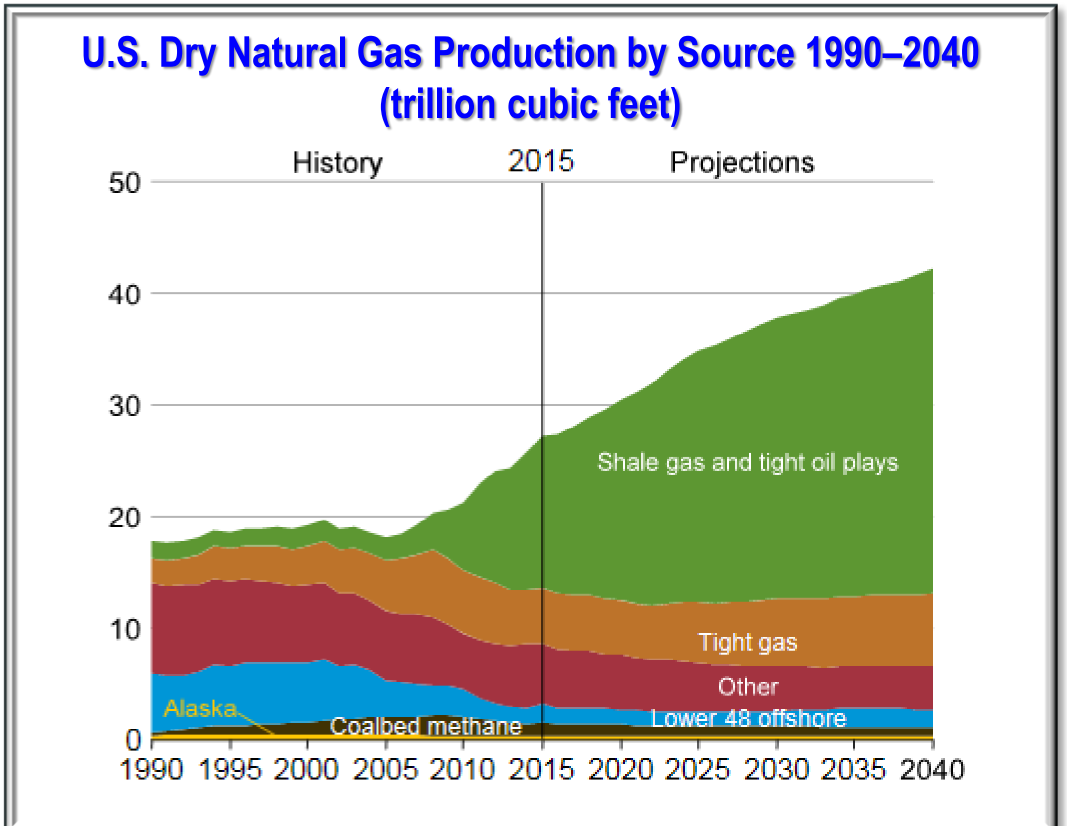
Low — *Ability to Mitigate Challenges* — High

| Feedstock Market Conditions | Technology Readiness | Investment Cycle/Strategy |
|---|---|---|
| Price Volatility | Catalyst | Funding Availability |
| Supply Security | Expertise in Area | Regulatory |
| Infrastructure | Lab capabilities | Tax implications |
| RM Quality | IP Strategy/RTP | Financing Rates |
| RM Logistics | Process Equipment | Extent of Leverage |
| Geography | BPCS/LOPA | Partnerships |

# Mitigating Feedstock Market Challenges

- Seek new opportunities that add flexibility
- Understand what drives volatility
- Take advantage of market floor/ceilings
- Look for preferential geographies

# US Chemical Expansion: Driven by Cheap Shale-gas




*U.S. Energy Info. Administration*
*Annual Energy Outlook 2016*

- **Abundant shale gas in North America** ➔ shift of feedstock in petrochemical industry from more naphtha to LPG
- **Less propylene production from steam cracking**
- **On-purpose propylene production to close the gap**

