# *Renewable feedstocks supplying the petrochemical industry*

**NARA, Seattle, May 3, 2016**

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SAFER, SMARTER, GREENER

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- Why is $CO_2$ utilization important?
- What is DNV GL doing about it?
- What are the barriers?
- Ways to overcome the barriers – current status
- Going forward


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# We are a global classification, certification, technical assurance and advisory company

OUR PURPOSE

## TO SAFEGUARD LIFE, PROPERTY AND THE ENVIRONMENT

# Only by connecting the details can we impact the bigger picture

- We classify, certify, verify and test against regulatory requirements, rules, standards and recommended practices
- We develop new rules, standards and recommended practices
- We qualify new technologies and operational concepts
- We give expert advice to enhance sustainable business performance


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# Global reach – local competence

**150**
years

**350**
offices

**100**
countries

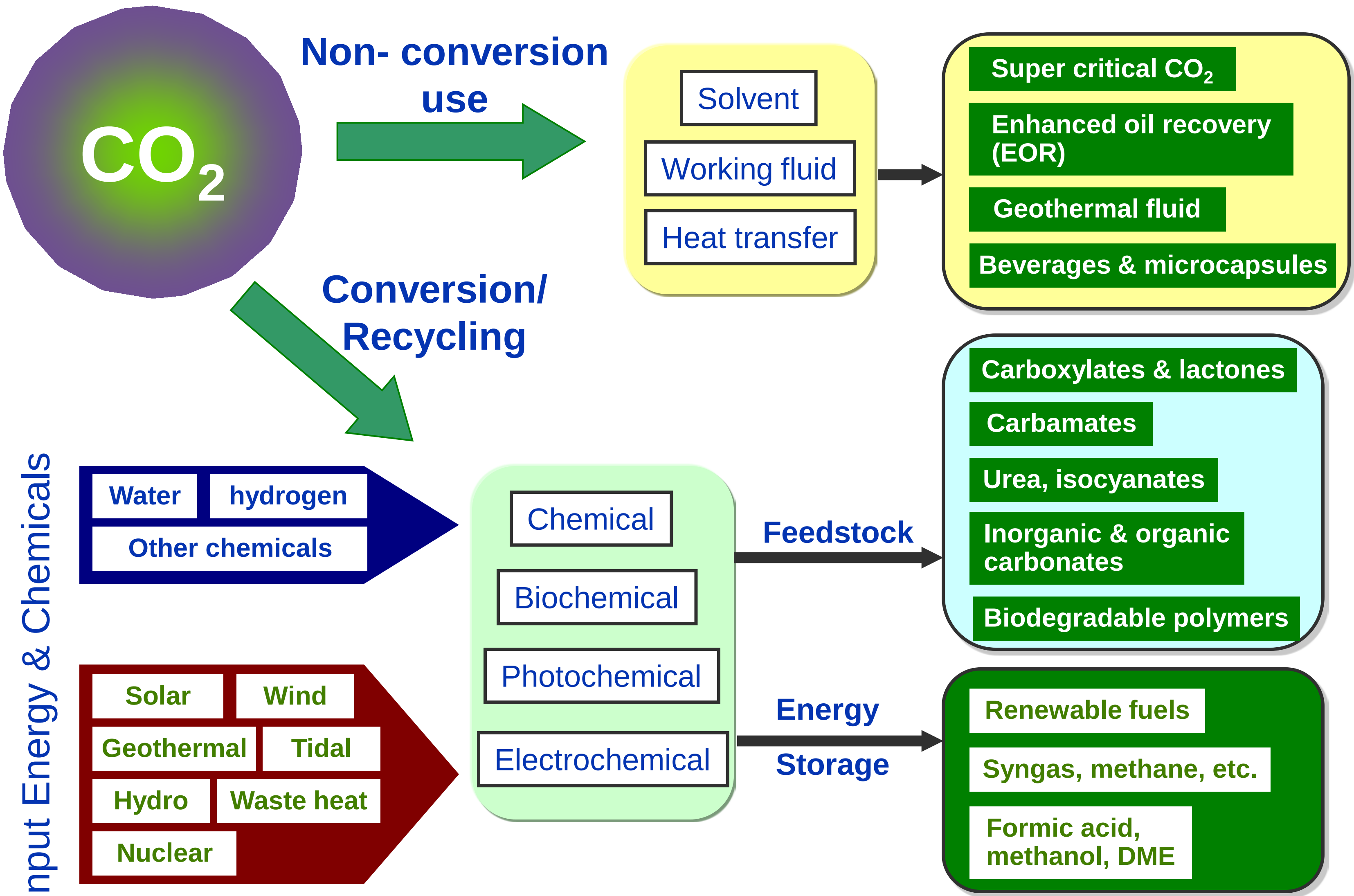
**15,000**
employees

# Why is $CO_2$ utilization important?

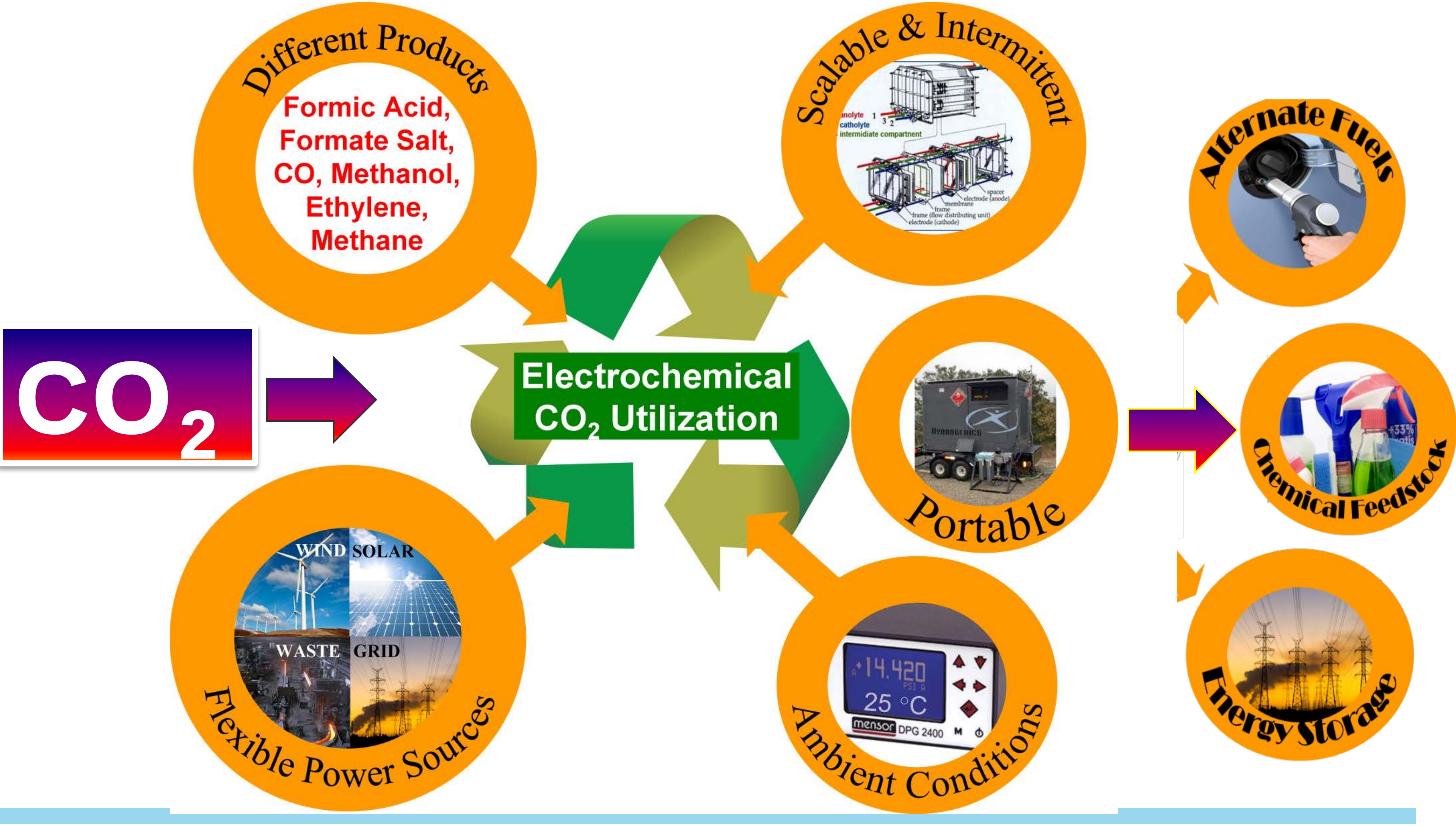
- The world will continue to rely mainly on fossil fuels and fossil-fuel based chemicals
- CCS is unlikely to meet its targets at least for the foreseeable future, but there could be large concentrations of $CO_2$ available
- Significant increases in renewable energy will require mechanisms to store excess electrical energy
- $CO_2$ utilization is capable of unlocking the vast innovation potential of society

