U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ADO Workshop

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Advanced Development & Optimization

Outline

I. History of D&D to DMT to ADO

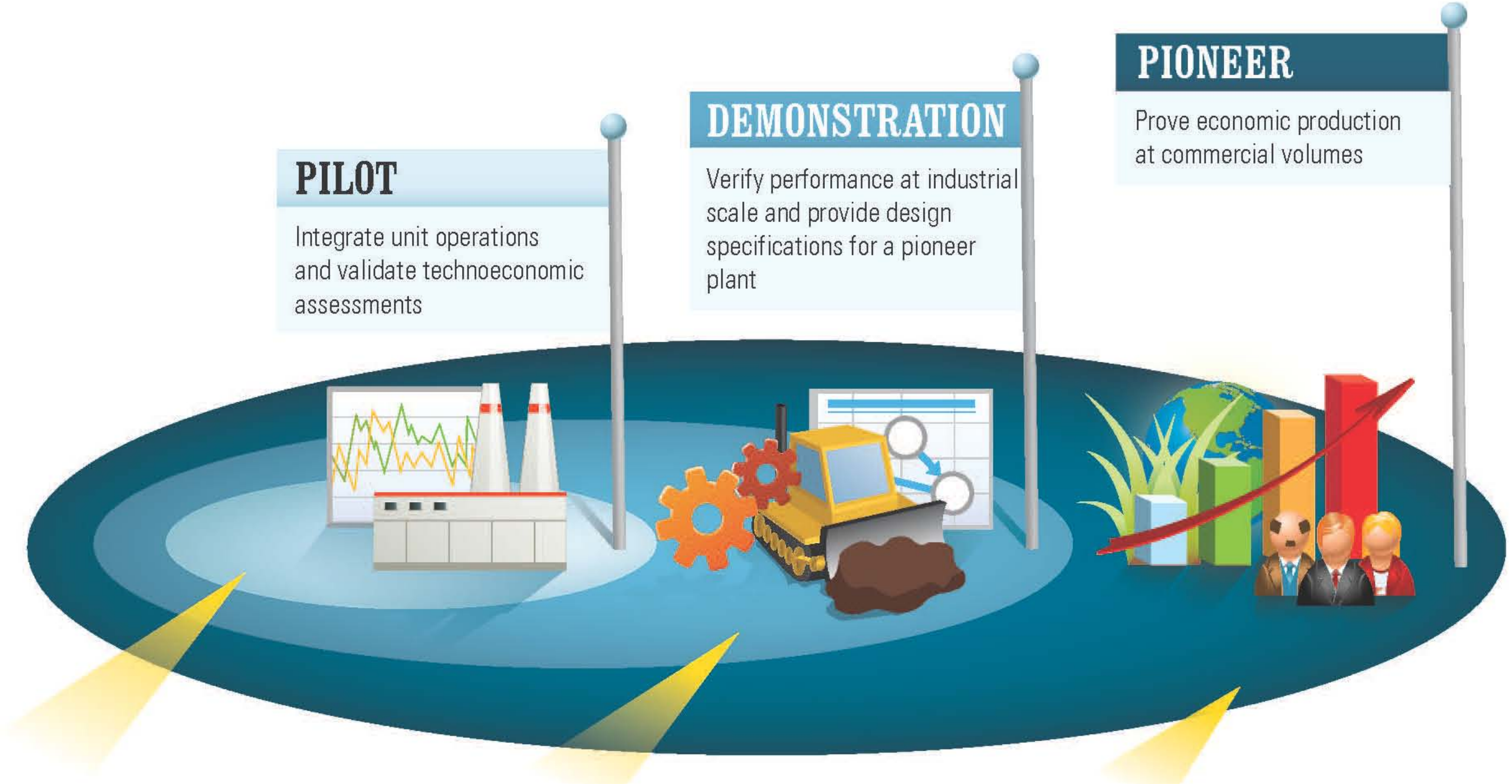
II. Past Investments

III. Introduction to ADO

