



# Research & Development in Delaware

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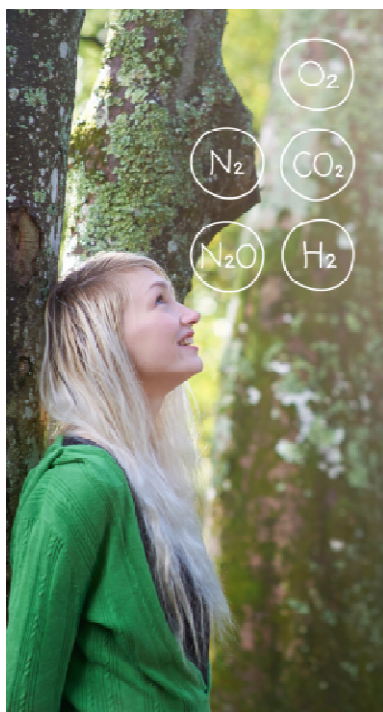
Delaware Research & Technology Center,  
22 March 2017



# Global Research & Development Role & Responsibilities

# Scientific Territory of Essential Small Molecules

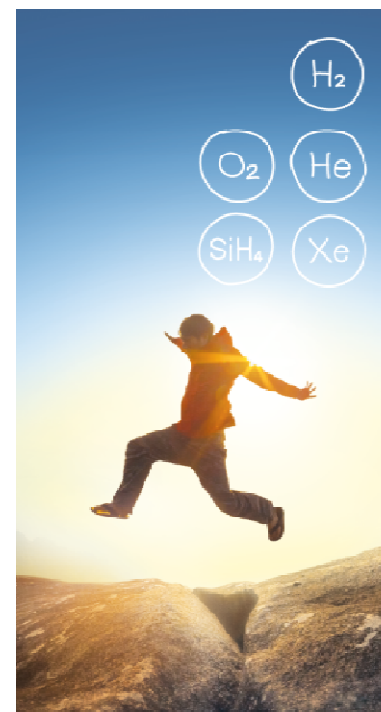
to Life



to Matter



to Energy



# Wide Range of Skills

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Process Engineering



Material  
Sciences



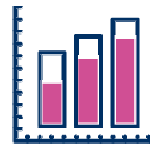
Combustion



Life Science



Applied  
Mathematics



Analytical  
Sciences



Fine Chemical  
Synthesis and  
Surface Science

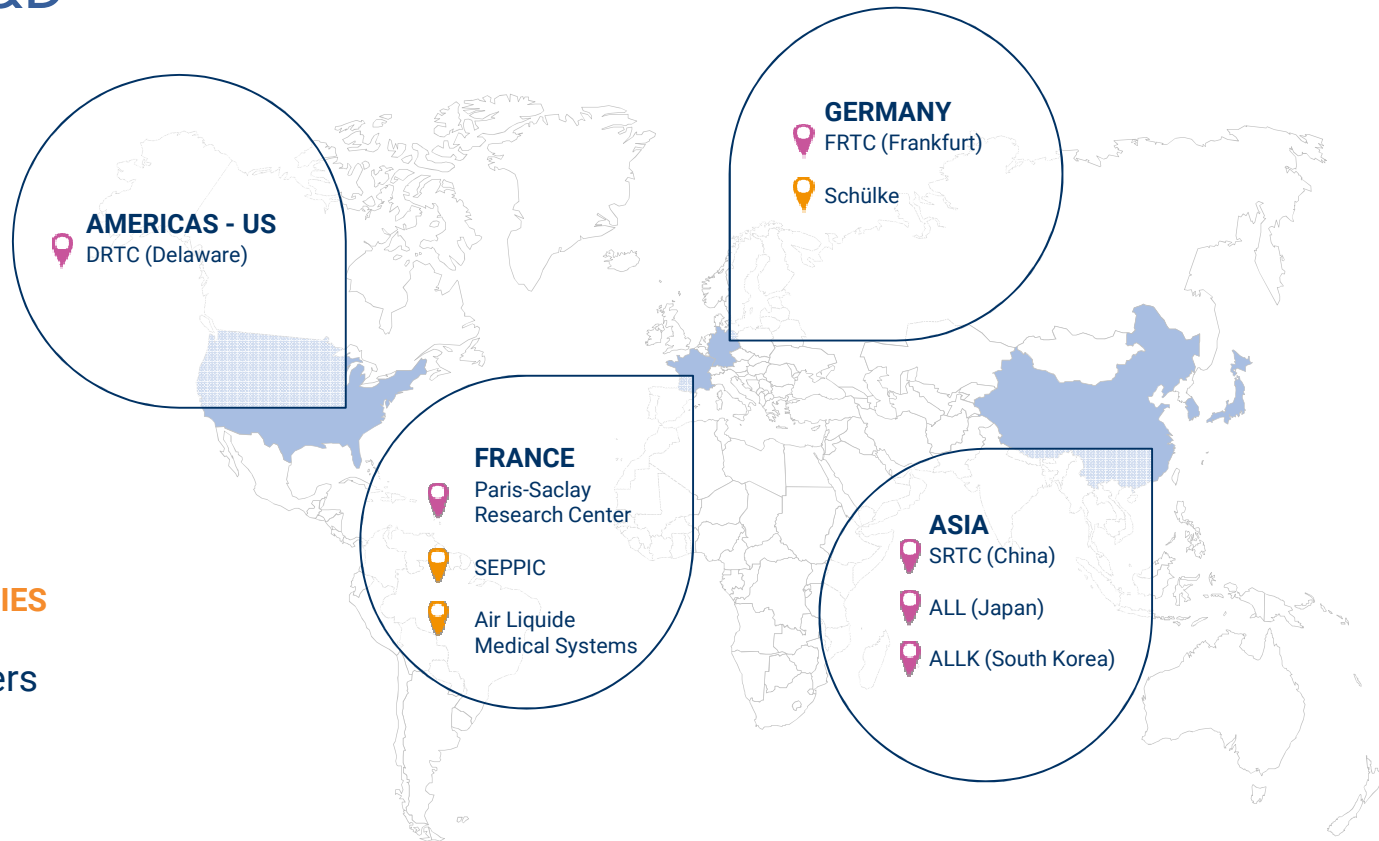


Design &  
Manufacturing

# Global R&D Network

 **GROUP R&D**  
 **R&D SUBSIDIARIES**

**1,100** researchers  
**9** R&D sites  
**3** continents  
**41** nationalities



## R&D 2016 Figures

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**217**