**From Fossil to $CO_2$ Economy**

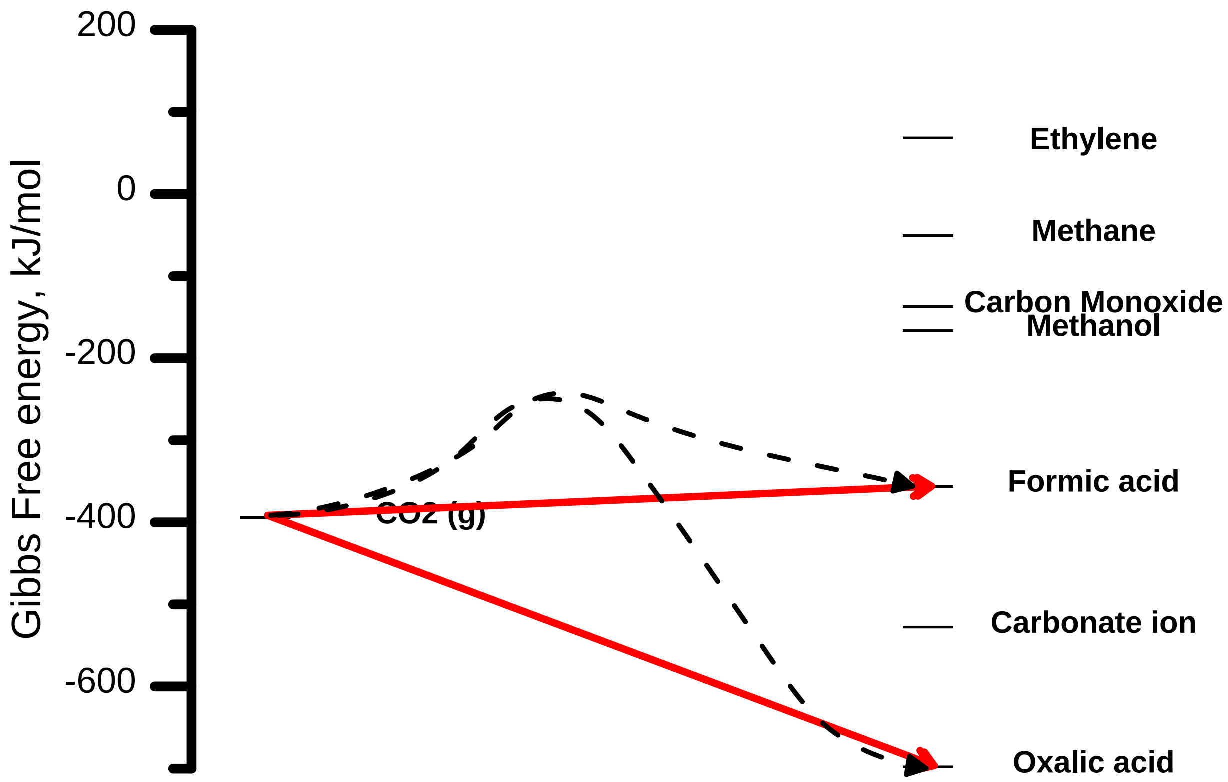
# There are many ways to utilize $CO_2$



# Advantages of Electrochemical Route over Other Processes



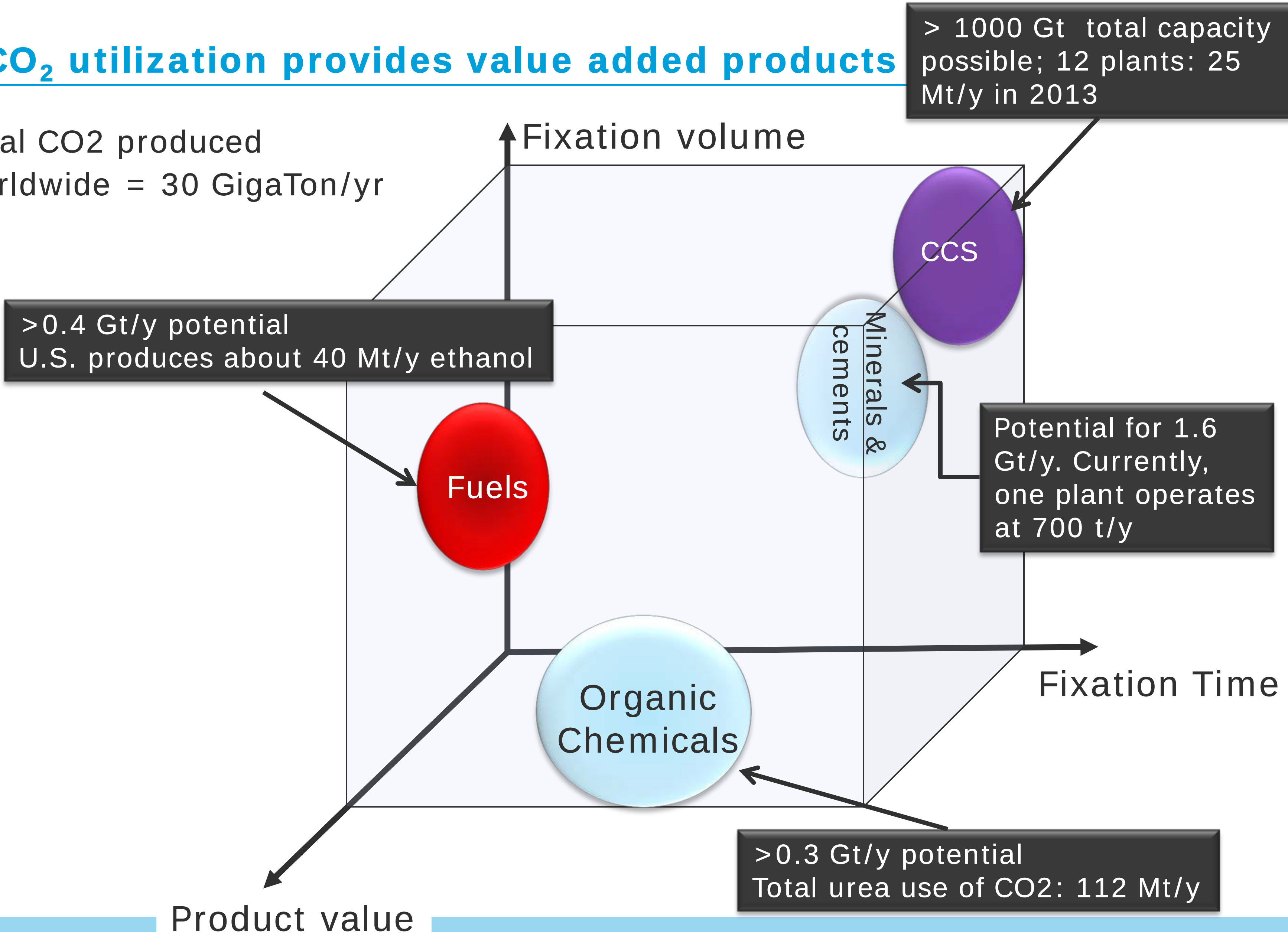
# Energy for $CO_2$ conversion can be modest



