# Intensifikasi Proses Produksi $H_2$ sebagai Energi Bersih Masa Depan

Air sebagai bahan bakar. Mungkinkah?

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# Intensifikasi Proses

- Emerging equipment, processing techniques, and operational methods promise spectacular improvements in process plants, markedly shrinking their size and dramatically boosting their efficiency. These developments may result in the extinction of some traditional types of equipment, if not whole unit operations (**Stankiewicz and Moulijn, 2000**).
- Apa yang dimaksud dengan Intensifikasi Proses?
- New paradigm shift in chemical processes
- Kemaslahatan intensifikasi proses


# Intensifikasi Proses

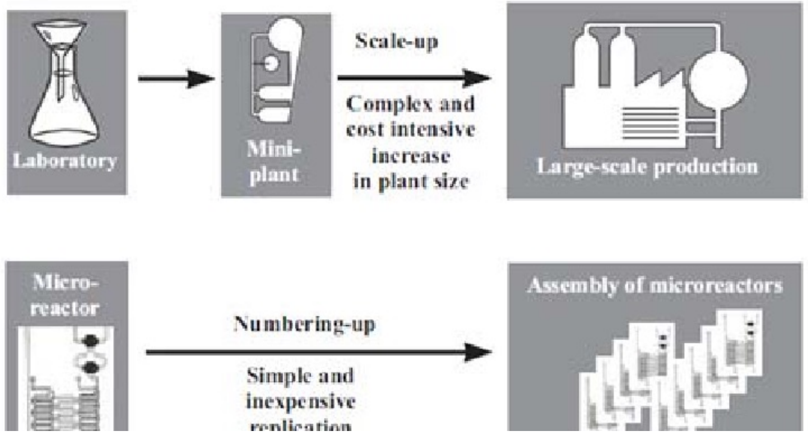


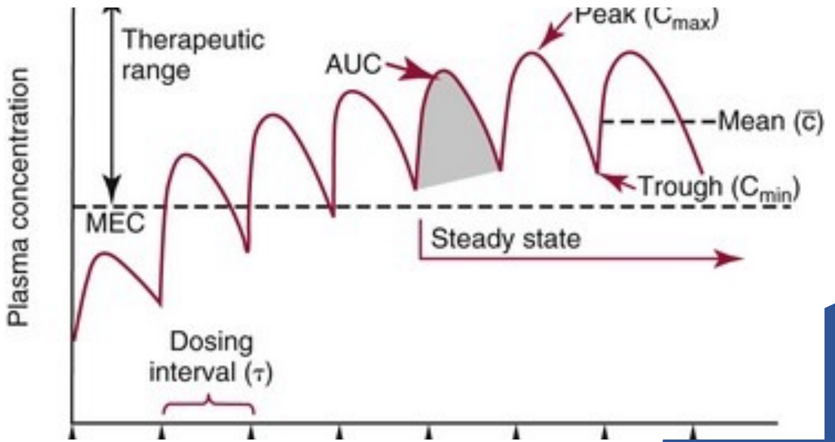
Pengembangan **peralatan** dan **metode** proses dan sistem pemroses + **material** yang **inovatif** dan **kreatif**