Industrial &  
Academic  
partners

**€288**

Millions  
Innovation  
Expenses

**1,100**

Researchers

**296**

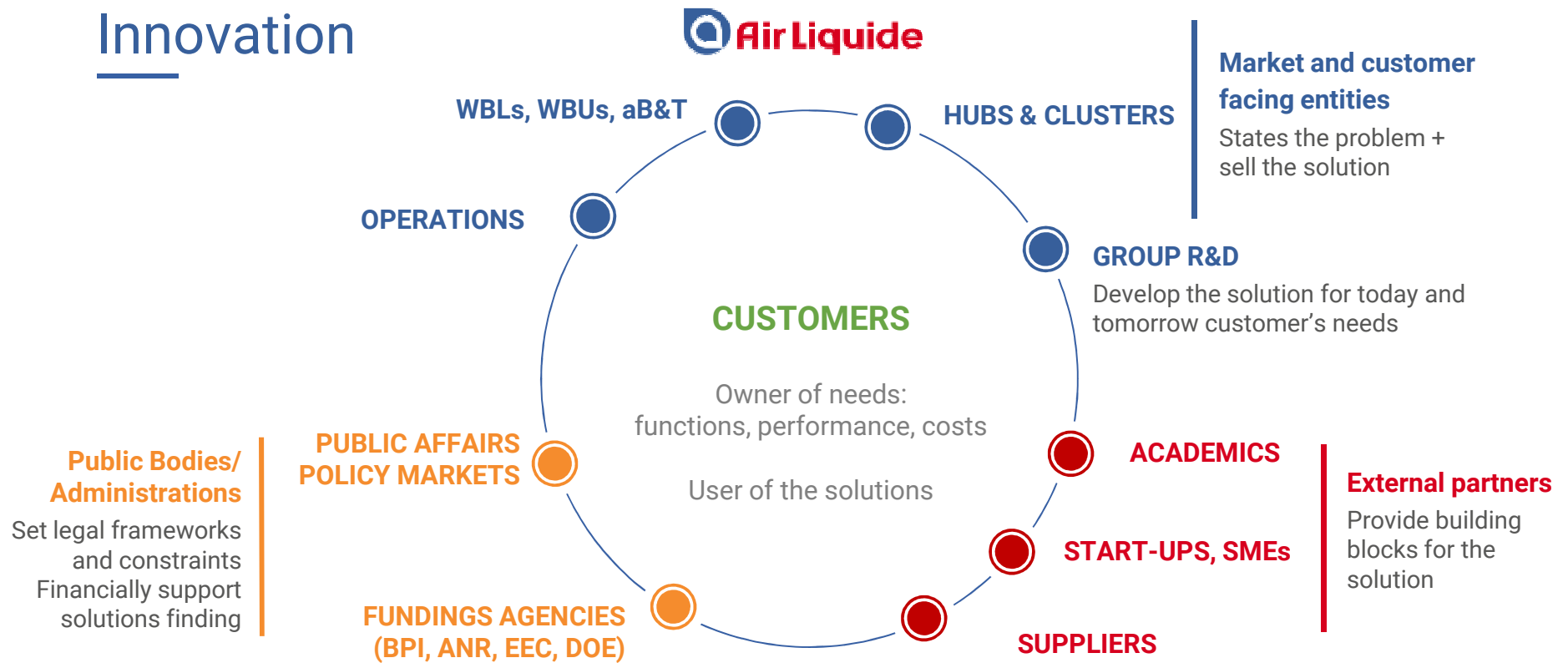
Patents

# Corporate R&D Mission

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**Partnering with our stakeholders, we bring value to Air Liquide customers through innovation, based on sound scientific competencies, broadening of our collaborative ecosystems and flawless execution.**

# Collaborative Innovation





# R&D Activity Segmentation

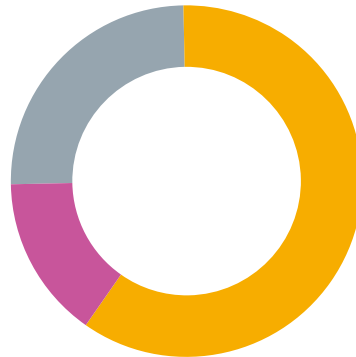
New techno, new competency development, Long term



Support to Operations



Technical assistance and expertise for operations



Key Projects



Solutions for short/medium internal and external customer needs