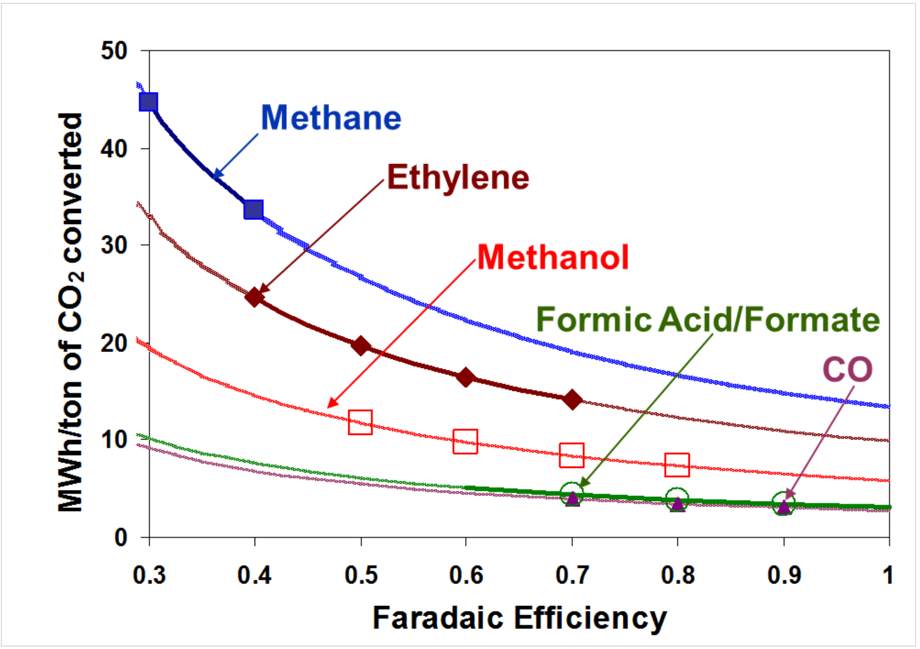

| Product | Gibbs Free energy, kJ/mol |
|---|---|
| Water to hydrogen | 237 |
| Iron ore to iron | 740 |
| Silica to silicon | 798 |

# $CO_2$ utilization provides value added products

Total CO2 produced worldwide = 30 GigaTon/yr

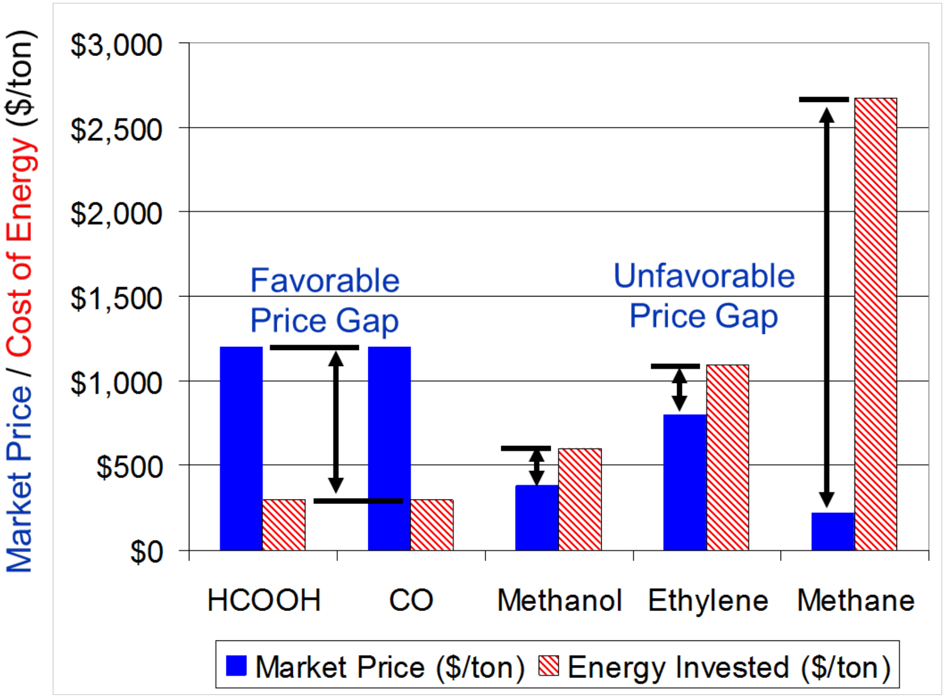


# Why Formic Acid ? Highest energy eff. & potential profitability

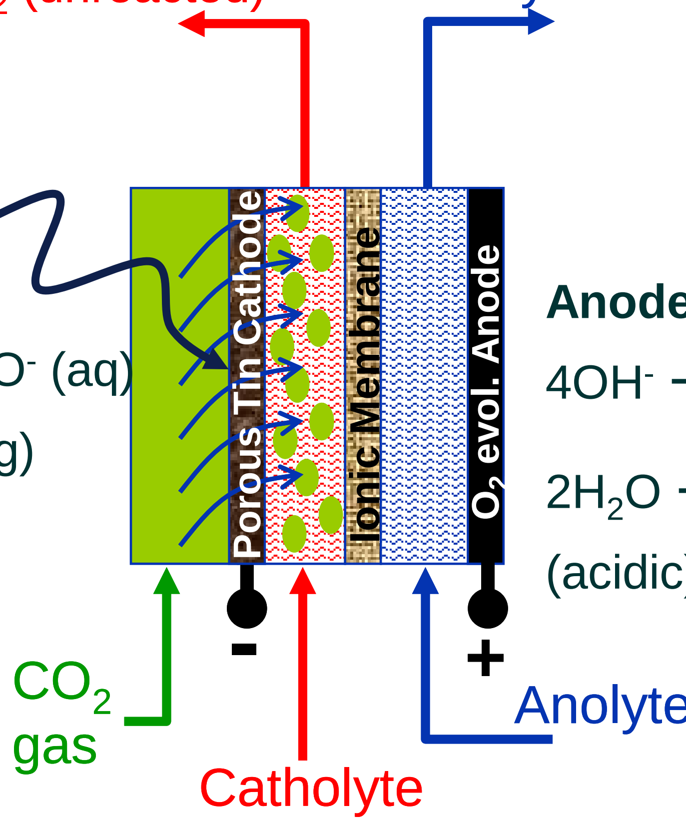



Formic acid (and CO) had highest selectivity and lowest energy consumption

Market price of Formic acid offered most favourable price gap



# Electrochemical Reduction of Carbon Dioxide to Formic Acid (ECFORM)




**Cathode Reactions**

$CO_2(aq) + H^+ + 2e^- \rightarrow HCOO^-\ (aq)$

$CO_2(aq) + 2H^+ + 2e^- \rightarrow CO(g)$

$+H_2O\ \ 2H^+ + 2e^- \rightarrow H_2(g)$

**Anode Reaction**

$4OH^- \rightarrow 2H_2O + O_2 + 4e^-$ (alk.)

$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$ (acidic)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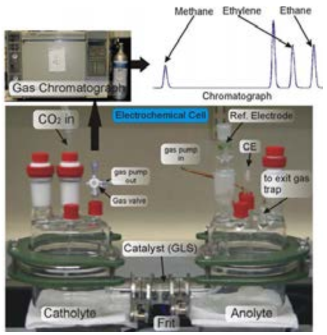
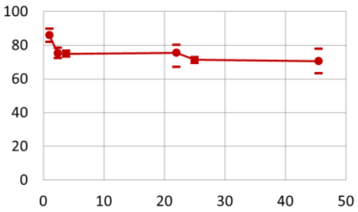
# DNV GL Efforts in $CO_2$ Utilization




Lab studies
Cu catalyst, $CH_4$, $C_2H_4$


Small reactor studies
Sn catalyst, HCOOH

Demo reactor, 1Kg/d
Self powered trailer

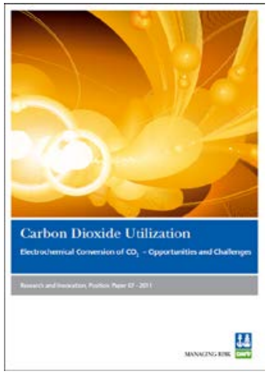



Improve process chemistry, catalyst life

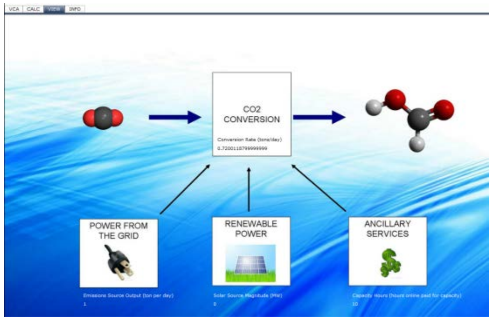
Focus on traditional DNV GL services

2008 2009 2010 2011 2012 2013 2014 2015

- Start of larger internal project
- Focus on formic acid
- Other conversion processes
- Energy analyses




