Pacific Northwest
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Process and Product Development with PNNL

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Advanced Development & Optimization Workshop

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U.S. DEPARTMENT OF ENERGY

Core competencies

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Dedicated facilities

- 55+ scientists and engineers
- 325+ patents
- $15M of DOE funded equipment
- 2,500 ft^2 high-bay

Expertise

- Catalysis
- Fungal biotechnology
- Process development
- Strategic analysis

High Throughput Center (HTC)

- **Automated material handling**
- **Material screening**
- **Analytics & data visualization**

New catalysts for enhanced biogenic carbon management

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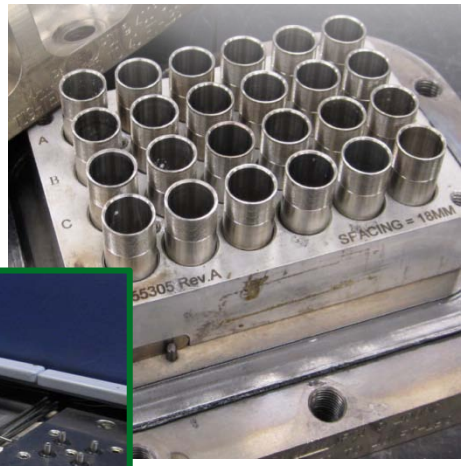
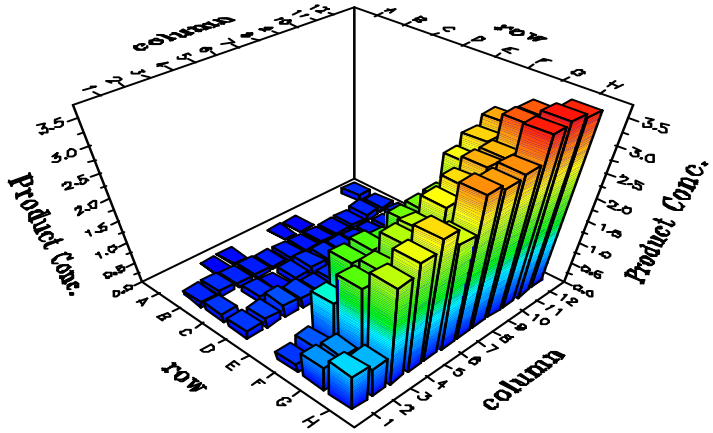
General rules for catalysts are known – but you must test new materials to discover new catalysts

- More than a shot-gun approach: We use established catalyst rules-of-thumb to initiate a wide search space of plausible candidates – and branch out from there
- Access to a large library of 100's of catalysts
- Batch (0.5-5 cm^3) and flow processing (0.05-1.0 cm^3)
- Automated materials handling for preparation of numerous custom catalysts simultaneously
- Advanced analytics to employ combinatorial methods to elucidate ternary and tertiary material interactions



Significance and impact

- Three commercial licenses granted from catalysts discovered and developed using these instruments
- Numerous patents granted -- at least 4 with minimal or no office actions demonstrating the novelty of these new materials
- New bio-derived feedstocks need new catalysts with stability in water-rich environments and activity near impurities



Unique capability – continuous flow reactors

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- Capabilities and know-how developed at multiple scales
- Continuous flow reactors
- Continuous improvement operation strategies and systems
  - Production of samples at all scales to support related research

8 x 1.4mL beds

3-40mL beds

Catalyst Screening

Catalyst Evaluation

400/800ml bed

Process Development

1 liter fixed and moving bed

Nominal temperature: Up to 450C
Nominal pressure: Up to 2000psi

20 liter bed + distillation

Success story

Renewable propylene glycol

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Breakthrough produces a clean alternative to petroleum; leads to new processing facility

PNNL discovers catalyst that efficiently converts sugar alcohols and glycerol to propylene glycol (PG)

Archer Daniels Midland advances PNNL discovery, builds Illinois production facility

Impact:

Propylene glycol, a chemical used in many products, now derived from green sources