IV. Leverage DOE and private investments

V. Questions

Enabling Commercialization Through Successive Scaling



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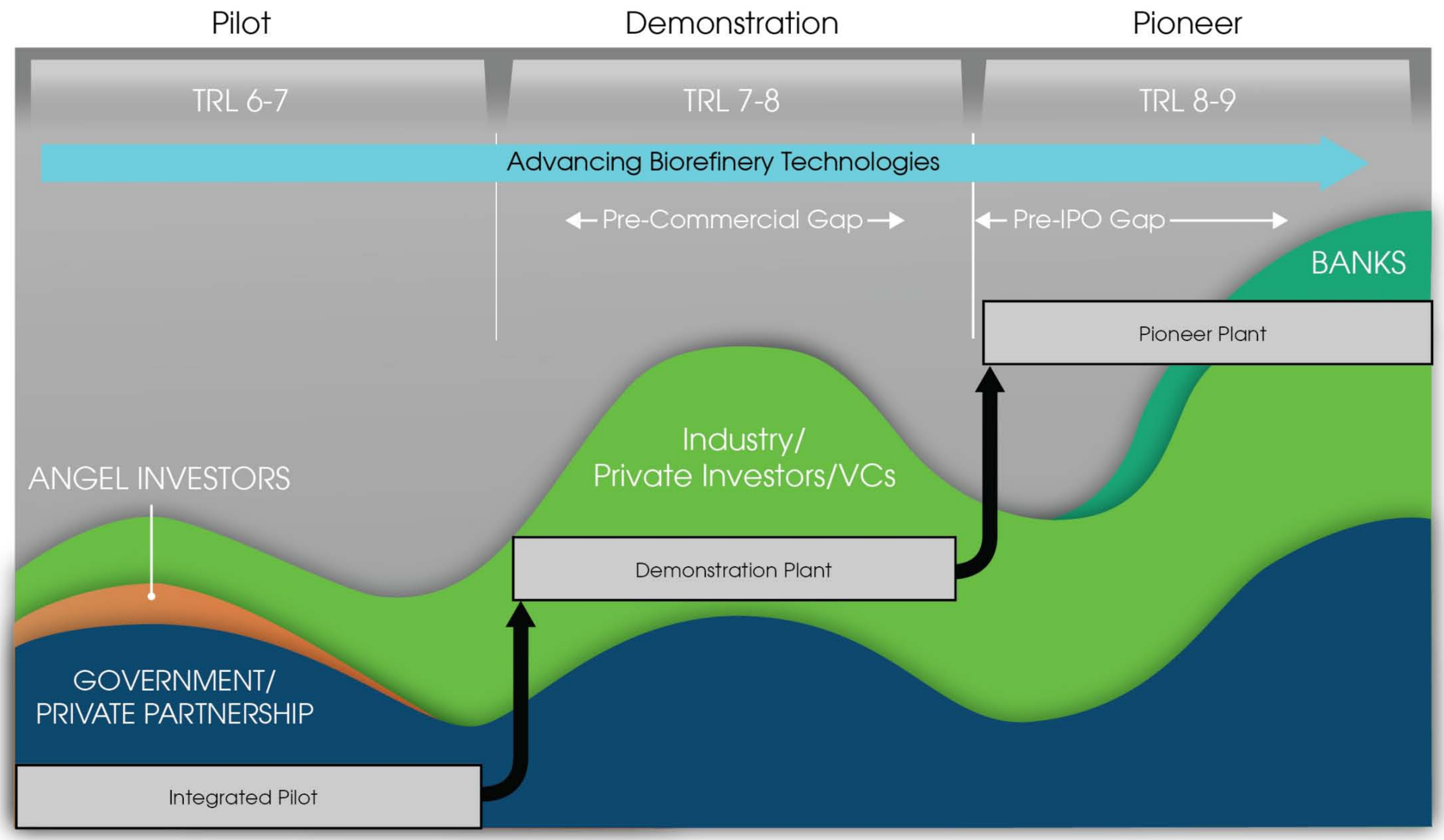
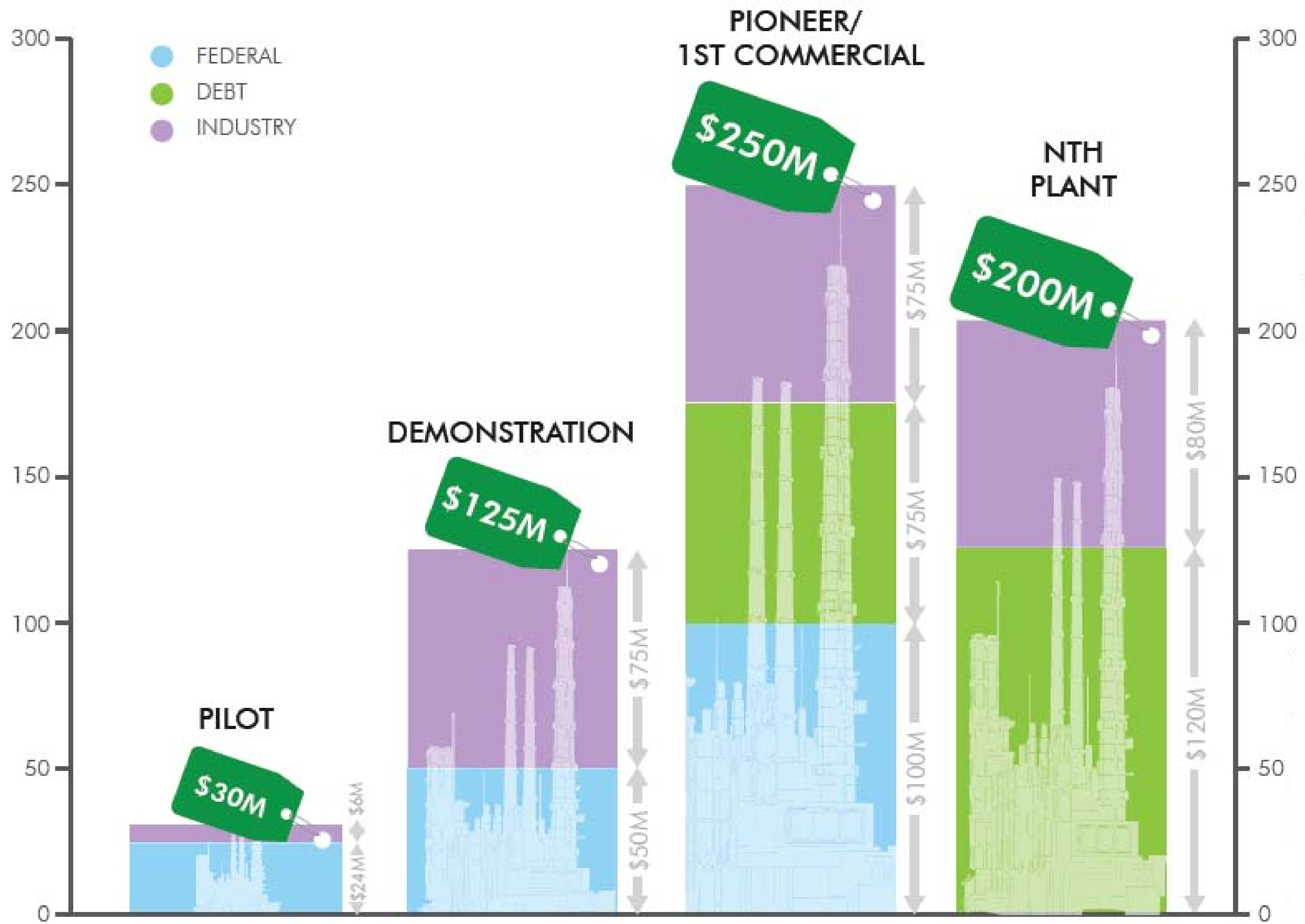
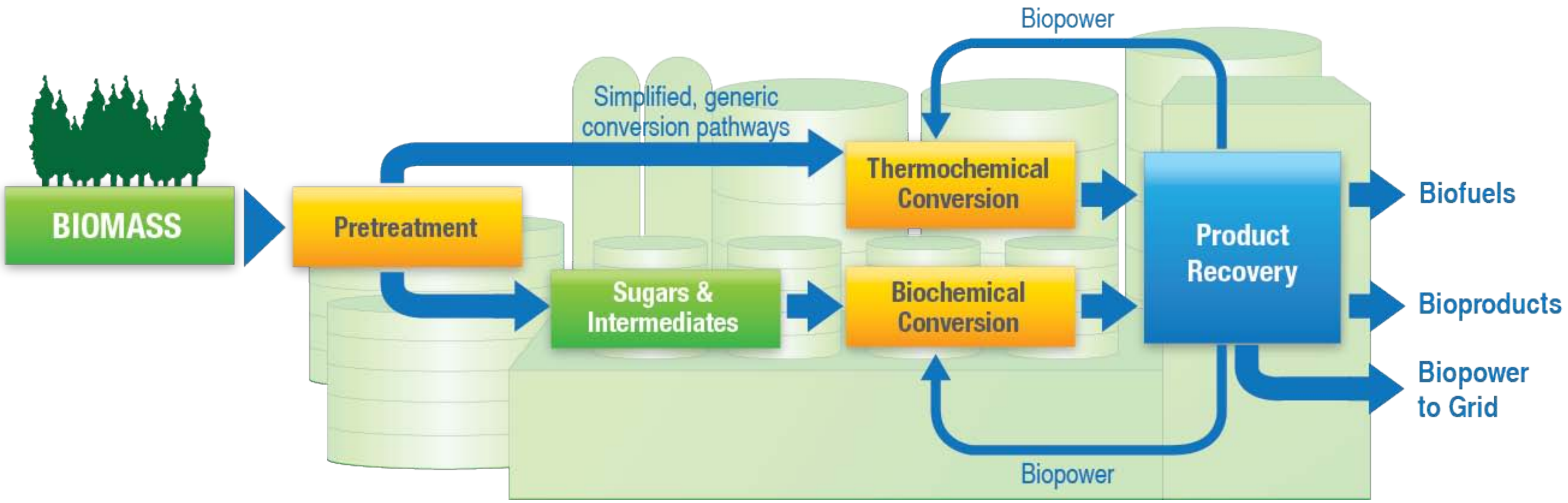
Valley of Death