Position paper on $CO_2$ utilization




- Value chain analyses
- Berkeley workshop
- Supported other networks

Interactions with other technology developers

Establish external partnerships to demonstrate value chains

# Barriers for adoption – $CO_2$ Utilization

| Technology Barriers | Financial Barriers | Policy Barriers |
| --- | --- | --- |
| High energy and chemical consumption | Competition with fossil fuels and chemicals | Lack of sufficient carbon incentive |
| Cost and energy requirements of $CO_2$ capture | Market saturation due to high $CO_2$ volumes | Lack of subsidies, loans, and credits |
| Long-term performance | Distributed production reducing scale advantage | Lack of an industry voice |
| Carbon balance | Long time horizon for return on investment | Lack of inclusion of novel $CO_2$ utilization pathways in international policies |

# Overcoming Technology barriers

Technology Barriers

High energy and chemical consumption

Cost and energy requirements of $CO_2$ capture

Long-term performance

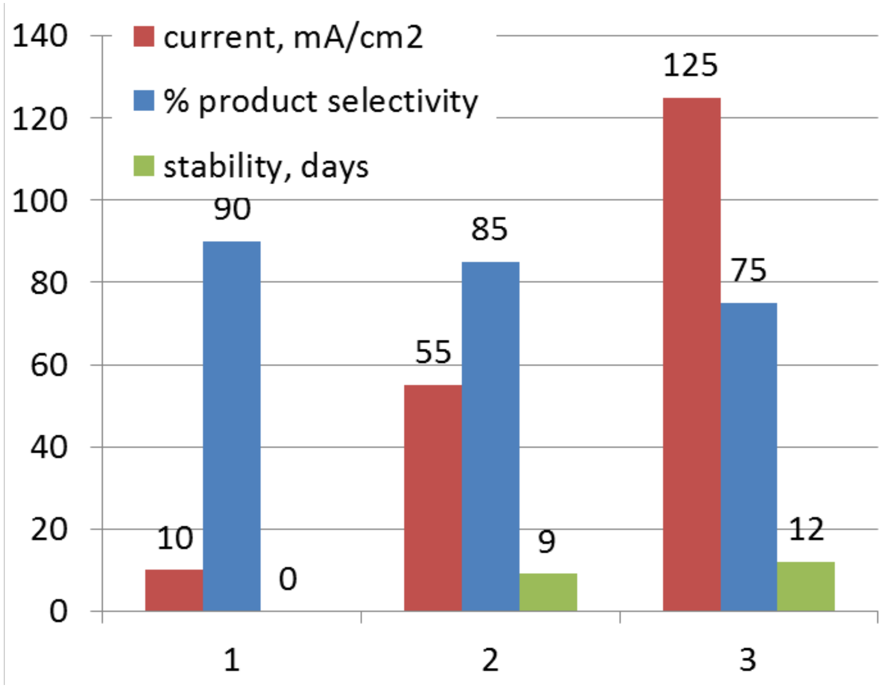
Carbon balance

- Reduce activation energies through novel catalysts, chemistry, and biology
  - Energy and chemical inputs must be balanced
- Single technologies won't be sufficient – leverage existing infrastructure and technolgies
- Long-term demonstration – test centers
- Novel capture technologies
  - Traditional absorption-based capture too big and expensive
- The use of renewable power, energy harvesting will improve carbon balance and economics – LCA analysis
- Standards & guidelines

## ECFORM
## Novel Electrodes to Increase current density to reduce CAPEX

|   | Catalyst - **Electrode** Substrate |
|---|---|
| 1 | solid Sn only |
| 2 | Sn - CFP |
| 3 | Nano Sn - CFP |

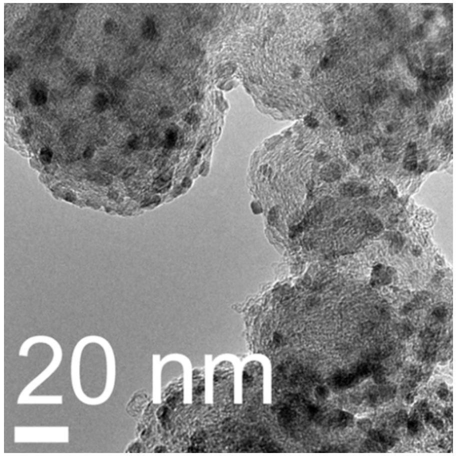
- **Current (rate of rxn)** directly influences the CAPEX (no. of reactors)
- Selectivity for formate reaction (Faradaic Efficiency) = 70 – 90%
- Stability of current and FE over time is key