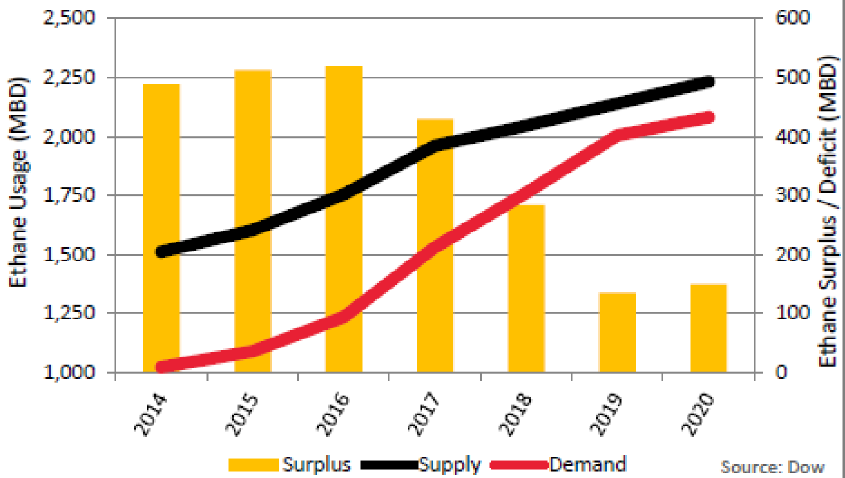
**Dow's Shale Gas Driven US Expansion:**
Investing >$4 billion into US Gulf Coast Operations

***Feedstock Market Conditions***

# Outlook for Feedstock Supply Favorable

*Feedstock Market Conditions*

## Ethane Expected to Be Long Into 2020+




Source: Dow

## Dow's View on Market Drivers

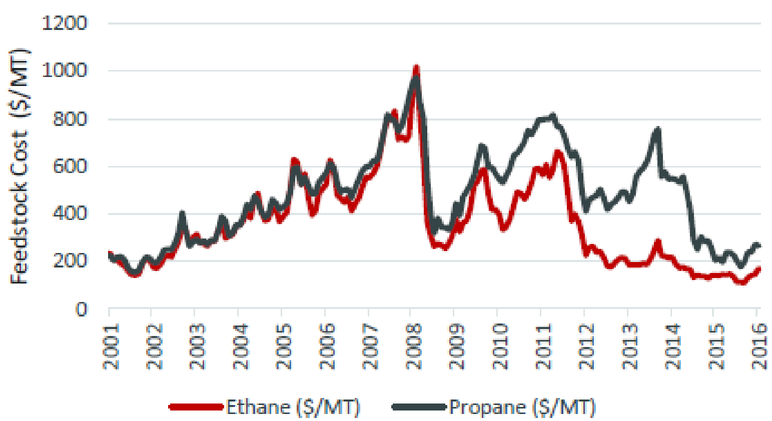
Favorable balances through next several years

- Gas well supplied
- NGL supplies grow with associated gas
- Forecasts include exports and new crackers

Propane supply/demand remains soft

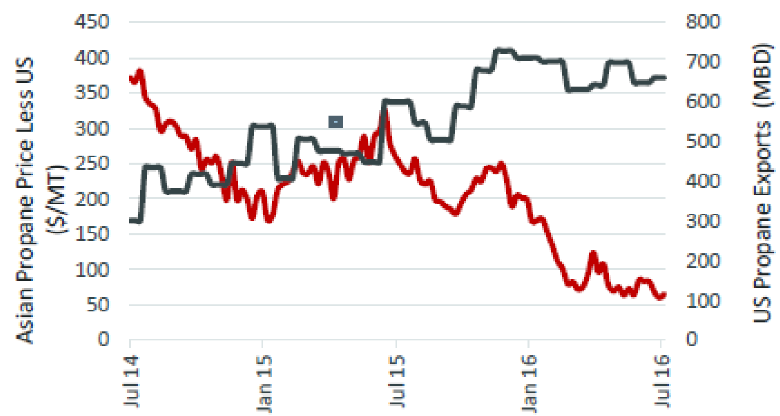
- Propane prices below naphtha
- Propane has historically – and will continue to – cap ethane price