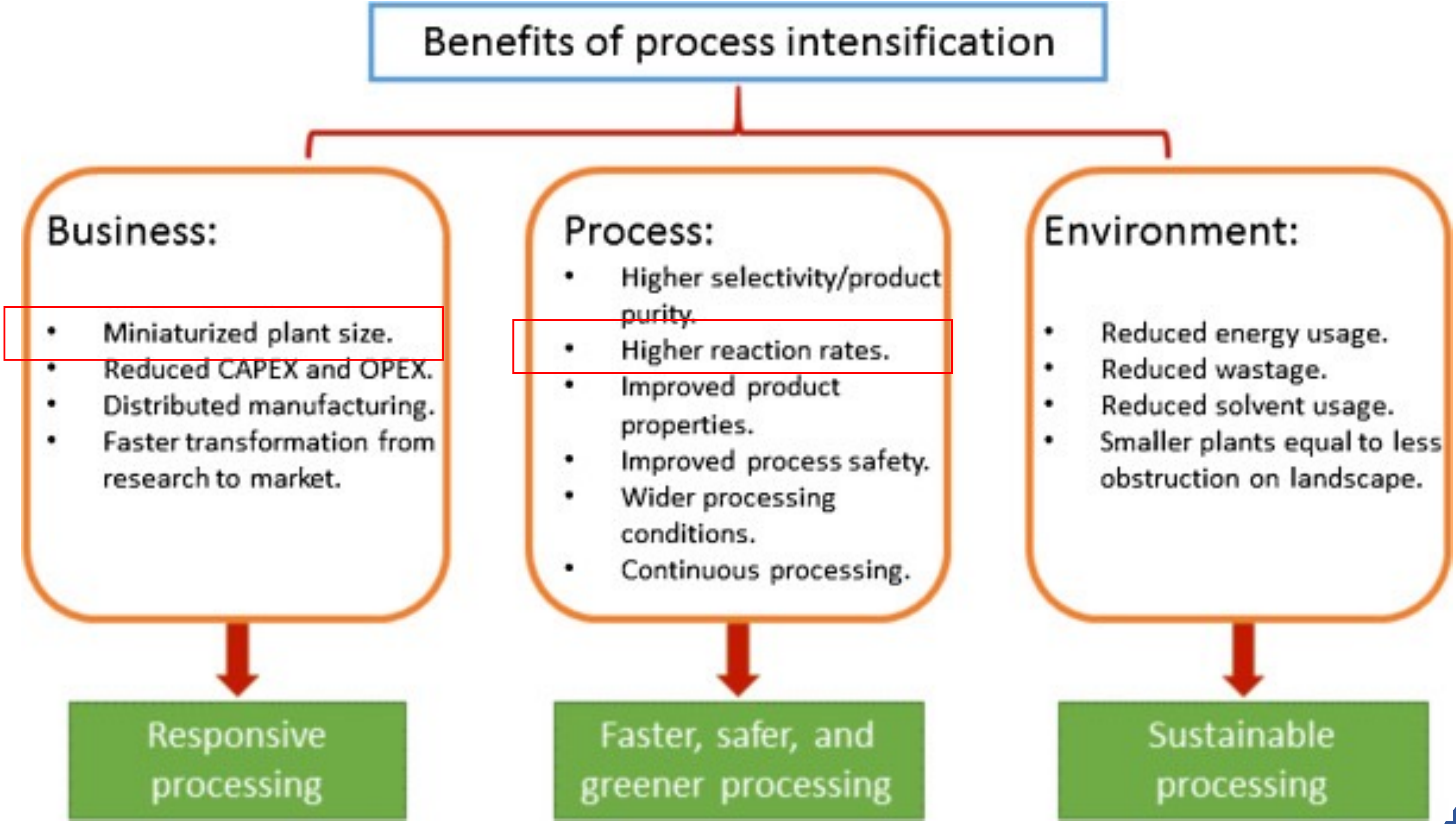
**Kinerja meningkat ribuan kali**

**New paradigm shift:**

- Scale up versus Scale out atau numbering up (Macroscale versus Microscale; Longer versus shorter time to market)
- Steady state versus Unsteady state