- ✓ Cost-competitive
- ✓ ADM facility can annually produce up to 100,000 metric tons of PG
- ✓ Chemical meets industrial and USP standards
- ✓ ADM is exclusive licensee

An example:

Exceptionally high quality fuel with environmental benefits

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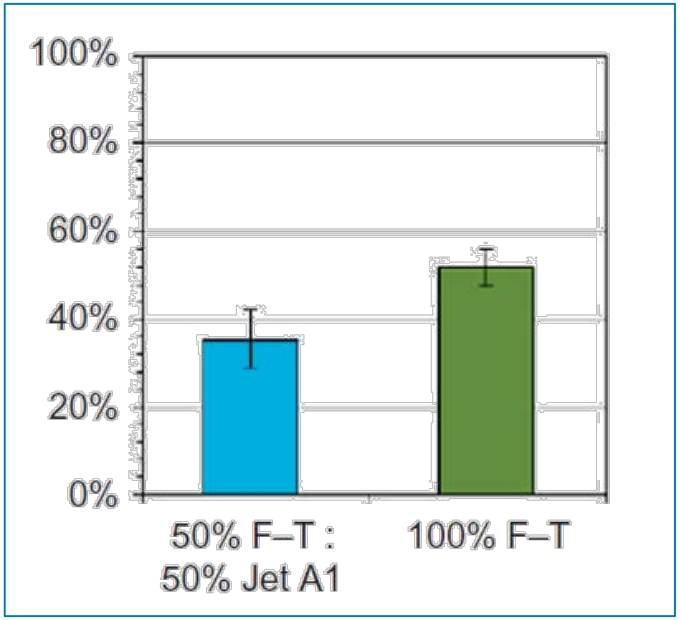
- ✓ 98% isoparaffin



particulate matter reduction

Product Quality Ethanol to Jet & Diesel

- Meets all ASTM specifications for jet
- Cetane = 53.6 (Diesel fuels are typically in the 40-55 range)
- Cloud Point = -60.1°C *(ASTM D 975 is regional, but an extreme case is < -28°C for MN. European standard EN 590 specifies* ***< -34°C for Class 4 arctic diesel****)*
- Pour Point = -66.0°C

Handler et al. Industrial and Engineering Chemistry

Lobo et al. Environ. Sci. Technol. 45 (2011) 10744-10749

Taking it to the next level with our partner, LanzaTech!

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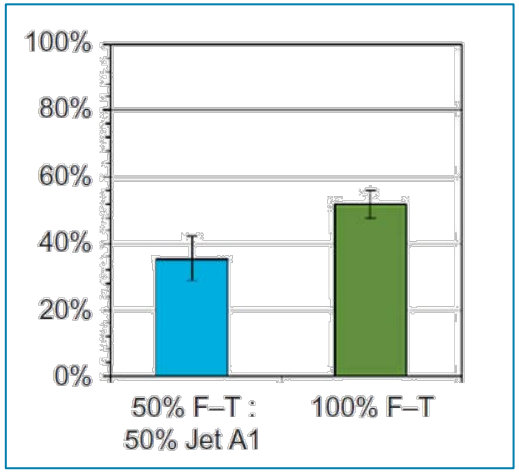
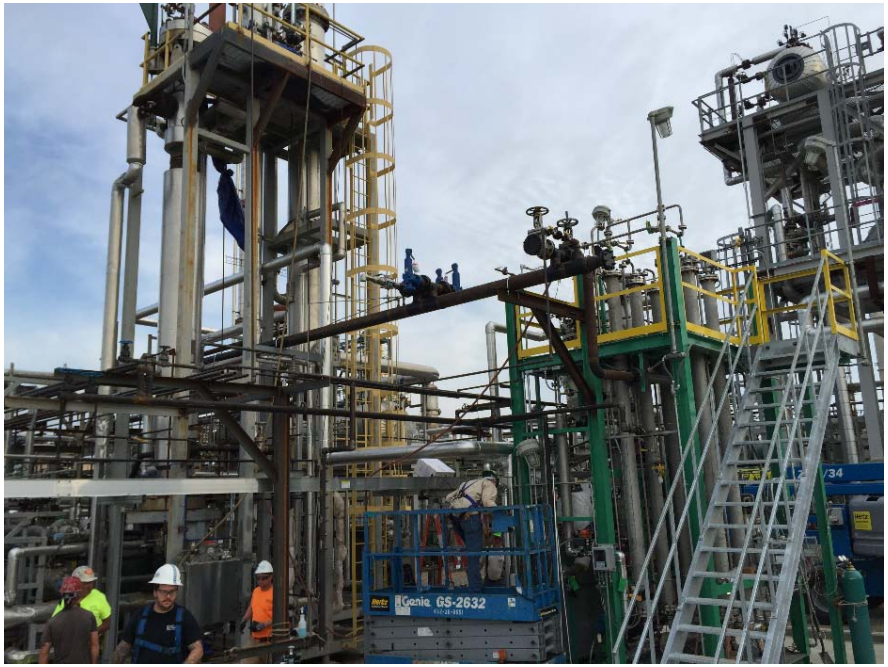
Scientific approach