# Research & Development in the Americas

# Delaware Research and Technology Center

## Mission Statement

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**Air Liquide innovation driver in the Americas, capitalizing on North America's scientific & creative strengths for the Group**

**Ensure technological and innovation support to Air Liquide's Americas operations, markets and customers**

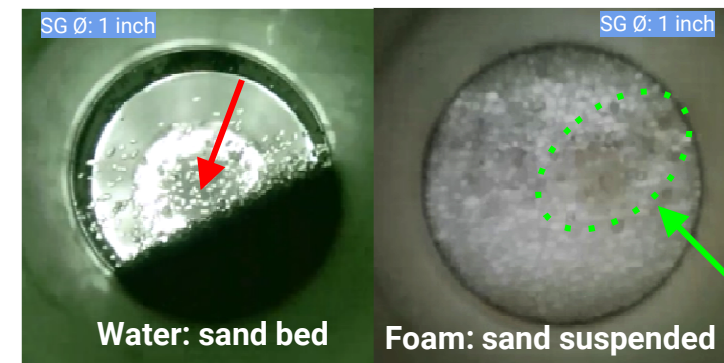
# Example: Unconventional Oil and Gas

Improve productivity and reduce the environmental impact of unconventional oil and natural gas recovery

## → Optimize industrial gas-based foam fluids for hydrocarbon recovery

- Improve **mobility control** in EOR
- Reduce water usage by **-70/85%**
- Target **2x** well productivity increase
  - Place proppant further into fractures
  - Develop understanding of foam/particle interactions