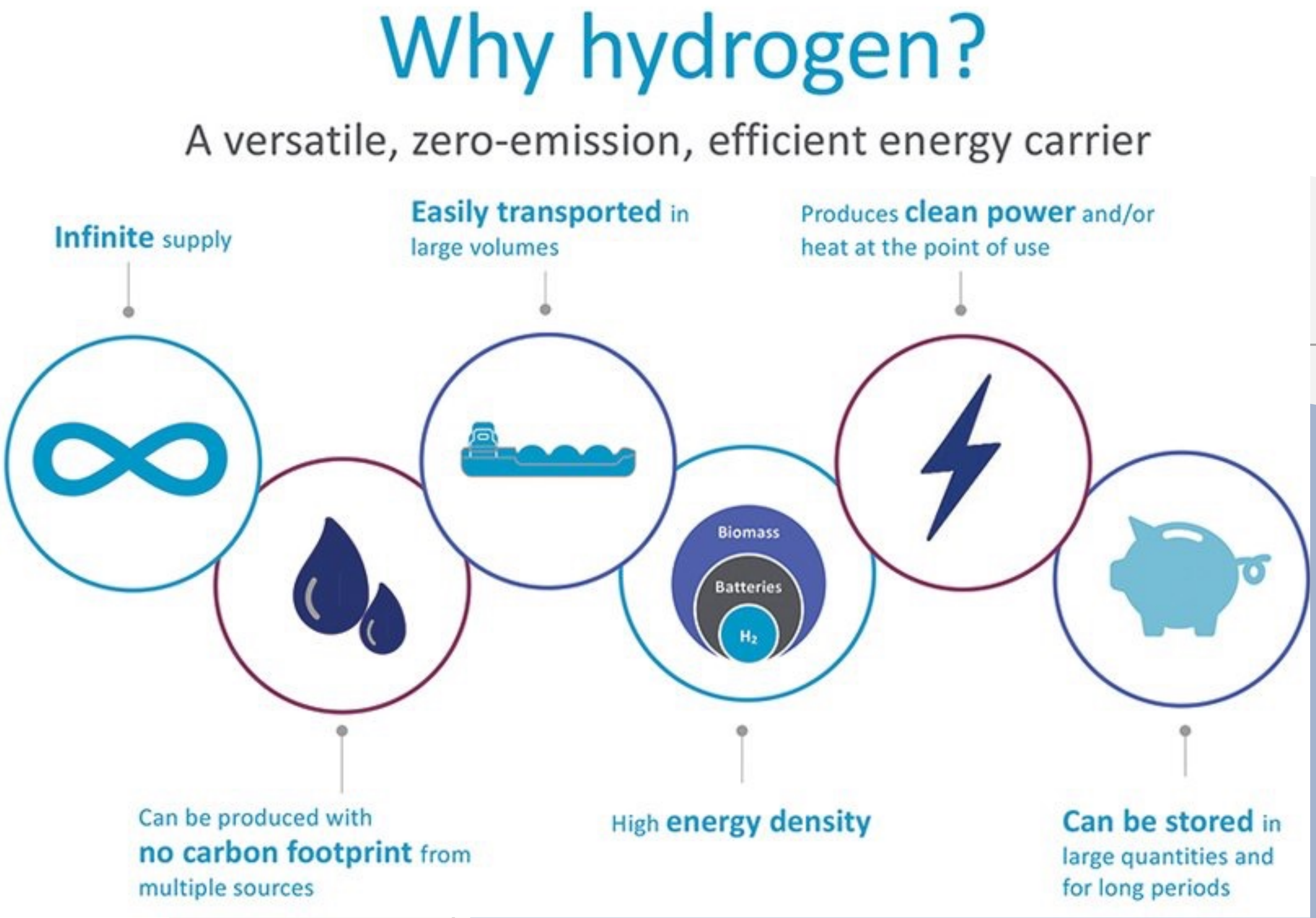




Benefits of process intensification
Business:
• Miniaturized plant size.
• Reduced CAPEX and OPEX.
• Distributed manufacturing.
• Faster transformation from research to market.
Process:
• Higher selectivity/product purity.
• Higher reaction rates.
• Improved product properties.
• Improved process safety.
• Wider processing conditions.
• Continuous processing.
Environment:
• Reduced energy usage.
• Reduced wastage.
• Reduced solvent usage.
• Smaller plants equal to less obstruction on landscape.
Responsive processing
Faster, safer, and greener processing
Sustainable processing

