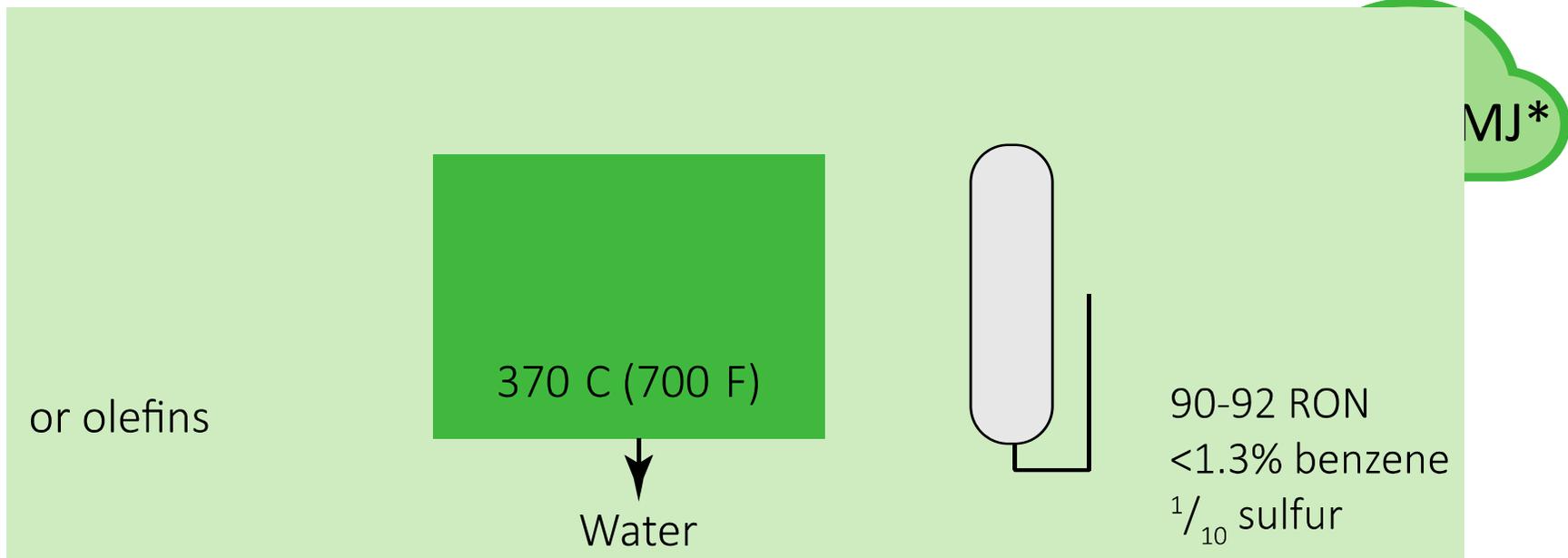


Methaforming: Profitable “last mile” technology for biofuels

Methaforming: One Step Conversion of Various Feeds into Gasoline



- Wide range of possible feeds
- Simple one step process
- No precious metals in the catalyst
- High yield of gasoline blendstock
- Capital and operating costs like a hydrotreater