- Ethanol → dehydration → oligomerization → hydrogenation → fractionation → synthetic paraffinic kerosene (ATJ-SPK)
- **Targeted fuel components** – isoparaffins



Particulate Matter Reduction

Lobo et al. Environ. Sci. Technol. 45 (2011) 10744-10749



Significance and impact

- Produced 4,000 gal of jet fuel (synthetic paraffinic kerosene) and 600 gal of diesel fuel (1,500 gallons starting from steel mill waste gas)
- Demonstrated catalyst/process multi-thousand hours with regeneration
- Validated feasibility and reproducibility at pilot scale

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A powerful driver: Turning liabilities into revenues

Recycling carbon: produce biofuels while solving another problem

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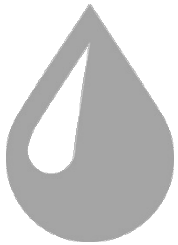
biotechnology

catalysis



CO-rich waste gas

Ethanol

Synthetic paraffinic kerosene (ATJ-SPK)

thermal chemistry

catalysis

Waste sludges

biocrude

diesel fuel

Success story

*Generation 2 HTL

Continuous process for algae to fuels

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Breakthroughs enable scale-up of hydrothermal liquefaction technology in less than four years from idea conception

PNNL discovers technique for converting whole algae to biocrude; leverages catalysis to turn biocrude into jet and diesel

Genifuel, Reliance, PNNL build continuous 1 metric ton/day HTL/CHG pilot system for algal feedstocks

Impact:

Near-term technology for deployment with favorable economics

- ✓ Scalable and ideal for wet feedstocks
- ✓ Blendstocks suitable for refinery integration
- ✓ High-quality jet and diesel fractions
- ✓ One of several algal HTL piloting efforts

Modular hydrothermal liquefaction system (MHTLS) *Generation 3 HTL

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The capability

- 12-16 liters/hour
- Solid-liquid separations at operating conditions
- Liquid-liquid separations for biocrudes that are heavier, or lighter, than water
- Product-feed heat recovery

Accomplishments

- 2 ½ year effort of multi-faceted team from DOE, PNNL, and industry
- Multiple commissioning runs met all operational objectives, confirming the value of this new capability
- kg – scale biocrude from algae
- Aqueous phase sent to ASU for recycling/algae cultivation studies

Transforming the energy landscape can only be successful through collaboration…

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LanzaTech — capturing carbon. fueling growth.