IBR Project Funding Profile – Investment Required



Technical Challenges



Challenges:
Feedstock Collection, Harvesting & Storage
Feedstock Preprocessing
Pretreatment
Conversion Yields
Bio/Chemical Catalyst Selectivity & Fouling
Process Integration
Continuous Throughput

Valley of Death for New Technologies: Some IPA Key Findings

- Commercializing some level of new technology - 40% of projects fail
- New technology projects – 80% don't meet performance expectations

- Incorrect assessment of the level of difficulty posed by underlying process
  - Leads to overoptimistic expectations on project and process performance
    - Average cost growth = 30%
    - Average schedule growth = 65%
    - Average production shortfalls over 50% in second 6 months of operation
    - Average startup durations 50% longer than industry average

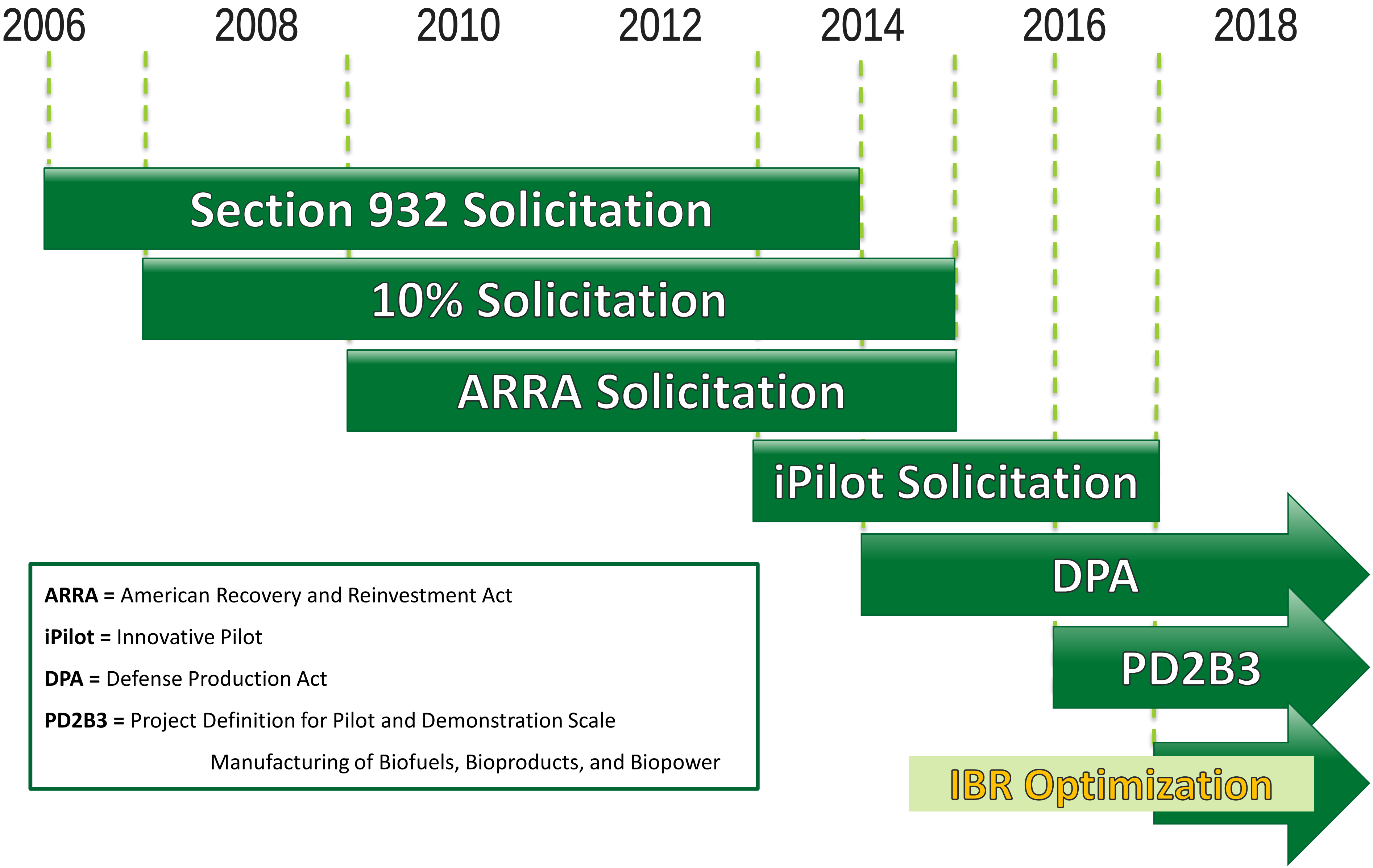
- Shortcomings often don't surface until startup and operation
  - Only remedy is costly de-bottlenecking and corrective engineering