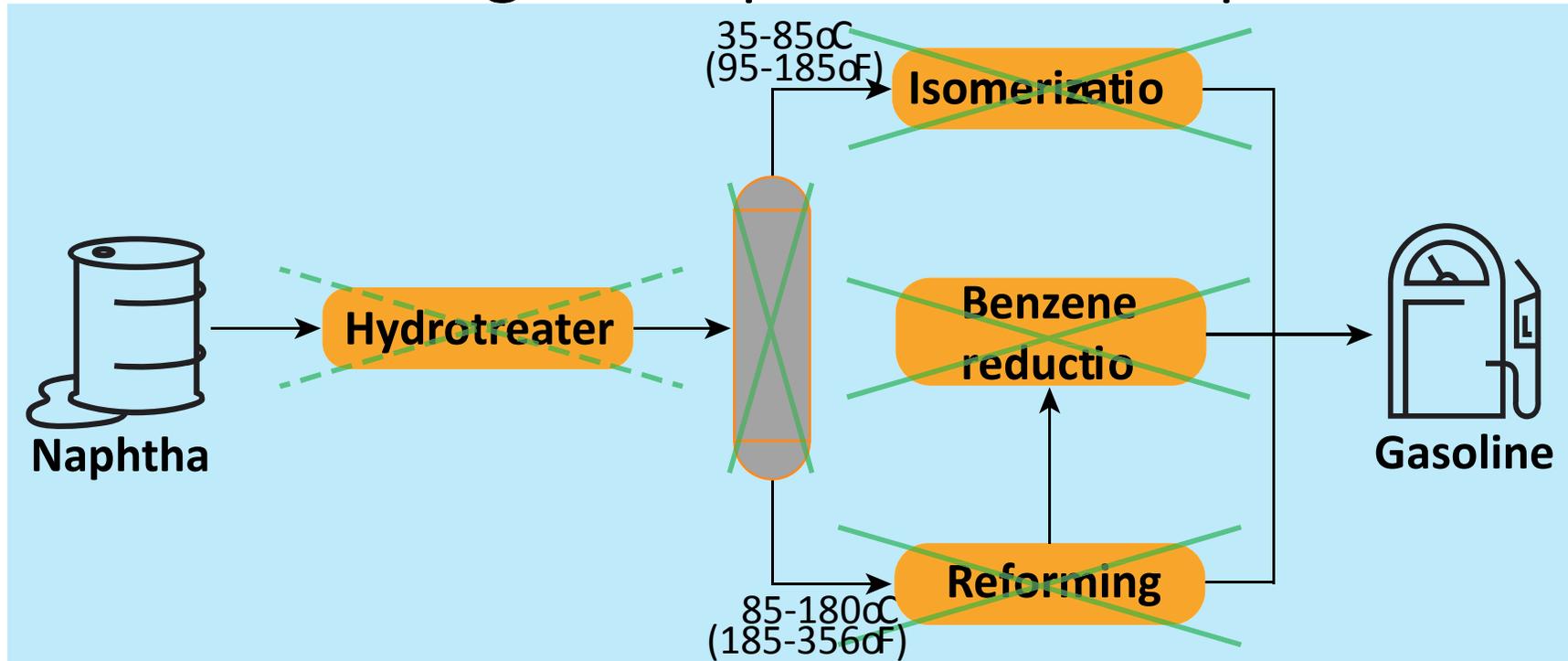
* Compared to 3.2 gCO₂/MJ for traditional naphtha processing.

Process Flow and Yields

- Process flow like a hydrotreater except:
 - Alcohol or another co-feed instead of hydrogen,
 - No recycle compressor.

- Yields like a reformer except:
 - Most benzene converted to toluene,
 - Part of alcohol becomes water,
 - Regenerate catalyst 1/mo (5 year life).