μBIO MicroBio Engineering

VTT

Central Contra Costa Sanitary District

GARDN Green Aviation Research & Development Network

Emerald Energy NW — Solutions with Power and Energy

Reliance Industries Limited — Growth is Life

Water Environment & Reuse Foundation WE&RF

Merrick & Company

Visolis — Carbon Negative Materials

Genifuel

Brown and Caldwell — essential ingredients®

metrovancouver — Services and Solutions for a Livable Region

InnaVenture

U.S. Department of Energy | Energy Efficiency & Renewable Energy
Bioenergy Technologies Office

Additional Slides

Multi-liter wiped-film distillation

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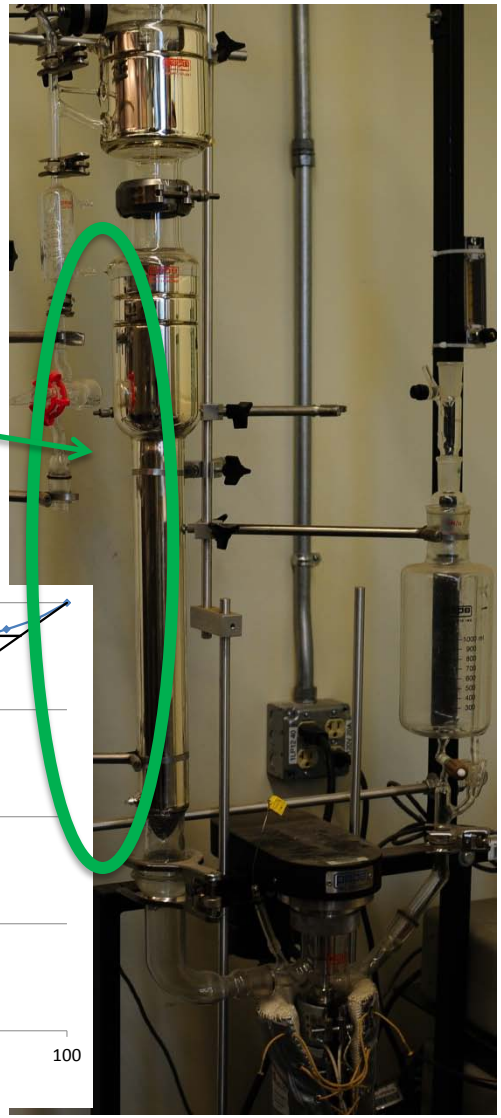
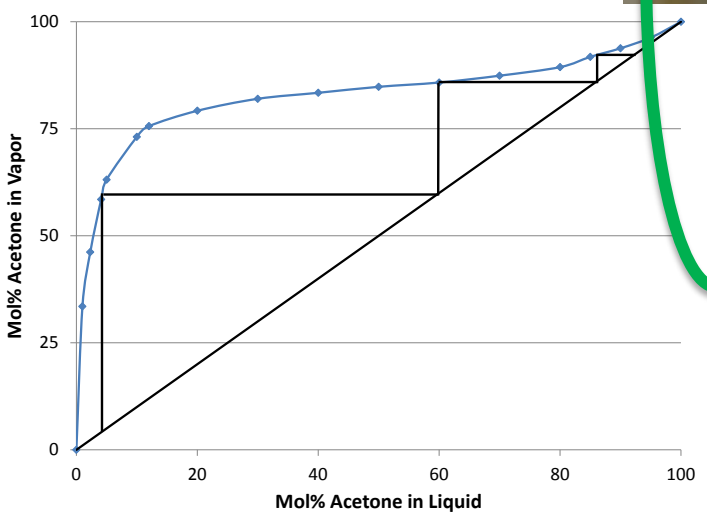
Generate liter quantities of compounds and mixtures for fuel testing

- Typical feed rate: 0.1-3 kg/h
- Continuous wiped-film reboiler allows for efficient distillation
  - Vacuum operation – lowers overall temperature
  - Short feed residence time – minimizes degradation of temperature-sensitive compound
- Hybrid configuration includes 2” diameter packed bed column
- Controllable reflux ratio for increased precision of mixtures



Significance and impact

- Sample generation for high volume fuel tests (e.g., RON & MON for gasoline)
- Packed column and reflux allow for precise temperature cuts when distilling gasoline, jet and diesel blendstocks
- Biologically derived fuel blends and co-products may be separated from broths via low temperature operation with short residence times



Biotechnology: EMSL user facility, platform chemical discovery through initial process development