- Core lesson:
  - Must understand and accept higher levels of project and process risk

Non-Technical Barriers to Commercial Success

- Business/Contracts
  - Feedstock Supply
  - Offtake Agreements
  - EPC
- Feedstock Infrastructure
- Biofuels Distribution
- Codes & Standards, Quality
- Public perception and acceptance of Biofuels
- Environmental concerns
- Finance - Strategic Investors
- Policy

IBR Program FOA History



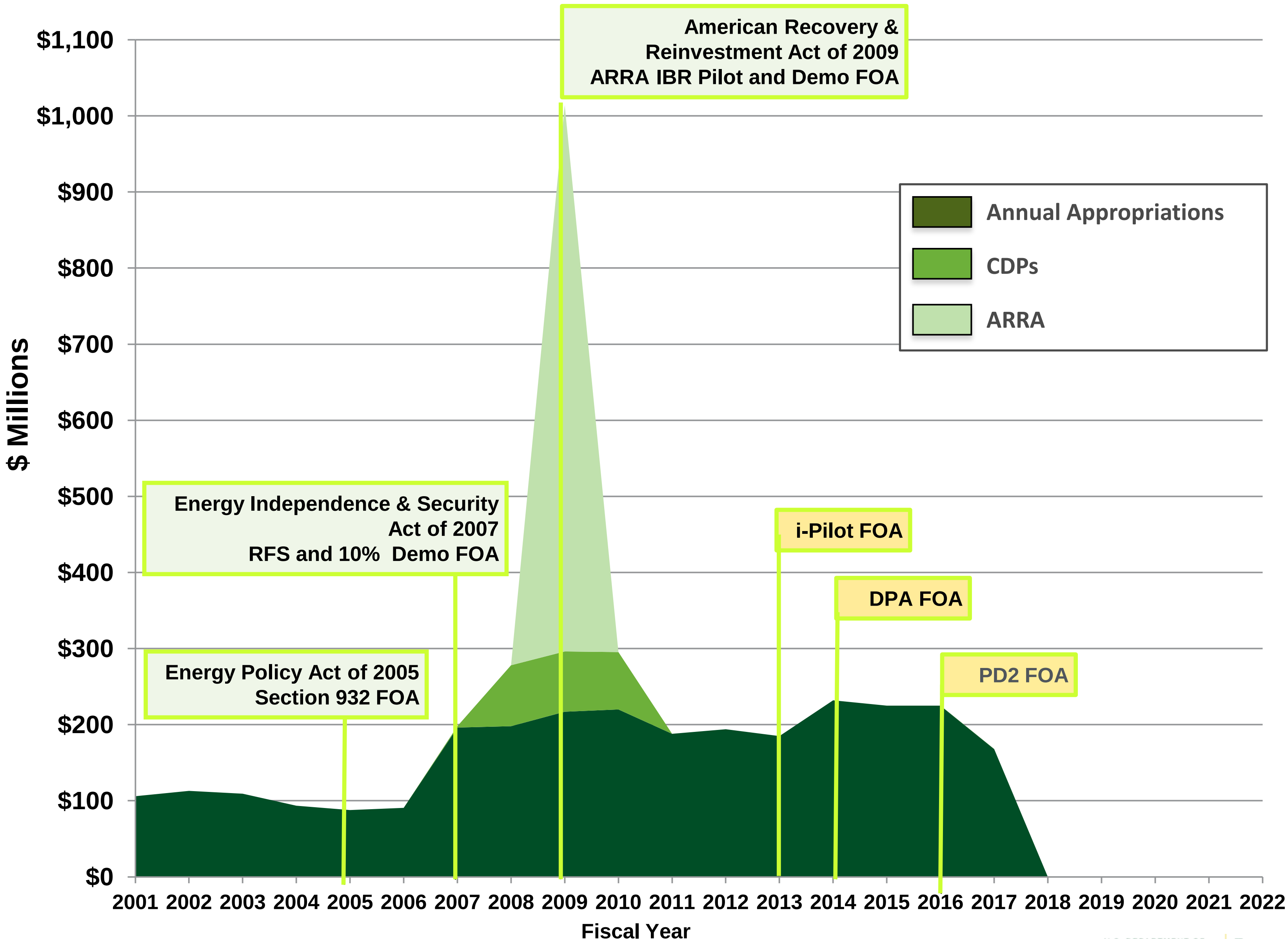
ARRA = American Recovery and Reinvestment Act

iPilot = Innovative Pilot

DPA = Defense Production Act

PD2B3 = Project Definition for Pilot and Demonstration Scale Manufacturing of Biofuels, Bioproducts, and Biopower