## ➤ Nitrogen and carbon dioxide sales



# Example: Calibration Gases

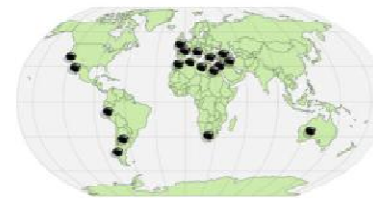
**Identify** appropriate gases, molecular and isotopic concentrations, and **validate stability**

→ **Stable isotope references gases** used in multiple industries:

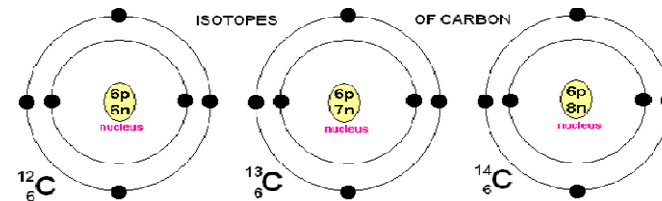
- **Forensic in Food & Beverage:** honey, olive oil, beef etc.
- **Oil & gas exploration:** Origin of well (biogenic vs. thermogenic), connectivity through a well
- **Environment:** pollutant migration

➤ **Specialty gases sales**

**Example: olive oil origin**



Multiple geographies



Proof of origin thanks to AL technology

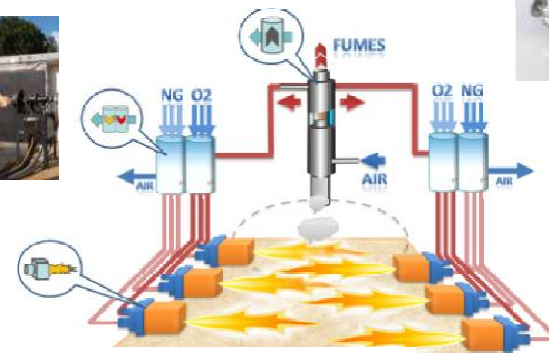
# Example: Energy Efficiency & Emission Reduction via Oxy-Combustion

Improve energy efficiency and reduce emissions of customers plants

- Support wide range of industrial furnace: glass, aluminum, steel, copper, kiln, lead, cupola, etc.
- Integrate with customer process such as waste heat recovery, fuel preheating
  - Furnace audit, production boost, custom burners, process tuning

➤ Oxygen sales

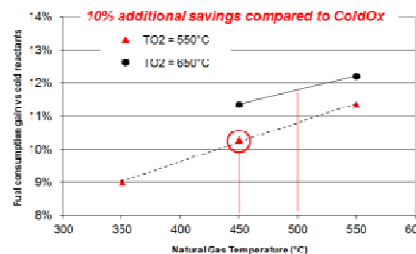
## Example: glass manufacturing



Burner, Heat exchanger, control logic

Burners work seamlessly in hot and cold

8-10 % fuel savings demonstrated



Up to 16% CO<sub>2</sub> reduction from air to HeatOx



Maintained same glass color, quality

# Example: Deposition and Etching Solutions for Semiconductors (1/2)

**Electronics manufacturers** (Apple, Samsung, Dell):  
**increase performance** (speed, memory capacity, bandwidth) for computers, cell phones, Big Data, Internet of Things and Artificial Intelligence