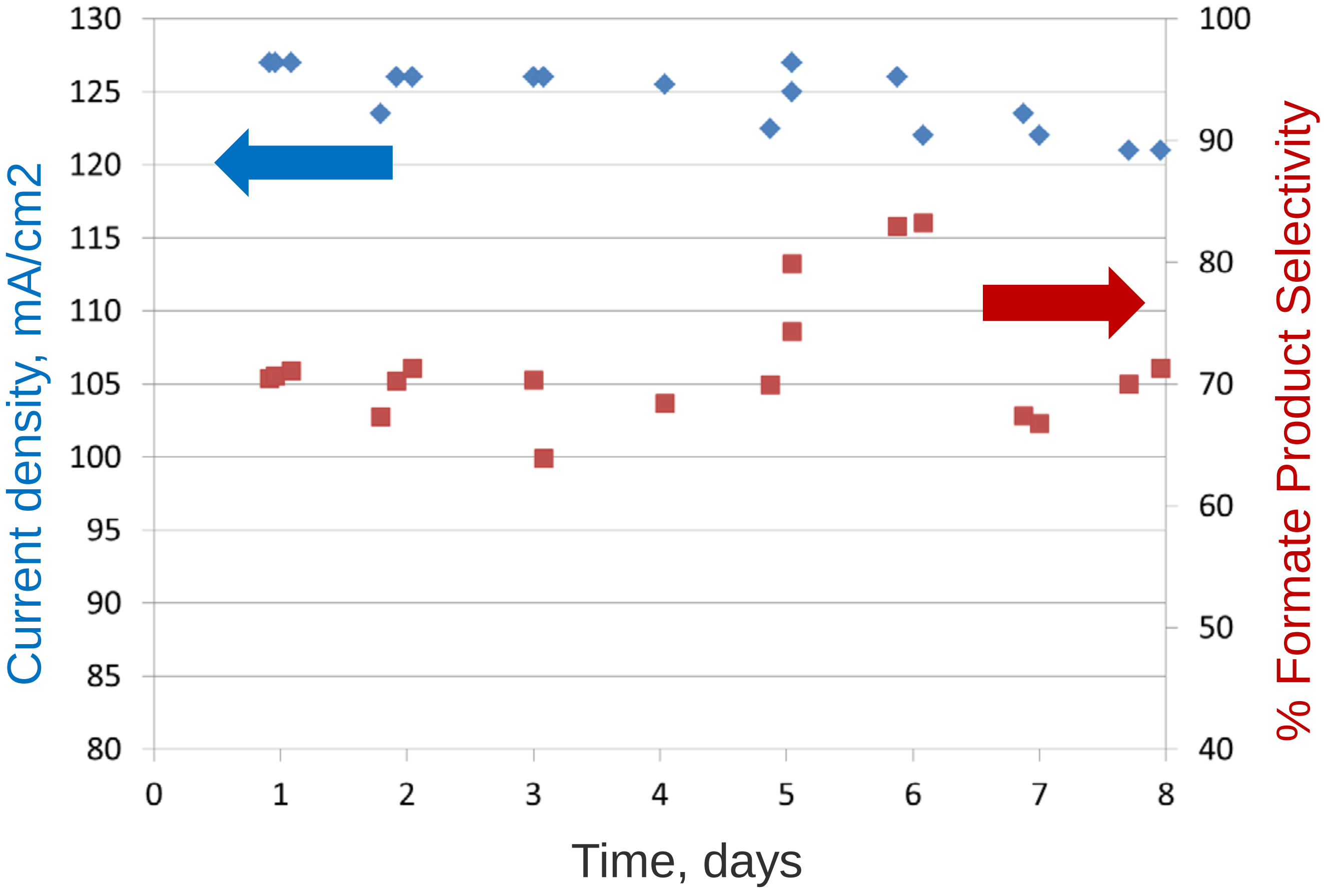

Catalyst – Electrode Type

## ECFORM
## Stable Performance – High Current density and formate selectivity

Nano-tin catalyst

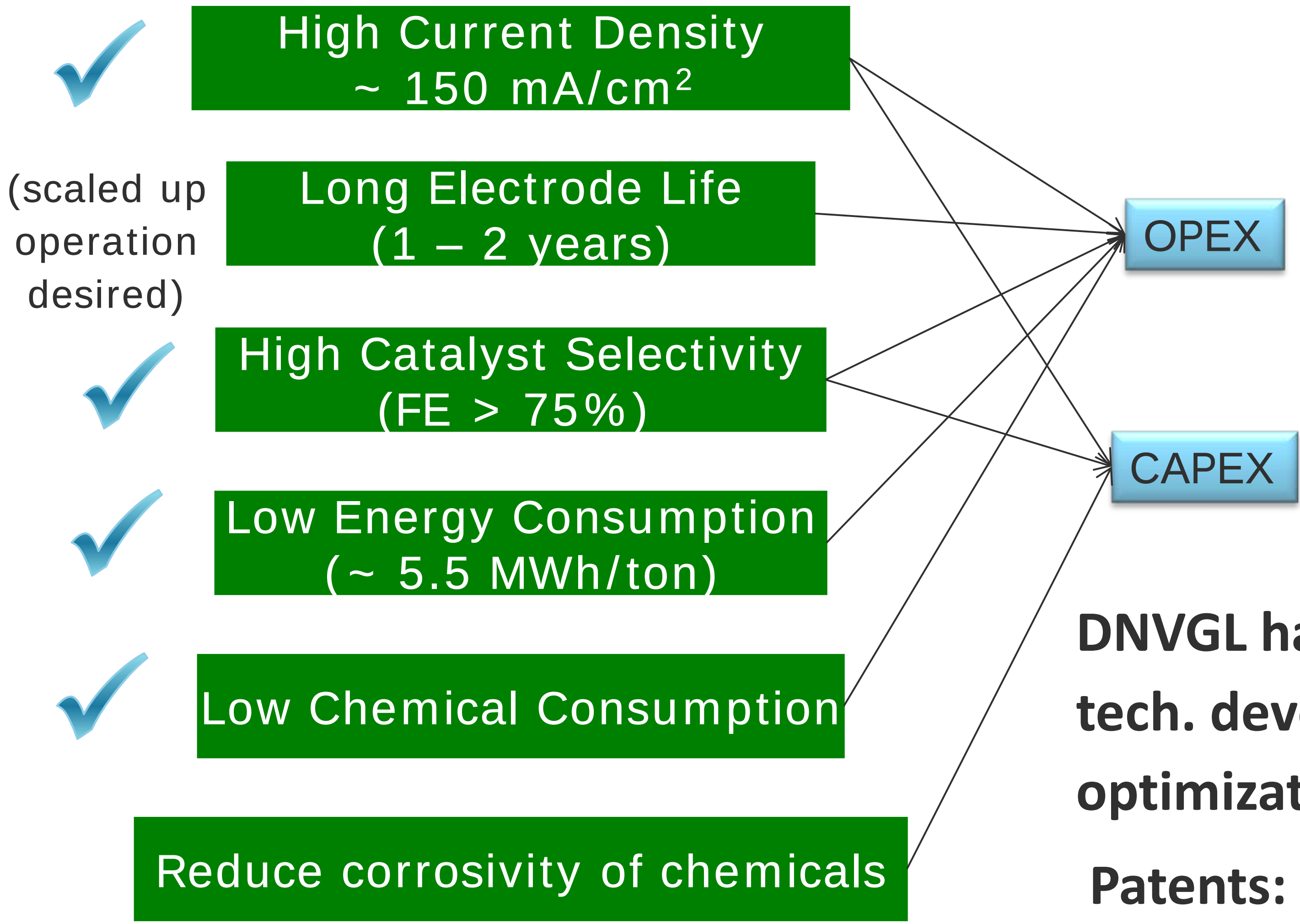



Setup




3x reduction in reactors achieved, hence lower CAPEX

## Technical Targets Achieved, Technology is ‘ready’ for scale-up




**DNVGL has de-risked by tech. development & optimization.**

**Patents: 2 issued, 3 filed**


DNV GL © 2013

# Overcoming financial barriers

Financial Barriers

Competition with fossil fuels and chemicals

Market saturation due to high $CO_2$ volumes

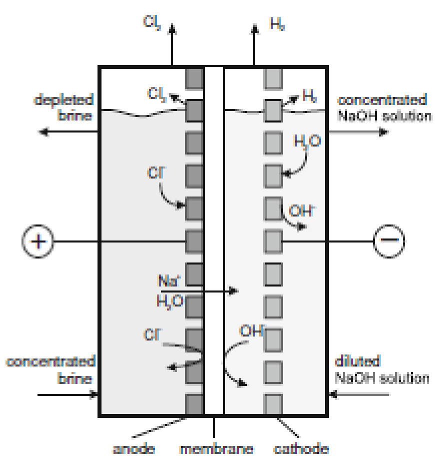
Distributed production reducing scale advantage

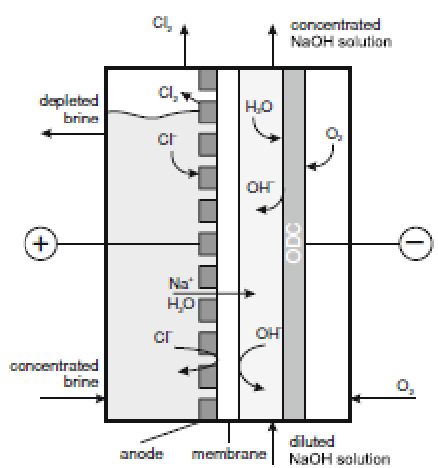
Long time horizon for return on investment

- **Establish niche markets, then expand**
- Government funding is essential to support long-term development
  - ARPA-e REFUELS project
- Prize schemes may bring novel solutions
  - CCEMC
  - X-Prize
- Government support is still essential
- Intergovernmental collaborations
- Standards and guidelines can reduce financial risks

# The Chlor Alkali Process – as a model for scale-up

- Three electrochemical processes (numbers from J. Appl. Elect., 2008)
  – Mercury (being phased out) – 3.1 to 3.4 MWh/t $Cl_2$
  – Diaphragm (asbestos and non-asbestos) – 3.2 to 3.8 MWh/t $Cl_2$
  – Membrane - 2.4 to 2.9 MWh/t $Cl_2$
- Long history
  – Over 100 years old
  – Energy reduction innovations occur even today (e.g., Oxygen depolarization cathodes)
  – Initial concept of ODC in 1950, but developn

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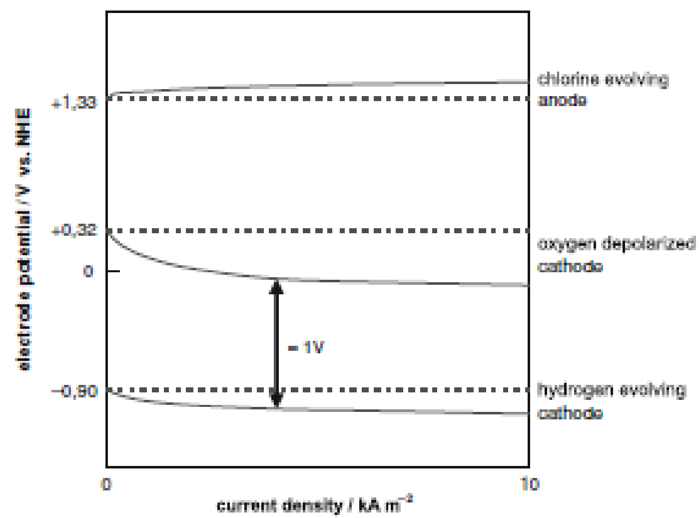