Major Legislative Drivers, BETO Funding, and IBR FOAs



BETO - IBR Program History

- **Demonstration & Deployment** 2009 – 2013
- **Demonstration & Market Transformation** 2014 – 2017
- **Advanced Development & Optimization** 2017 >

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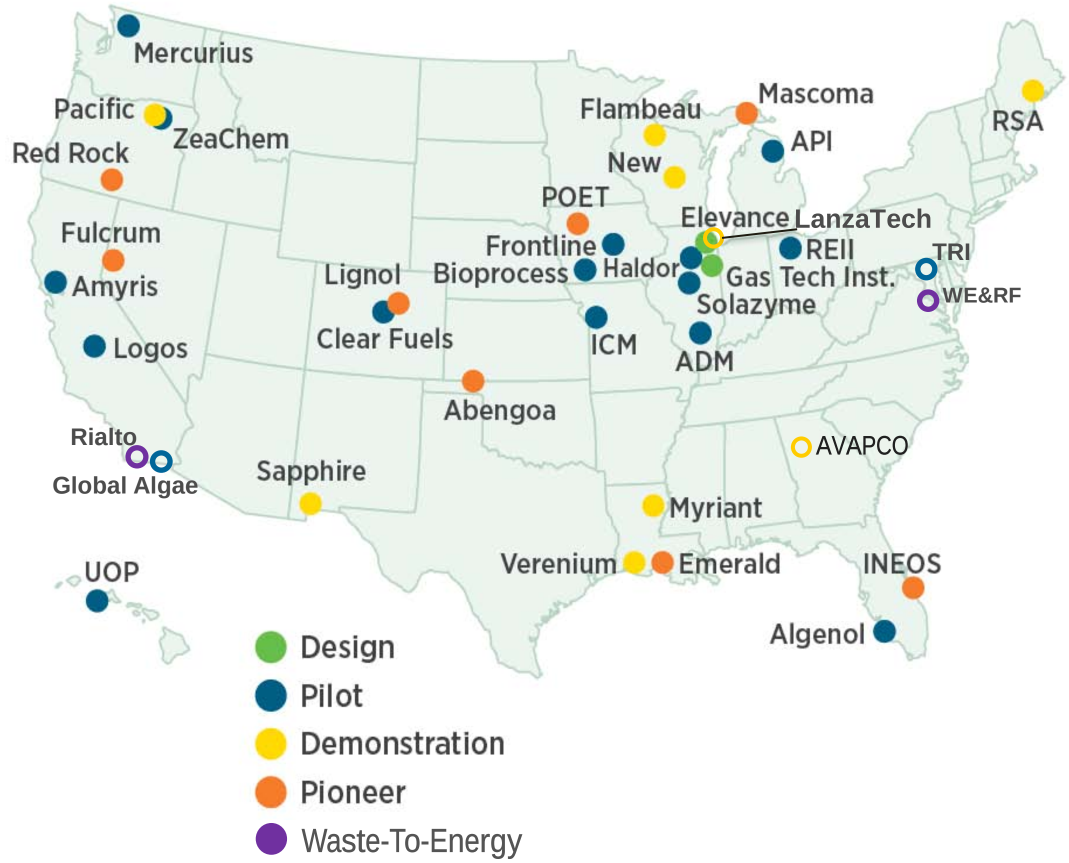
Distribution of IBR Projects since 2006

Since 2006, a total of 42 pilot, demonstration and pioneer-scale facilities

- Recently selected six new projects under the PD2B3 FOA

BETO investments have allowed industry partners to:

- Enable the development of first-of-a-kind IBRs
- Prove conversion technologies at scale
- Validate techno-economic assessments, and
- Gain investor confidence