## Propane Caps Ethane




Source: Dow, Bloomberg, Liquidity Partners

## US Propane Exports Exhausting Available Buyers




Source: Dow, Bloomberg, US EIA, SGX, Liquidity Partners

# Mitigating Technology Risk:

Technology Readiness

- Use a stage gate approach to assess TRL
- Get key stakeholder buy-in at beginning
- Determine shortcomings and comparisons with NBA
- Utilize Strategic partnerships
- Hire expertise if not available internally
- Build upon and learn from the past
- Utilize equipment suitable for the process
- Use your best most advanced tools
- Set ambituous targets- both CAPEX/OPEX
- Utilize catalyst vendors for scale-up
- Clear implementation plan for first commercialization with contingencies

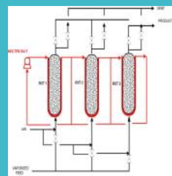
# Evolution of Catalytic Cracking Processes

**Technology will converge to the Best Economic Solution**

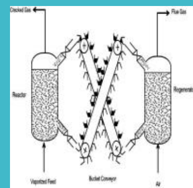
**The question is …..When?**

*Technology Readiness*

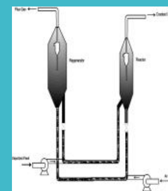
**Gasoline ~1,200,000[8] kTa**



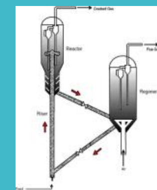
Houdry 1936[22]



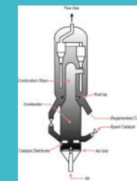
Moving Bed 1938[22]



FCC 1942[22]



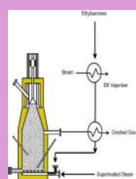
FCC/Riser/Zeolite 1960-65[22]



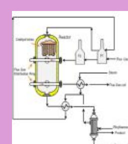
2 Stage RG 1972[22]

Maximum Evolution

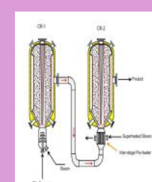
**Styrene ~27,500 kTa[9]**



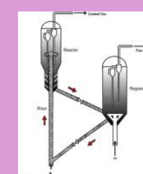
Axial Adiabatic 1940[23]



Heated Case 1965[23]



Radial Adiabatic 1972[23]

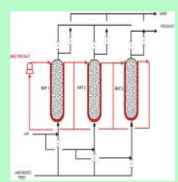


SNOW Process 2005

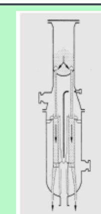
Slower Evolution

**Propylene ~89,000 kTa On-Purpose ~5,000 kTa[9]**

FCC Byproduct
Steam Cracking Byproduct

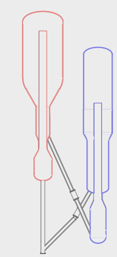


CATOFIN® Unit (c4) 1980's[12]



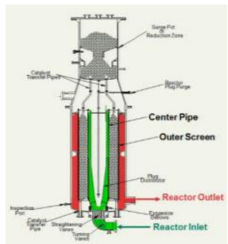
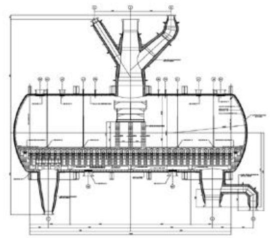
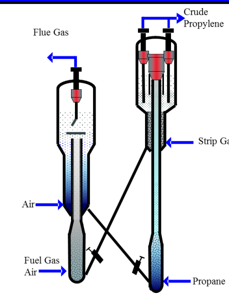
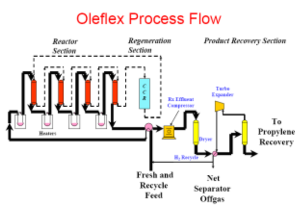
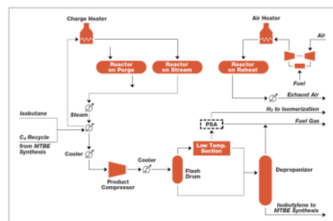
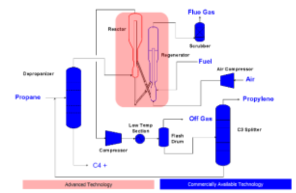
OLEFLEX™ Unit 1990[11]