Methaforming is Simpler and Cheaper



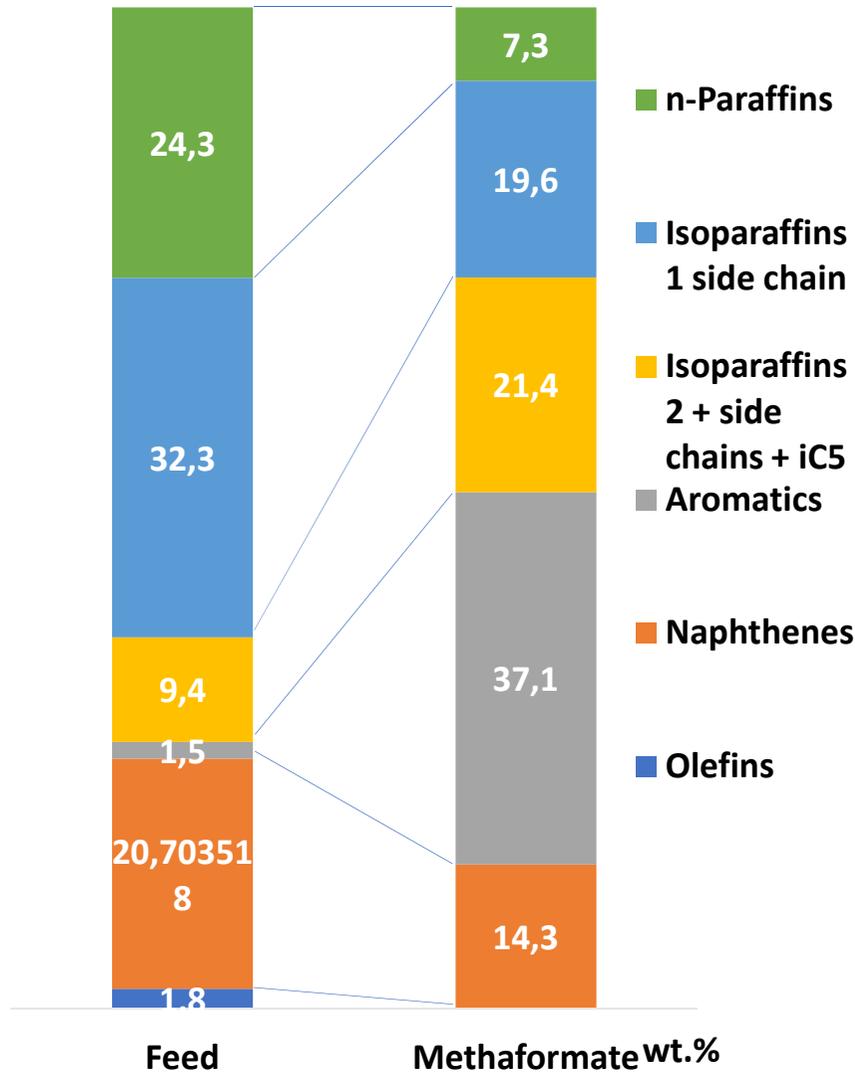
Catalytic reforming and isomerization

- Most common technology
- Feed hydrotreater required
- Several process units

methaforming

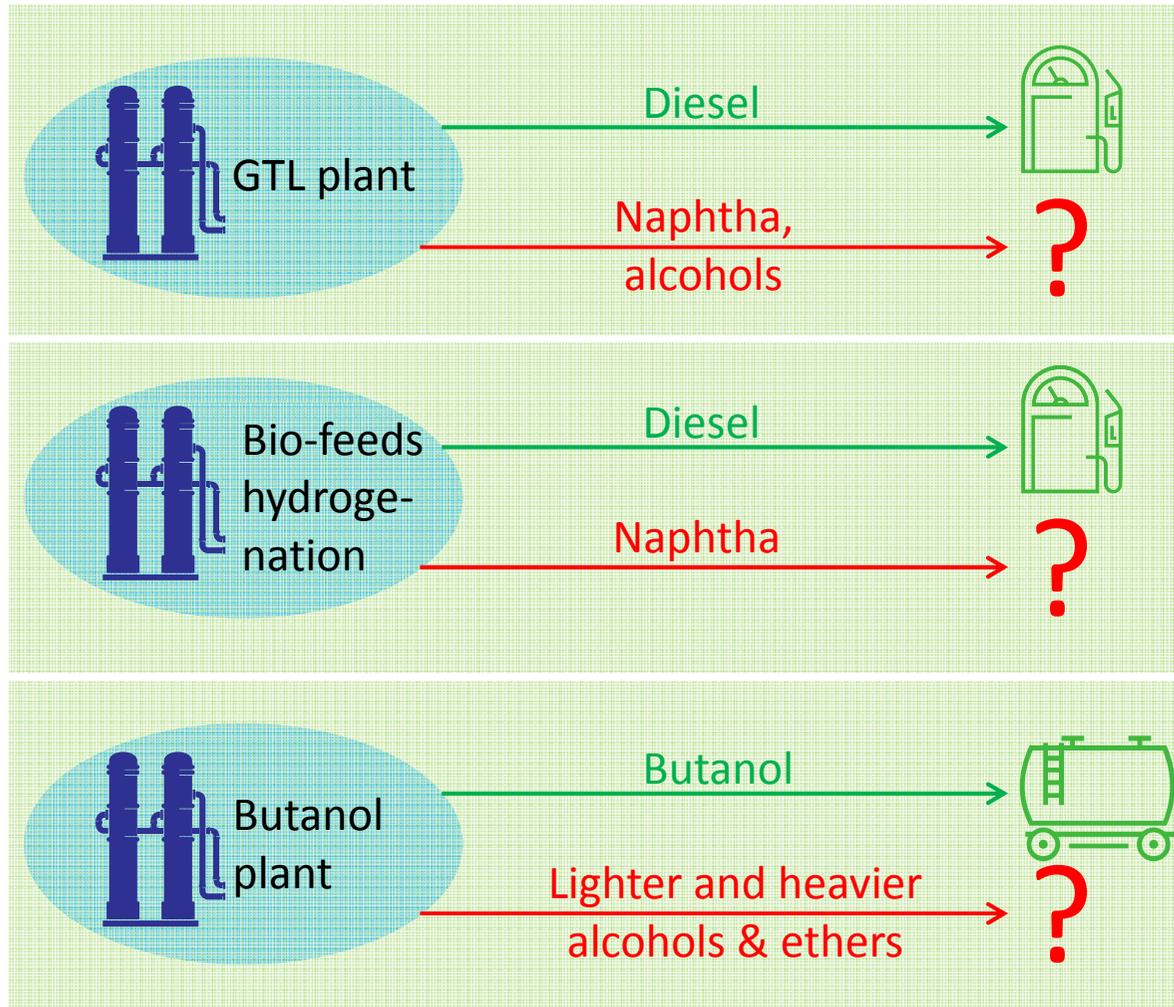
- Reduce costs to 1/3
- Reduce sulfur by 90%
- Simple single process unit