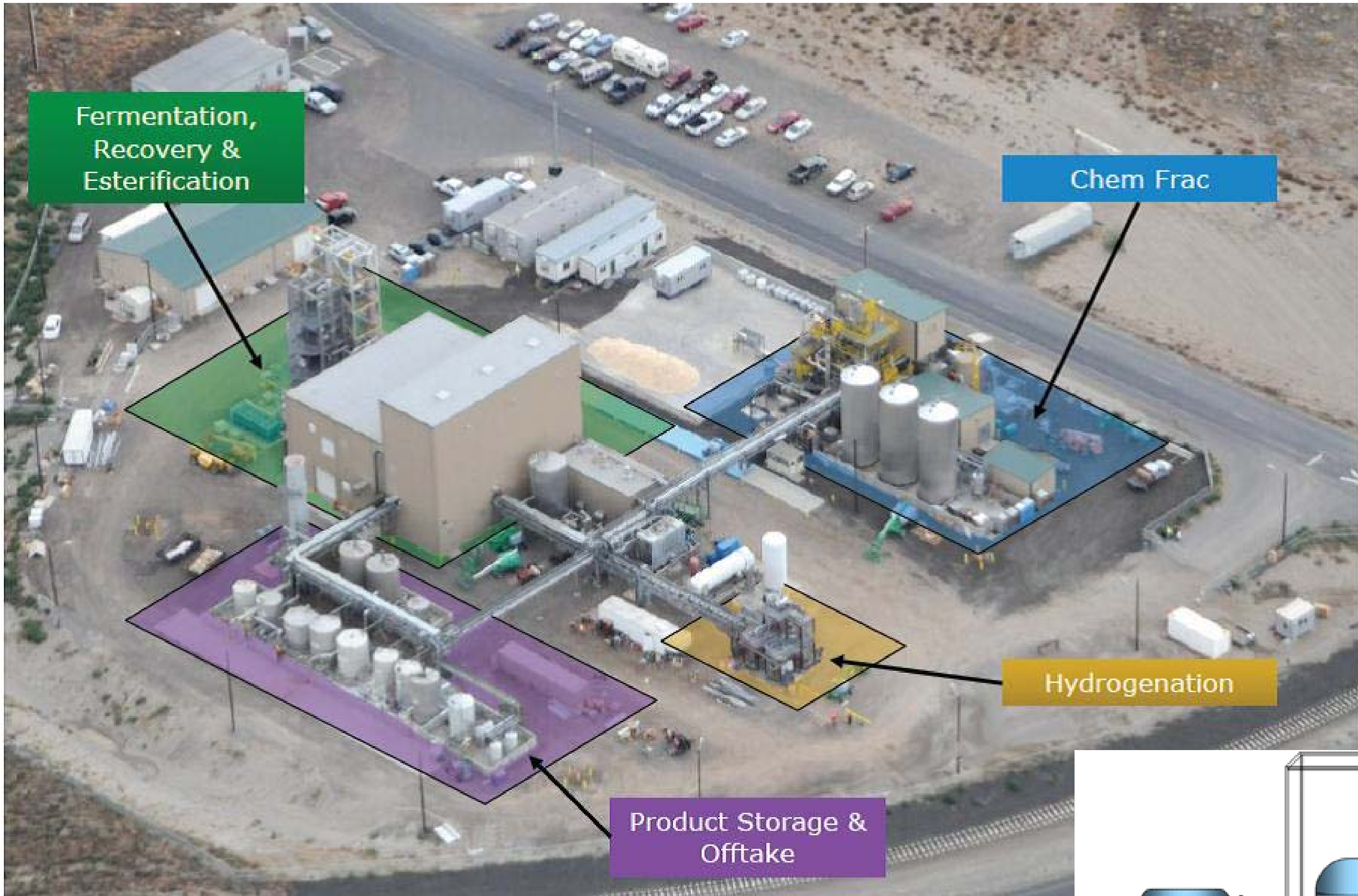


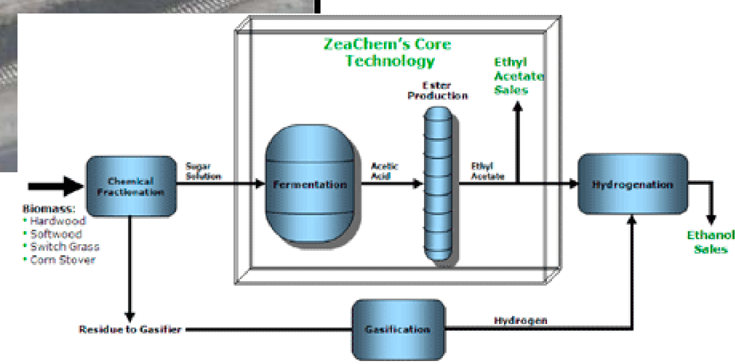
****Open circle designates a recent PD2B3 FOA selection****

American Process Inc. – Pilot Plant

Courtesy of American Process, Inc.

ZeaChem – Pilot Plant





ZeaChem's 250,000 gallon per year integrated biorefinery finalizing construction in 2013.

Logos/EdiniQ - Pilot

Clear Fuels – Rentech – Pilot Plant

Honeywell UOP – Pilot Plant

Sapphire – Pilot

Courtesy of Sapphire Energy, Inc.

Red Shield Acquisition

Olde Town Fuel & Fiber, Maine

Myriant's Bio-Succinic Acid Plant – Demonstration Plant

INEOS New Planet Biorefinery – Demonstration Plant

Abengoa Bioenergy – Pioneer Commercial Plant

POET Project Liberty – Pioneer Commercial Plant

Aerial view of POET-DSM's Project Liberty cellulosic ethanol plant in Emmetsburg, Iowa

DuPont Cellulosic Ethanol Facility

Nevada, Iowa

- DOE investment supported development work with NREL

Pioneer Commercial Scale Facilities

Domestic Facilities:

- POET Emmetsburg IA –
  - 1000 tons/day, 25 MGPY
- ABENGOA Hugoton KS –
  - 930 tons/day, 25 MGPY
- DuPont Nevada IA –
  - 1000 tons/day, 30 MGPY

International Facilities:

- BETA Renewables
  - 770 tons/day feedstock throughput
- GranBio
  - 22 MGPY Ethanol production
- Raizen (Iogen technology)
  - 300 tons/day, ~10 MGPY

PD2B3 FOA Selections

- In December 2016, DOE announced up to **$12.9 million** for six projects

Demonstration-Scale Integrated Biorefineries	**AVAPCO, LLC**
	LanzaTech, Inc.
Pilot-Scale Integrated Biorefineries	**Global Algae Innovations**
	ThermoChem Recovery International, Inc.
Pilot-Scale Waste-to-Energy Projects	**Rialto Bioenergy, LLC**
	Water Environment & Reuse Foundation