**Semiconductor manufacturers** (Intel, TSMC, Micron) continuously:

**Compete on:**

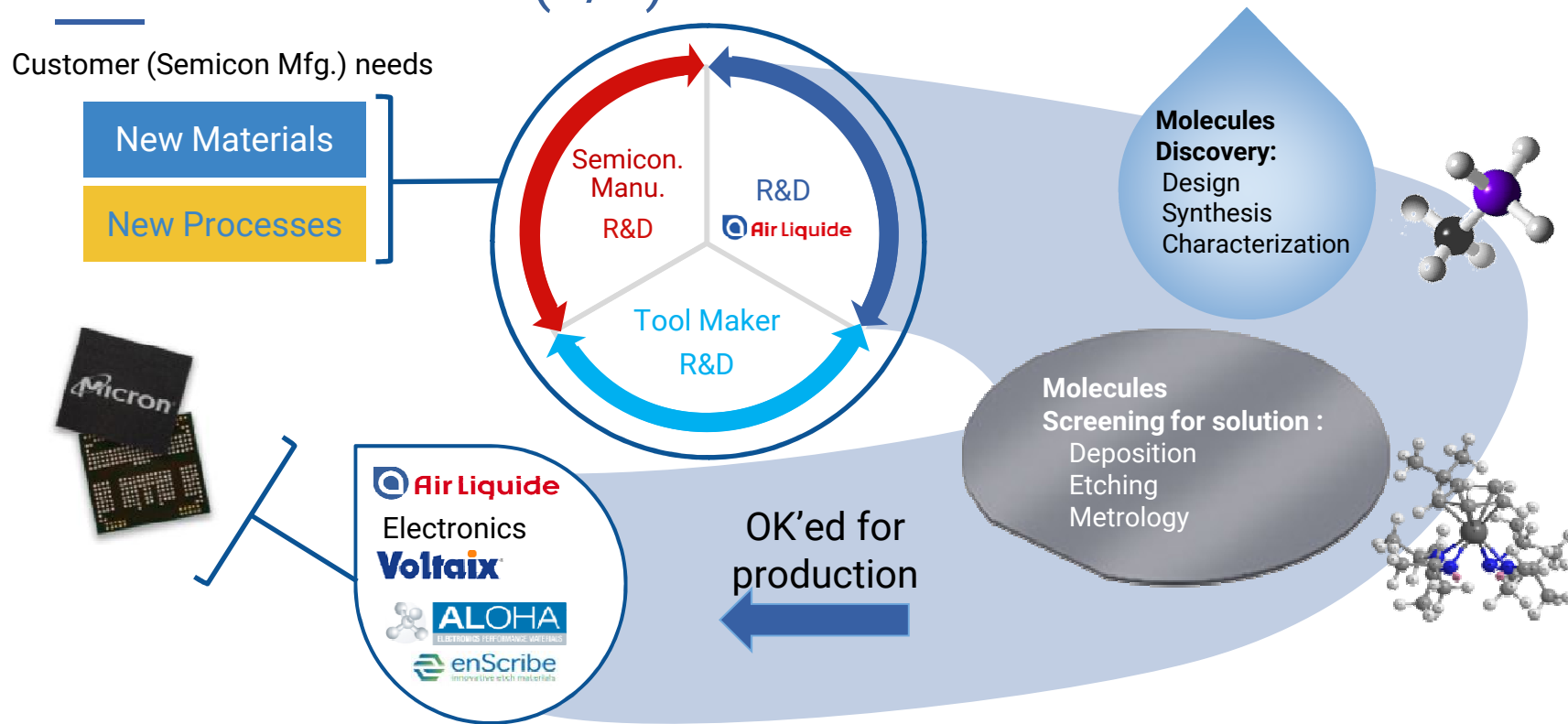
- **Performance** (*bits, Memory capacity*) of their chips
- **Lower energy** consumption

**Need for:**

- **New materials** (*different properties*)
- **New methods** to deposit or process them
- **More complex architectures** to be manufactured

➤ **R&D contribution to Air Liquide Advanced Materials**

# Example: Deposition and Etching Solutions for Semi-conductors (2/2)





# Air Liquide R&D - Airgas Interactions

## Cost Synergies



# Air Liquide R&D - Airgas Interactions

## Revenue Synergies



### Currently implemented

- Gas applications: increased involvement of R&D teams in large bulk gas markets
  - Combustion
  - CO<sub>2</sub>
  - Applications development
- E-biz and digital: combine Airgas and R&D digital expertise
- New offering development leveraging Airgas market channel
  - Stable isotopes for O&G/Environment/Forensic
  - Engine emissions testing
  - Extension of foam applications in O&G recovery

# Conclusion

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- Sound and expert Air Liquide R&D...
- ... supporting new offers development and operations efficiencies

➤ **to leverage on Airgas national unmatched footprint**



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