EMSL user facility

Applied multi-omics, cell isolation and systems analysis, microscopy

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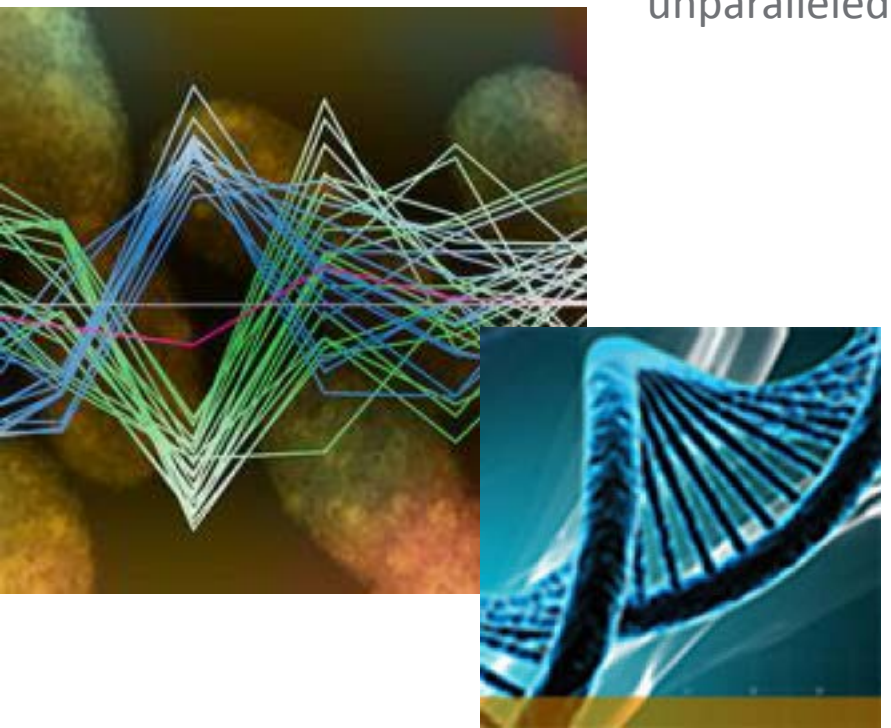
Challenge: poor tolerance of microbial production hosts toward high concentrations of excreted product

- Concentrations > 100 g/L for viable economics

Biosystem design success story

Resequencing of over 200 strains and subsequent reconstruction of sets of mutations has provided unparalleled insight on the genomic basis of tolerance.

https://www.emsl.pnl.gov/emslweb/



Microbial communities success story

Integrated omics revealed the structure and function of a complex cellulose-degrading microbial community, which could lead to greater use of plant biomass for biofuel production.