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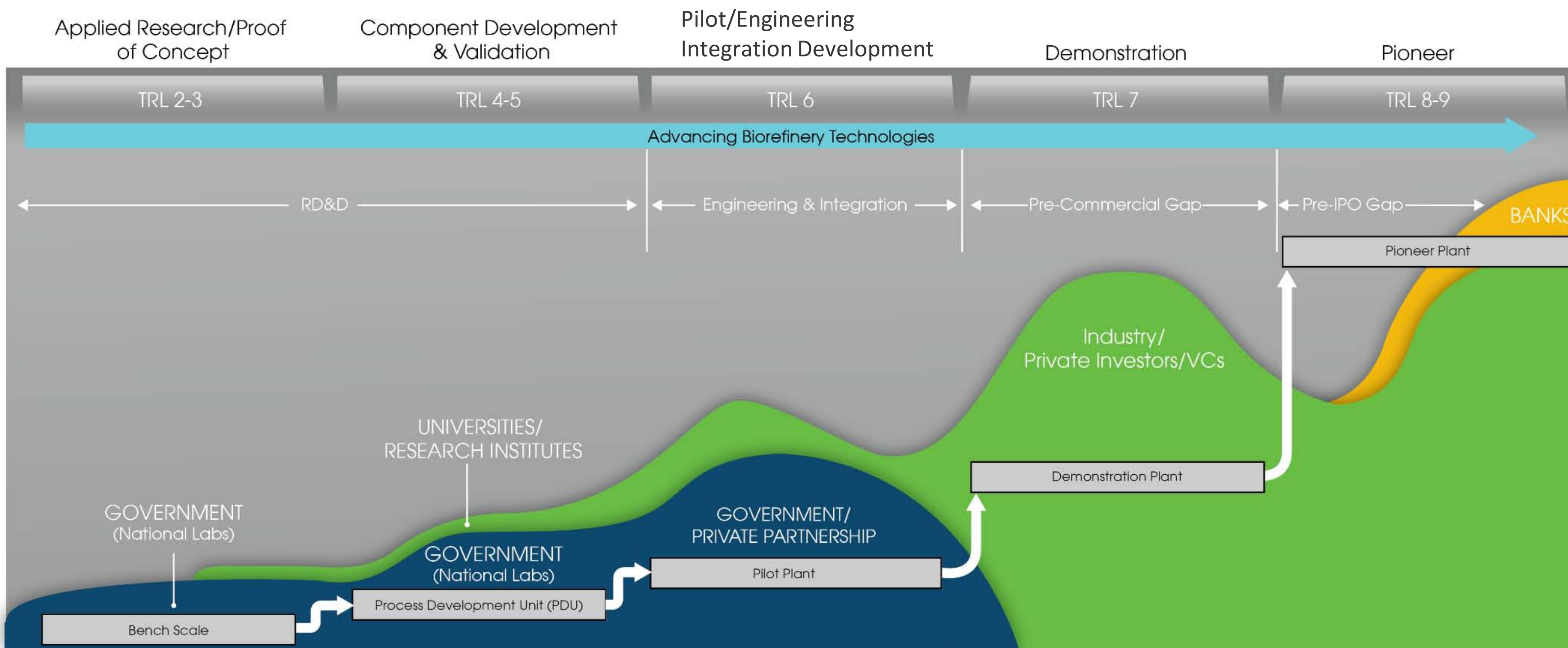
Multi-Step Pathway to Commercialization



Average Total Project Cost				
$1-5 million	$5-10 million	$25-50 million	$50-100 million	$250-500 million +
Average Biomass Throughput				
Grams/day	Kilograms/day	<50 Tonnes/day	50-250 Tonnes/day	+ 250 Tonnes/day
Production Volumes				
mL/L (batch)	Liters/ Gallons (batch)	0.1-1 M gpy (campaign)	1-10 M GPY (extended campaign/ continuous)	>50 M GPY (continuous)

GOVERNMENT   PROJECT RECIPIENTS & PARTNERS   BANKS

The Future of ADO

- Key Focus Elements
  - Engineering scale types of work
  - Unit operations development as opposed to integrated pilot
  - TRLs 4 - 6

OMB R&D Definitions

Term	Definition
Basic research	Experimental or theoretical work undertaken primarily to acquire new knowledge. May include activities with broad or general applications. Exclude research directed towards a specific application or requirement.
Applied research	Original investigation undertaken in order to acquire new knowledge. Directed primarily towards a specific practical aim or objective.
Experimental development	Creative and systematic work, drawing on knowledge gained from research and practical experience, which is directed at producing new products or processes or improving existing products or processes. Like research, will result in gaining additional knowledge. Include: • The production of materials, devices, and systems or methods, including the design, construction and testing of experimental prototypes. • Technology demonstrations, where a system or component is being demonstrated at scale for the first time, and it is realistic to expect additional refinements to the design (feedback R&D) following the demonstration. • Not all activities that are identified as "technology demonstrations" are R&D. Exclude: • User demonstrations where cost and benefits are being validated for a specific use. • Pre-production development, which is defined as non-experimental work on a product or system before it goes into full production, including activities such as tooling and development of production facilities.

DOE Technology Readiness Assessment (DOE G 413.3)

- TRL indicates the maturity level of a given technology
- TRL is **not an indication** of the quality of technology implementation in the design

Tech Development Level	TRL	Definition
Systems Operations	9	Actual system operated over full range of expected mission conditions
System Commissioning	8	Actual system completed and qualified through test and demonstration
	7	Full-scale, similar system demonstrated in relevant environment
Technology Demonstration	6	Engineering / pilot scale, similar system validation in relevant environment
Technology Development	5	Laboratory scale, similar system validation in relevant environment.
	4	Component and/or system validation in laboratory environment.
Research to Prove Feasibility Basic Technology Research	3	Analytical and experimental critical function and/or characteristic proof of concept
	2	Technology concept and/or application formulated
	1	Basic principles observed and reported