Less Evolution



Circulating Fluid Bed

# Current Commercial PDH Technologies and Dow Fluidized Catalytic Dehydrogenation (FCDh)

| | Oleflex™ | Catofin® | Dow PDH |
|---|---|---|---|
| **Reactor** |   Multi-stage, adiabatic, moving bed reactor, CCR Regenerator |  Multi-reactor, Adiabatic Fixed-bed |   1 Proprietary Fluidized Reactor<br>1 Proprietary Fluidized Regenerator |
| **Process** |   |  |  |
| **Catalyst** | Pt-Sn/alumina | Chromia/alumina | Ga-Pt/alumina |
| **Reactor Outlet Pressure, psia** | 16-24 psia | 7 psia | 19-25 psia |
| **Conv. per pass** | 35 - 40% | 48 - 53% | 43-53% |
| **Sel. to C3=, mol%** | 89%@ XX conv;<br>84% @ 40% conv | 86+ @ XX% conv | 92-96% @ 43%-48% conv |

*Technology Readiness*

*Oleflex™ and Catofin® info. from process brochure, presentation, journal publication and patent literature*

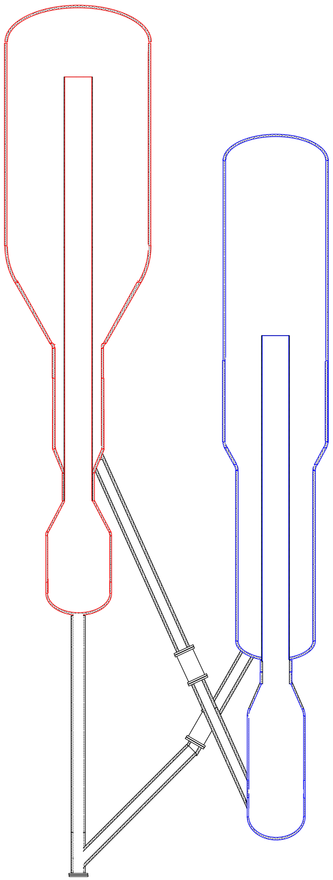
# Dow Catalytic Dehydrogenation Technology

*Technology Readiness*

## Delivers Significant Capital and Operating Cost Advantage over existing commercialized technologies

Circulating fluid bed technology for reaction and regeneration

- Lowest Energy Cost (20% reduction)
- Lowest Raw Material Consumption (5% lower unit ratio)
- Lowest capital cost outlay
  - Simple 1 regenerator and 1 reactor system without furnaces
  - 25% less capital (including catalyst)
- Sustainable technology: Low $NO_x$ and $CO_2$ emissions