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# Technology Advances = Reduce Energy / Increase Efficiency

NAFION® Cation Ion Exchange Membrane Employed

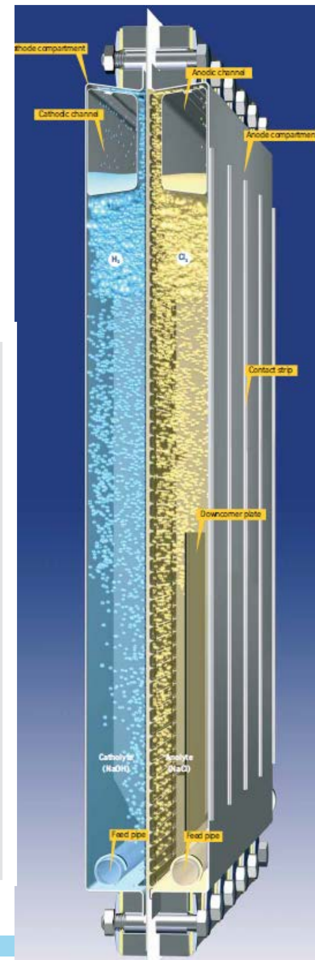
Mixed Metal Oxide Based Dimensionally Stable Anodes – long operating life

UHDE:
Total supported: 20 MMtpy

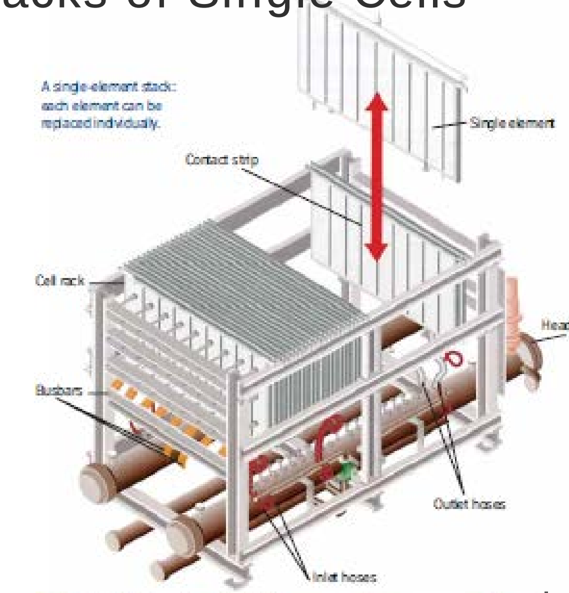
Largest: 1 MMtpy

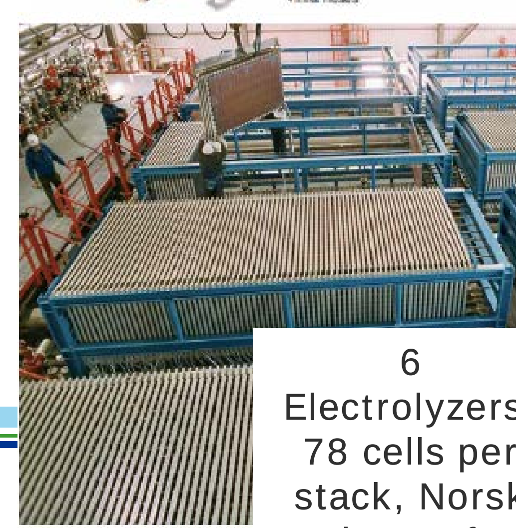
| Operating data | |
|---|---|
| **Current density** | up to 7 kA/m² |
| **Power consumption** | see graph |
| **Cell temperature** | 88-90 °C |
| **Service life** | |
| anode coating | > 8 years |
| cathode coating | 8 years |
| membranes | > 4 years |
| gaskets | > 4 years |
| compartments | > 20 years |
| **Active area per element** | 2.72 m² |

Optimized Single Cells



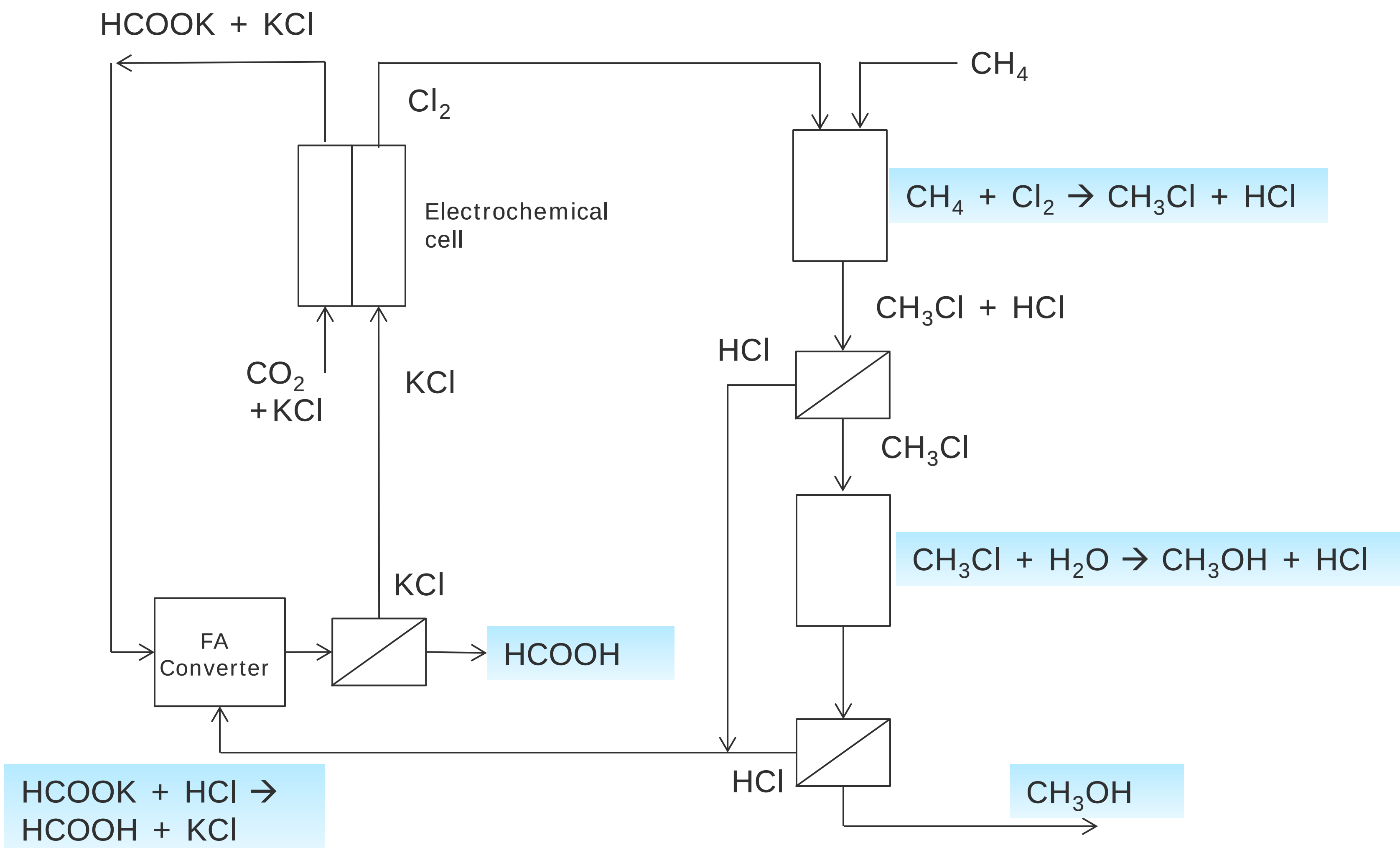
Modular – Skid Mounted Stacks of Single Cells