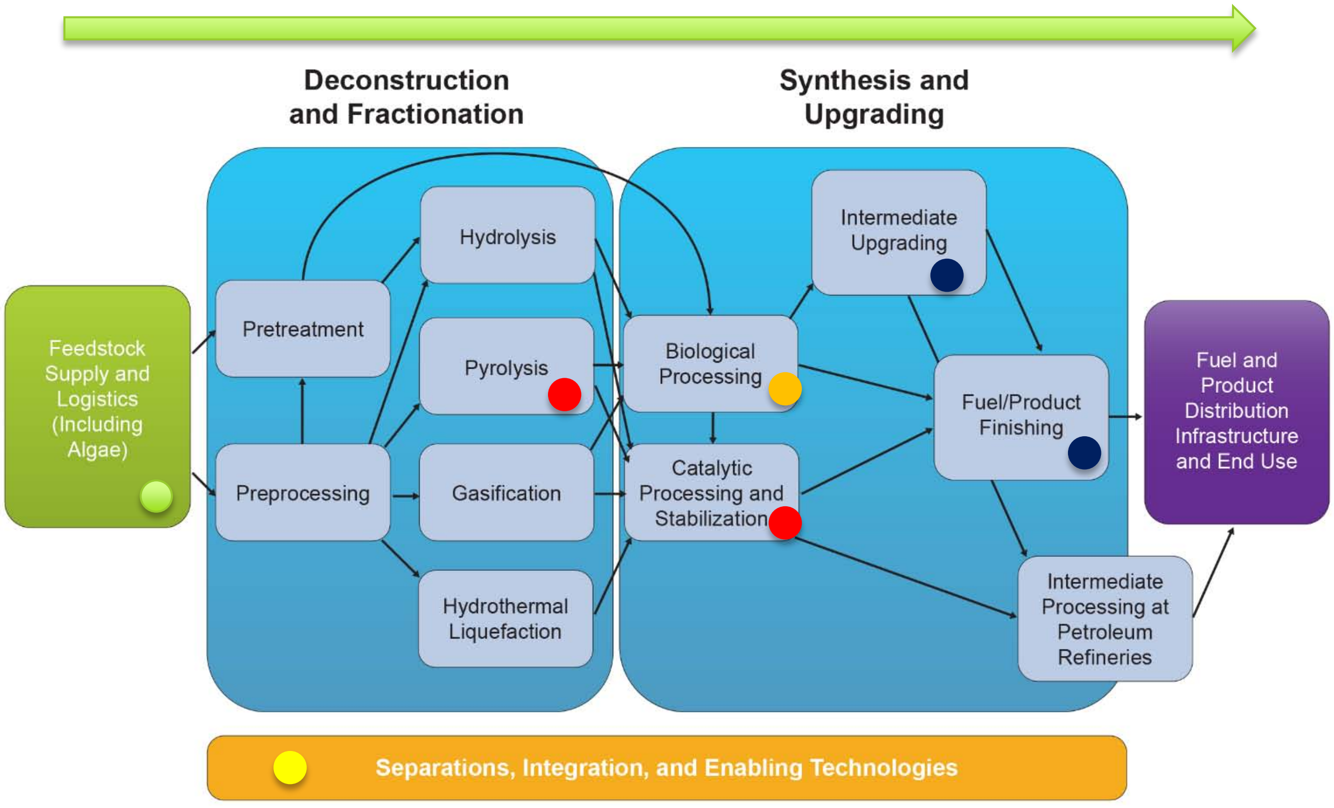
DOE introduced scale when defining TRL's 5-7

Indicators of Readiness

- Technology Readiness Level (TRL) measures the maturity of a technology (typically a process unit operation)
  - TRL does not measure robustness of technology integration into a system (connectivity)
  - Higher TRL does not indicate that a unit operation will successfully integrate into an overall process
- Integration Readiness Level (IRL) addresses unit to unit connections
- Systems Readiness Level (SRL) calculates integrated system maturity / readiness
- Manufacturing Readiness Levels (MRL) indicates development of a manufacturing base

➢ Understanding relationships between and within unit operations is critical to inform R&D gaps and future technology development

Conversion Pathways from Feedstocks to Products



Examples of Lab capabilities include:

- Feedstock Supply & Logistics (INL)
- Pyrolysis + Catalytic Processing and Stabilization (NREL)
- Intermediate Upgrading +Fuel/Product Finishing (PNNL)
- Biochemical Fermentation (NREL)
- Electrolytic Separation

Lab Scale – Example NREL Photos

Capabilities across BETO Laboratory Portfolio

BETO Laboratories:

- No single fully integrated process – integration is virtual

Biomass Feedstock PDU (INL)

Advanced Biofuels PDU (LBNL)

Integrated Biorefinery PDU (NREL)

Available Non-DOE Pilot Facilities

Biofuels and Bioproducts Process Pilot Verification Capabilities RFI Responses

- Facilities reporting the capability to perform conversions on a scale of approximately 0.5 or greater tons of dry biomass input per day
    - 13 biochemical facilities
        - 10 employing sugars fermentation and 3 employing anaerobic digestion
    - 14 thermochemical facilities
        - 7 employing pyrolysis (1 integrated, 6 non-integrated) and 7 employing gasification (4 integrated, 3 non-integrated)
    - Several others employing other pathways or in design phase
    - Tables of non-confidential data, describing the unit operations of each facility
    - https://energy.gov/eere/bioenergy/downloads/biofuels-and-bioproducts-process-pilot-verification-capabilities-rfi
    - It can be accessed from the Conversion page

- Also see Responses to DE-FOA-0001615: Request for Information: Cellulosic Sugar and Lignin Production Capabilities (Go to bioenergy.energy.gov → Bioenergy → Research & Development → Conversion Technologies → Results of Cellulosic Sugar and Lignin Production Capabilities Request for Information)

The Future of ADO

- Key Focus Elements
  - Engineering scale types of work
  - Unit operations development as opposed to integrated pilot
  - TRLs 4 - 6
  - Extend development of BETO R&D and Consortia work
    - Feedstock-Conversion Interface Consortium
    - Agile Biofoundry, Chem Cat Bio, CCPC
    - Advanced Biofuels/Drop-Ins
    - Aviation and Marine
    - Products
  - Maximize use of existing National Laboratory and Private facilities

The future is …

In our hands

Questions

Jim Spaeth

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