Methaformer Yield Details



Delta: PROD - FEED		
Product	mt	Change, %
n-Paraffins	(0.185)	(76)
Isoparaffins	(0.098)	(23)
1 side chain	(0.171)	(53)
2+ side chains + iC5	0.073	78
Aromatics	0.274	na
1 ring	0.266	na
2 rings	0.009	na
Naphthenes	(0.196)	(64)
5-C-ring	(0.084)	(49)
6-C-ring	(0.112)	(83)
Olefins	(0.017)	(95)

Nearly every renewable fuel has low value byproducts



Feed Flexibility – Key to Profitability

Acceptable main feeds

- Light naphtha and solvents,
 - GTL naphtha,
 - Benzene-rich naphtha,
 - Narrow fractions of C₆-C₇ hydrocarbons,
 - Gas condensate,
- Virgin naphtha,
 - Natural gasoline,
 - Pyrolysis gasoline,
 - Raffinate from aromatics extraction unit,
 - Light FCC naphtha,
 - Mixes of these.

Feed Flexibility – Key to Profitability

Acceptable co-feeds

- Ethanol,
 - Methanol,
 - Propanol, butanol and heavier alcohols,
 - Ethers,
 - Light olefins,
- Other byproducts of alcohol production,
 - Crude alcohols with up to 50% water,
 - Mixes of these.

Methaformer vs Traditional Reforming Suite (HDS+semi-regen reformer)

New 860 K tpa unit (20 K BPD)	Methaforming	Alternative	Δ Methaforming - Alternative
Yields*, \$ million/yr	29	24	+ 5
OpEx, \$ million/yr	8	12	- 4
CapEx, \$ million	25	55	- 30
Total NPV, \$ million	120	20	+ 100

methaforming

\$ 9 million/yr profit advantage
\$ 30 million lower CapEx

Net present value @12% is \$100 million higher

* Yields include fuel gas produced/consumed, H2, RON value.

Convert Semi-regen Reformer

Existing 860 K tpa unit (20 K BPD)	Methaforming	Alternative	Δ Methaforming - Alternative
Yields, \$million/yr	126	95	+ 31*
OpEx, \$million/yr	13	23	- 10
CapEx, \$million	20	-	+ 20
Total NPV, \$million	750	490	+ 260*

methaforming

\$ 41 million/yr profit advantage
\$ 20 million CapEx to convert

Net present value of conversion @12% is \$260 million*

***Excluding carbon credits opportunities**

Methaforming Light Virgin Naphtha with C2= vs. Isomerization with Recycle

New 190 K tpa unit (5 K bpd)	Methaforming	Alternative (isom)	Δ Methaforming- Alternative
Yields, \$million/yr	55	55	0
OpEx, \$million/yr	3	8	- 5
CapEx, \$million	25	43	- 18
Total NPV, \$million	375	320	+ 55