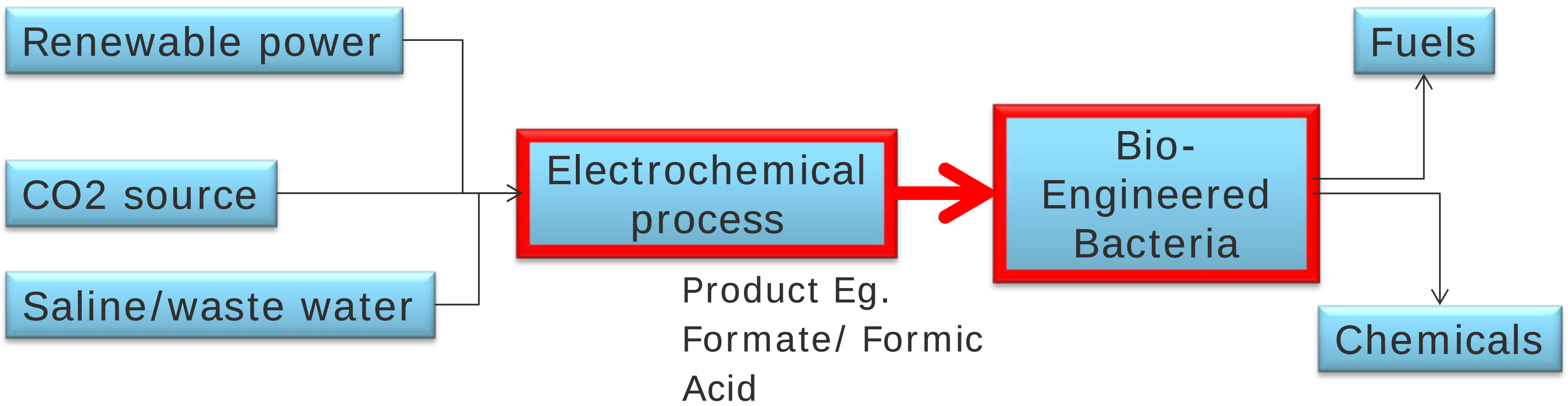



6 Electrolyzers, 78 cells per stack, Norsk

# Combined Electrochemical and Thermochemical routes
# Net reaction : $CO_2 + CH_4 + H_2O \rightarrow CH_3OH + HCOOH$

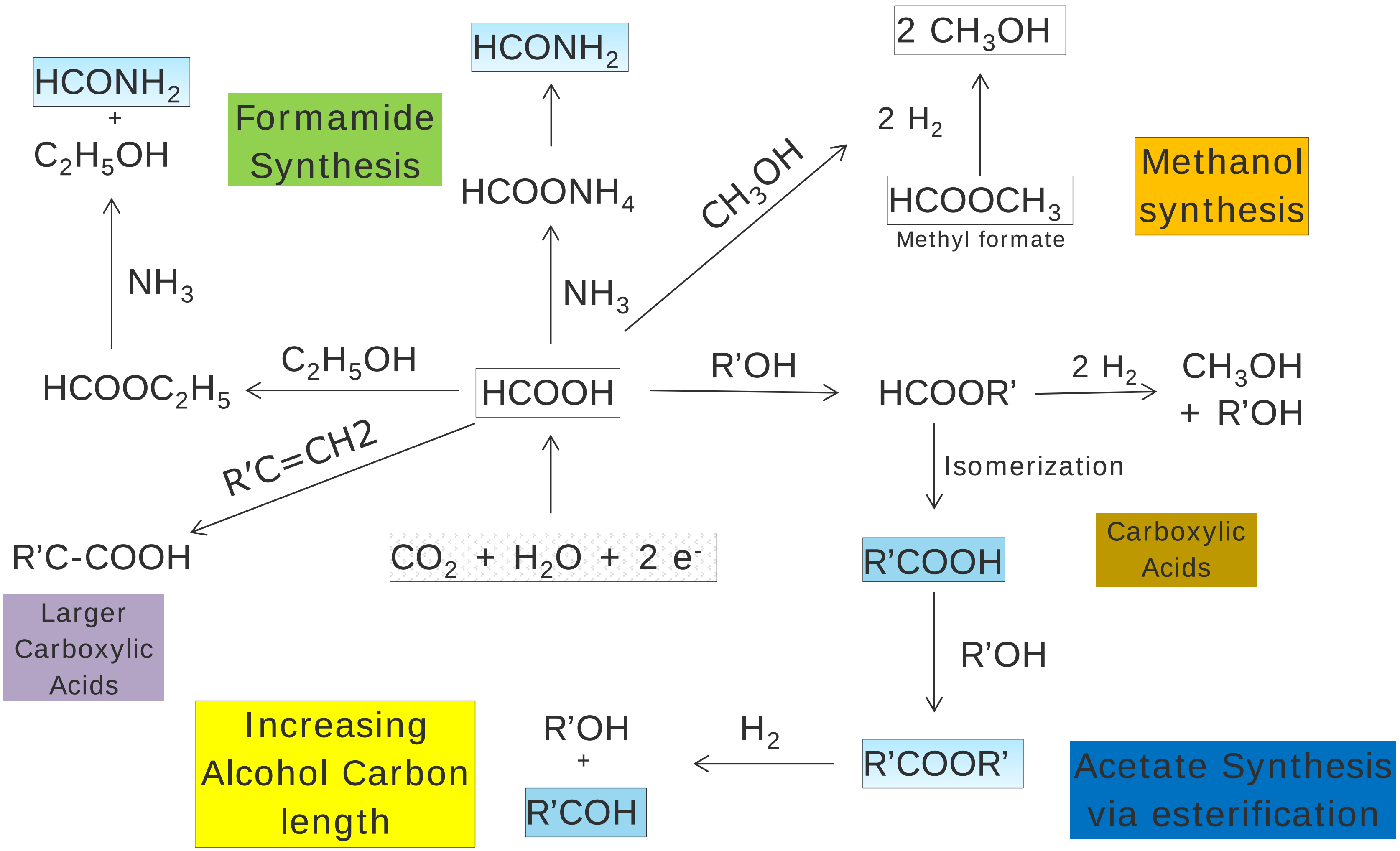


# New Niche Markets: Electro-fuel Pathway




- Greater energy efficiency (15-30%) vs. biofuel (3-8%) pathway
- Production de-coupled from the sun
- Land-use minimized / no limitation with geography
- No competition with food (corn, sugar)
- Flexibility in end fuel – butanol or diesel (depending on organism)
- Significant net reduction in $CO_2$ emission

# Formic Acid As Feedstock





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# Renewable Feedstock to Basic Building Blocks