Fungal genomics – Aspergillus & L. starkeyi

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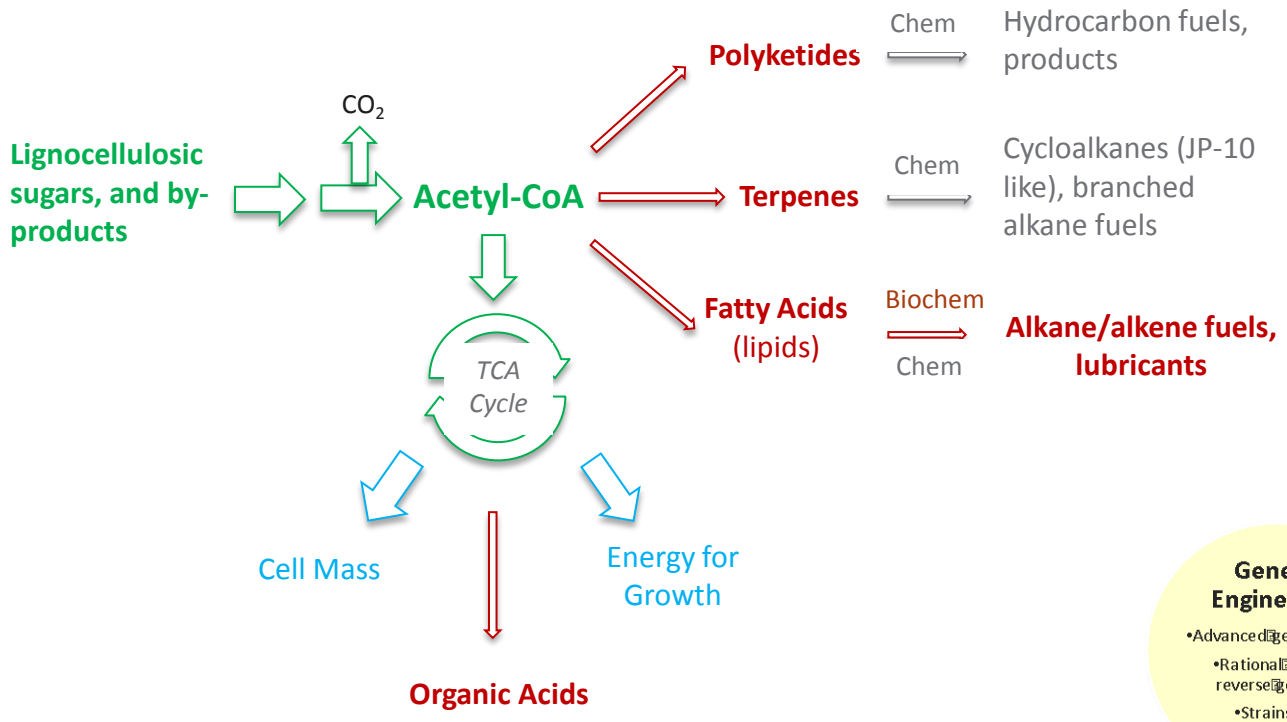
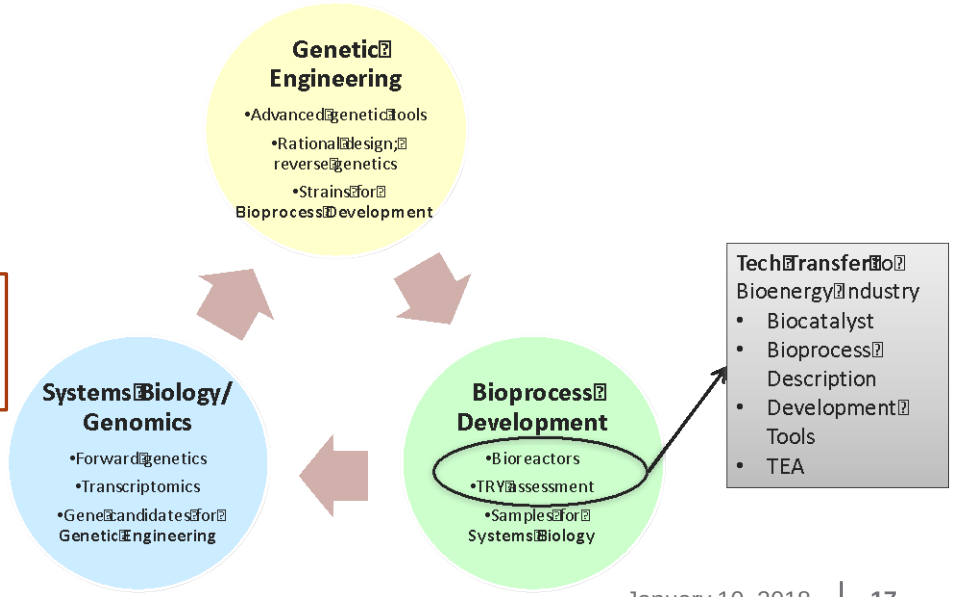


Maximize 'TRY'

- High ***titer*** for downstream processing efficiency
- High ***rate*** to minimize CapEx/OpEx
- High ***yield*** to maximize use of high-cost biomass

Robust organisms that convert complex hydrolysates containing inhibitors and mixed sugars



Bioreactor operation and optimization using chemometric data and machine learning

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