methaforming

\$ 5 million/yr profit advantage
\$ 18 million lower CapEx

Net present value @12% is \$ 55 million higher

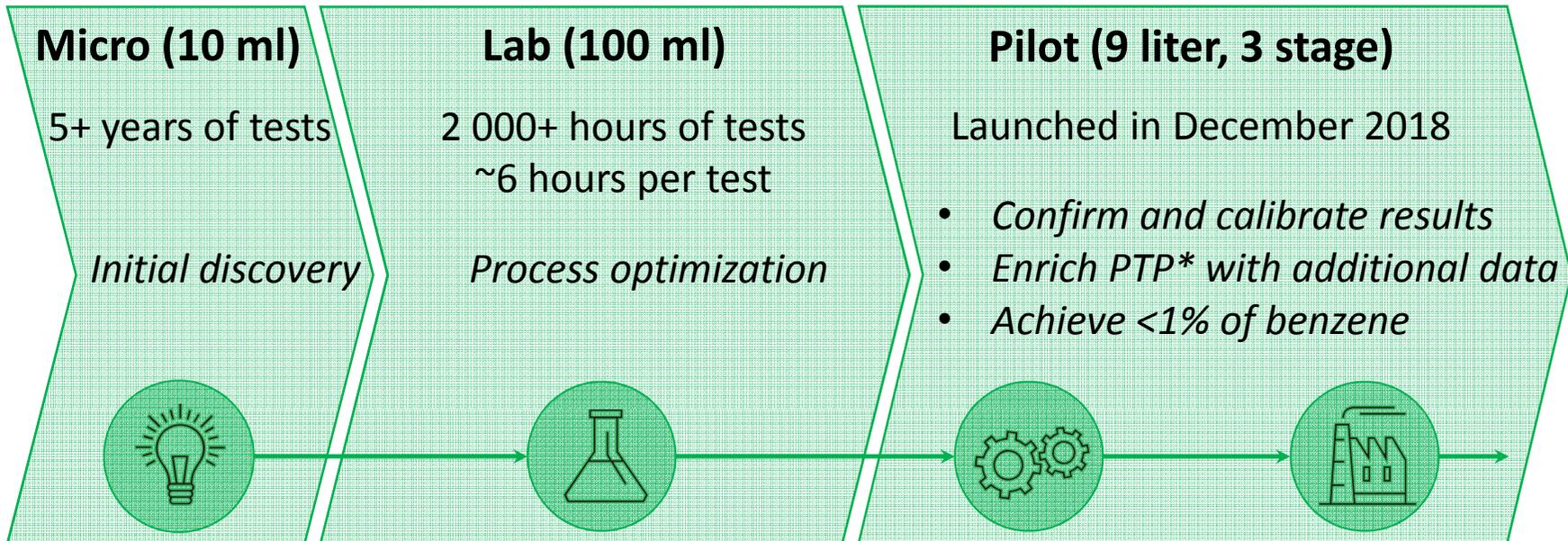
Grassroots Unit to Process Raffinate and FCC dry gas

New 88 K tpa unit (2 K BPD)	Our Unit	Alternative (direct blending)	Δ Our Unit - Alternative
Yields, \$million/yr	62	41	+21
OpEx, \$million/yr	4	0	+4
CapEx, \$million	14	0	+14
Total NPV, \$million	+100	n/a	+100