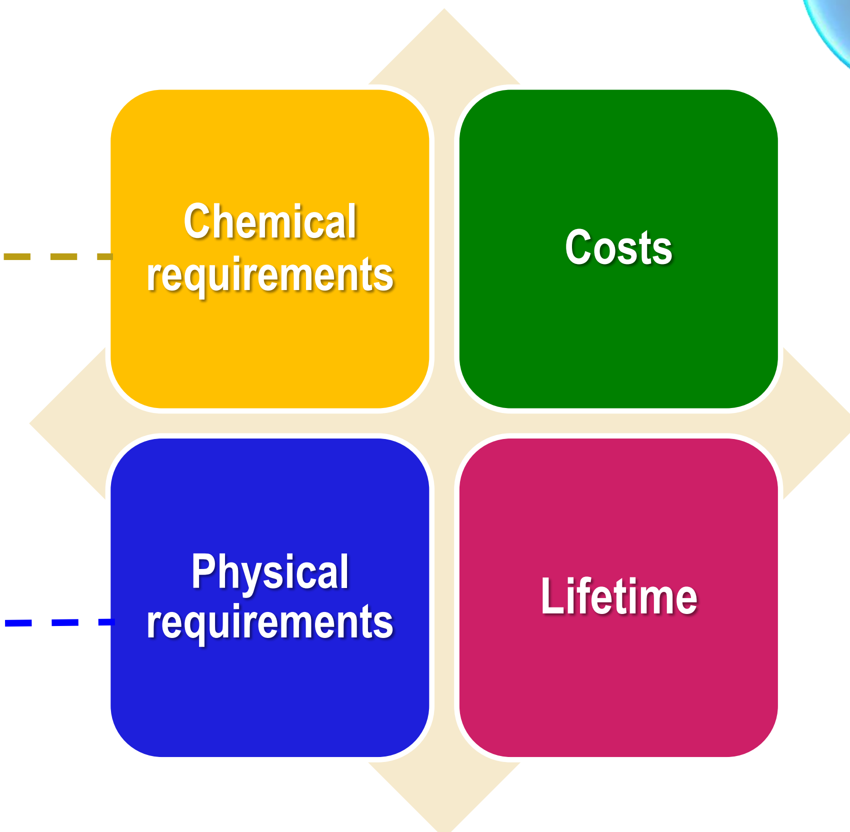
Based on proven FCC technology

- Invested in and Partnered with FCC Experts for over 10 years
- Leveraged FCC know-how from industry
- Design variations from FCC validated
  - Pilot Plants
  - Models
- Reliable production
  - FCC Plants routinely operate 4-6 years between turnarounds
  - Catalyst can be continuously replaced as needed

# Catalyst for Dow PDH

- Dehydrogenation
- Combustion of fuel and coke
- Regenerability
- Resistance to feed impurities

- Proper hydrodynamics
- Attrition resistant




## Catalyst: GaOx Supported on Fluidizable Alumina with Pt promoter

- Ga is the key dehydrogenation ingredient
- Trace amount of Pt important for fuel combustion

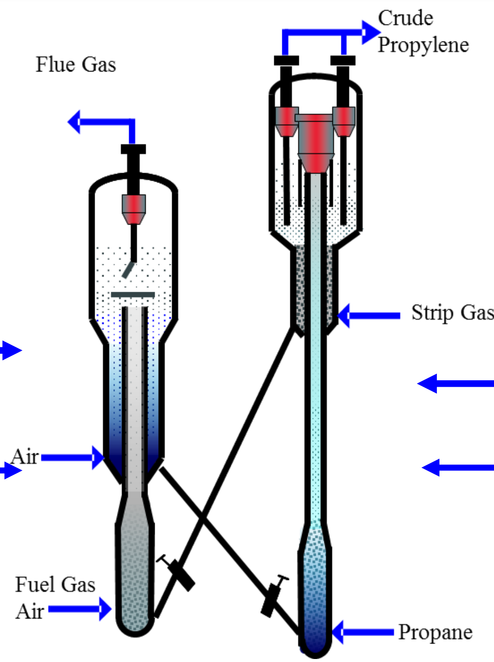
# The Dow Catalytic Dehydrogenation Process is a Platform Reactor Technology

*Technology Readiness*

- Most economical PDH technology that can integrate with a cracker
- Plants scale down at attractive capital intensity
- Reactor technology can plug and play into multiple plant configurations

**New PDH**

**Retrofit Existing PDH**




**Multiple Chemistries**

- EB→Styrene
- Propane → Propylene
- Butane →Butene
- Isobutane→Isobutene

**New Crackers**

**Retrofit Crackers**

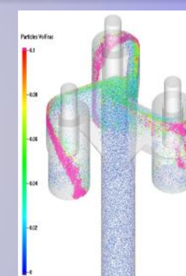
# Dow Catalytic Dehydrogenation Technology Development History: Ready for Commercialization

- Index and Process Flow Sheets are Complete
- Reactor/Regenerator Design Complete
- Layers of Protection Analysis Complete
- Process and Instrumentation Diagrams Complete
- IP Portfolio Growing and Robust (>20 applications 3 key grants)
- Scale-up Plan uses a multi faceted approach

***Technology Readiness***





**Next Step**

- ✓ Lab Reactors
- ✓ PDH DCR
- ✓ PDU
- ✓ Cold Flow
- ✓ FCC SME's
- ✓ Modeling
- Small Commercial Integrated with Cracker
- World-Scale Commercial

*Thank You!*