**Renewable feedstocks**

$CO_2$

Sugars

Biomass

Waste streams

→

**Simple Molecules**

HCOOH

Methyl Formate

Methanol

Alkyl Formate

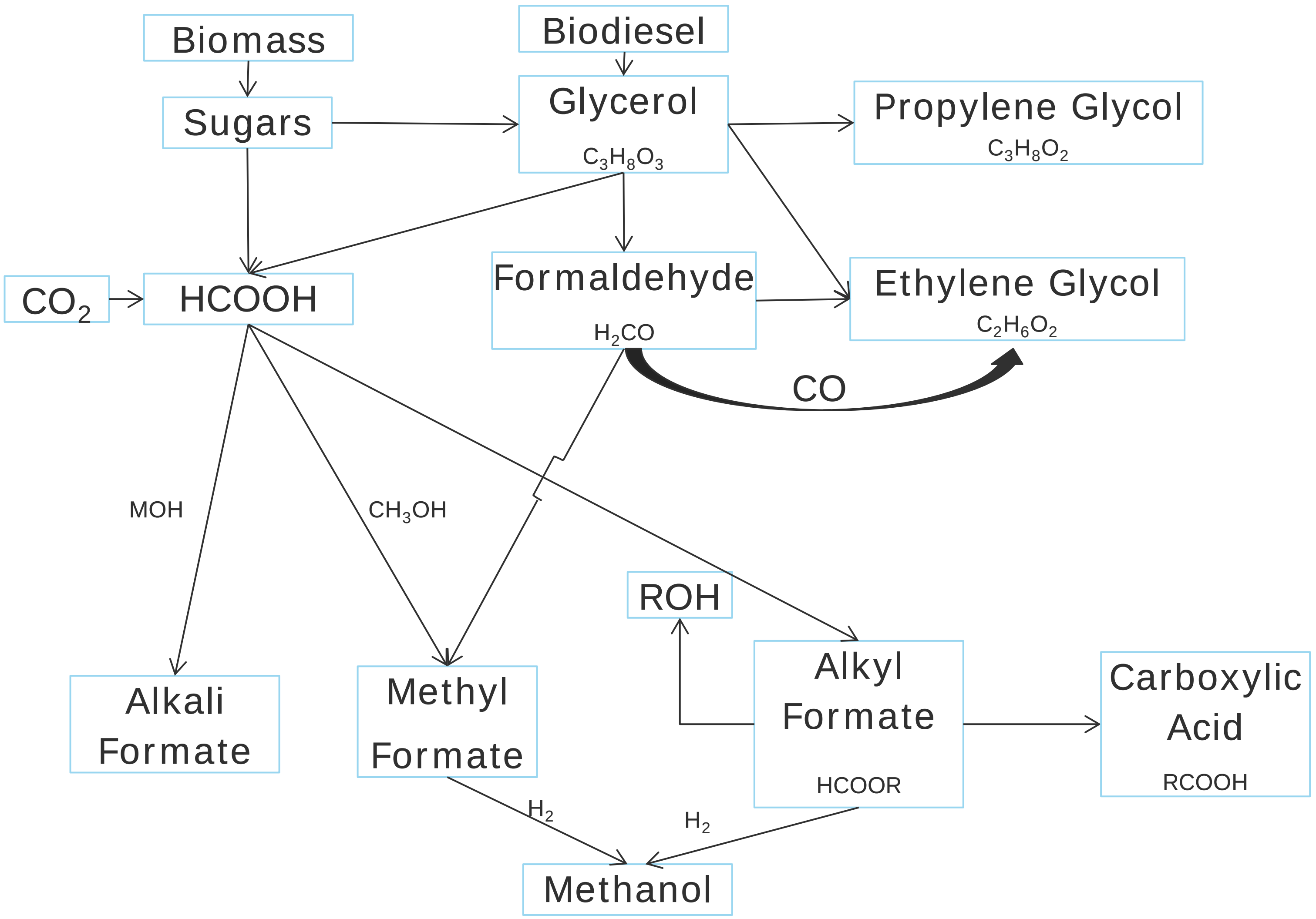
Alkali Formate

Carboxylic Acid

Formaldehyde

Glycols

# Large volume markets are Accessible





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# Overcoming policy barriers

Policy Barriers

Lack of sufficient carbon incentive

Lack of subsidies, loans, and credits

Lack of an industry voice

Lack of inclusion of novel $CO_2$ utilization pathways in international policies

- Consistent policy support is essential
  - Pew report: 74 to 96% drop in wind energy market when production tax credits expired
- Improved communication to policy makers
  - Public polls on CCS show greater support to utilization
- Inclusion in renewable fuels standards
- An industry voice is needed to convince and hold policymakers
- Influence IPCC and other intergovernmental bodies
- Iowa Tax credit for bio-based Chemicals
- 'Skyfill' – create a level playing field for alternative feedstocks


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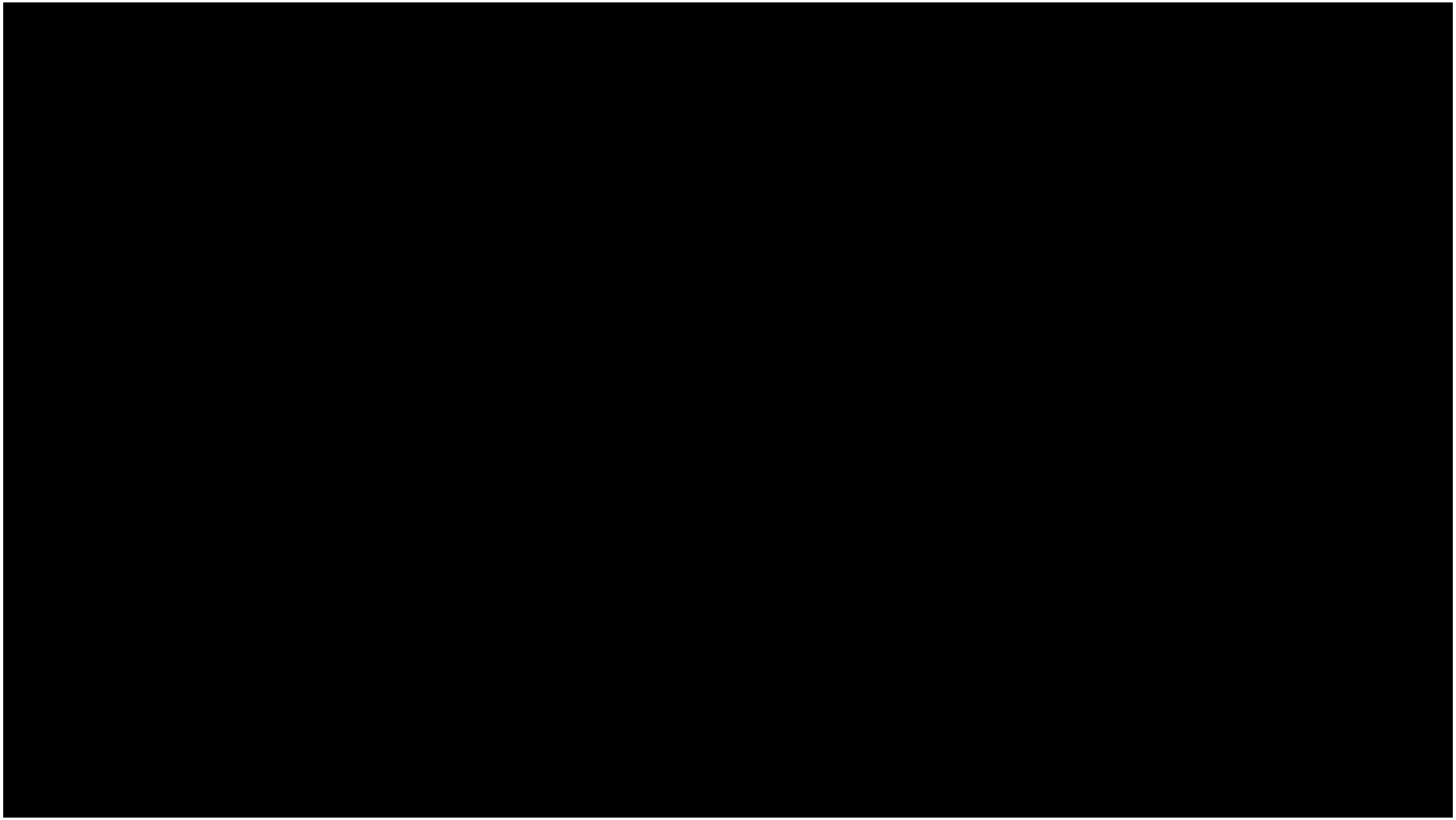
# Scientific Leadership





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# Renewable Translation

*"I know ~~you~~ **CCU and biomass feedstock advocates** are taking it in the teeth out there. But the first guy through the wall, he always gets bloodied. Always. ~~This is~~ **Renewables are** threatening not just a way of doing business, but in their minds is threatening the ~~game~~ **petrochemical establishment**. But what's really on their minds is that it is threatening their livelihood, threatening their jobs, threatening the **foundation of the chemicals industry** ~~way they do things~~.*

*"And every time that happens, whether it is a government, or a way of doing business or whatever it is, the people who are ~~holding the reins~~ **making energy and climate change policy decisions,** who have their hands on the switch, they go bat-shit crazy.*

*"I mean anyone who is not tearing down their ~~team right now~~ **CCS and reversing their LNG import terminal plans** and rebuilding it using ~~your model~~ **biomass**, they're **just burning** dinosaurs. They~~'re sitting on their ass~~ **will be sweating their asses off** ~~on the sofa~~ **in 2050.** ~~October watching the Boston Red Sox win the World Series."~~*

By Ed Rode, DNV GL
With apologies to the writers of 'Moneyball'

# Summary

- Significant innovation and technical progress has been made, need to scale up to pilot
- Novel combinations of technologies to maximize the utilization potentials and derive critical economies and carbon balance
- The nexus between CO2 utilization and renewable energy must be better exploited
- We must communicate better to decision makers
- Standards and guidelines help in reducing financial risks and improve interoperability


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# *Renewable feedstocks supplying the petrochemical industry*

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