methaforming \$ 17 million/yr profit advantage

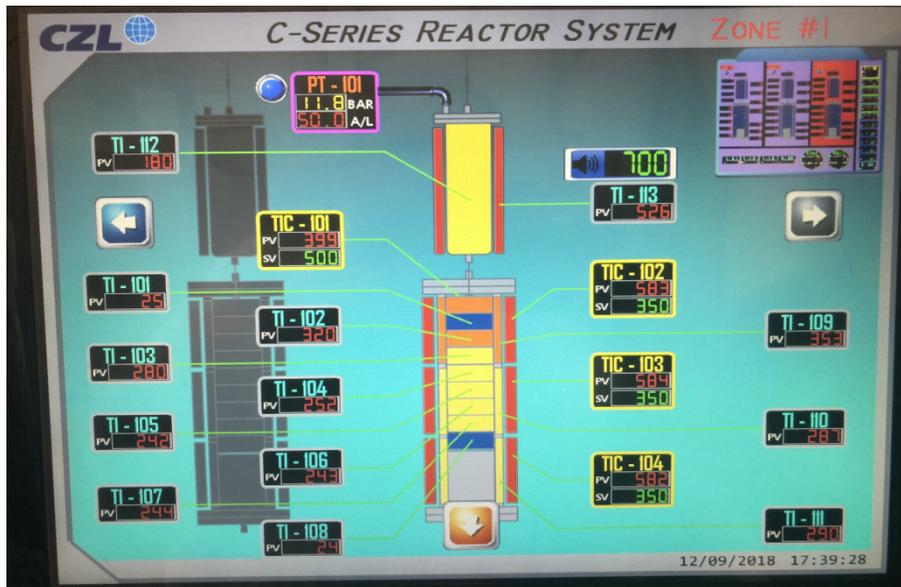
Net present value @12% is \$100 million

Pilot Plants



* Preliminary technology package – documentation to design a commercial plant.

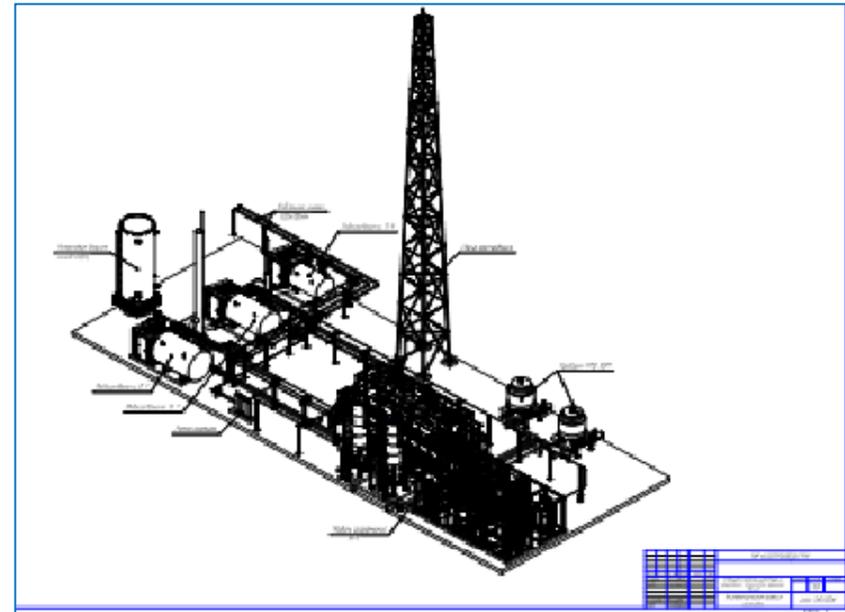
Methaforming demo plant*



*In cooperation with Omsk refinery, Russia

Skid Mounted Methaformers Ready for Order

- Detailed mechanical design complete.
- Two sizes, prices at FOB Black Sea:
 - 6 k tpa (150 BPD) for \$900 K (6 mo delivery);
 - 21 k tpa (530 BPD) for \$2 million (15 mo delivery).
- Includes all inside battery limits (ISBL).
- OSBL by owner – much may already exist
 - feed and product tankage, MeOH/EtOH receiving;
 - hydrogen-rich gas H₂S removal, LPG sweetening;
 - utilities: fuel gas, electricity, wastewater treating.



Technology Acceptance by Refiners

- **Owner of 6k tpa (150 bpd) first commercial plant** now building 12k tpa (300 bpd) Methaformer.
- **Refiner in Uzbekistan:** FEED done for 55k tpa (1300 BPD) Methaformer.
 - Feed: light naphtha, full range naphtha.
- **Major Russian refiner:** pre-engineering in progress for 480k tpa (11k BPD) unit, launch in 2023.
 - Feed: raffinate, benzene precursor naphtha, FCC dry gas, methanol.
- **Merchant processor in US:** Convert 65 K tpa of low-cost spot purchased naphtha into finished gasoline.

Summary

- Upgrade low value byproducts of biofuel production to drop-in gasoline and LPG
- Produce gasoline from naphtha, FCC dry gas and methanol at 1/3 the cost with comparable yields
- 5 times carbon footprint reduction compared to traditional naphtha PFD
- Can be profitable even at very low scale



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