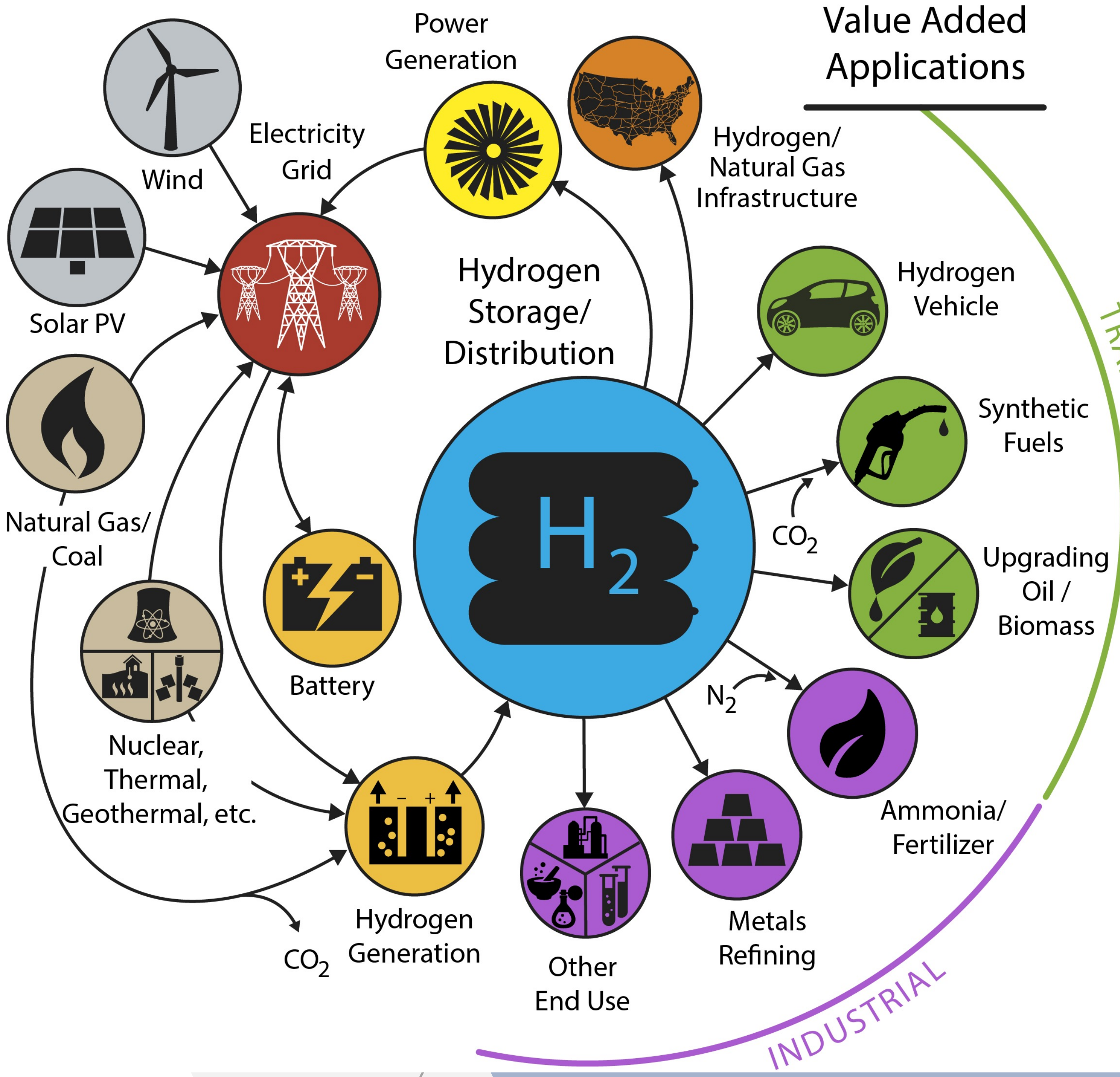

Bagaimana implementasi dari intensifikasi proses dalam proses produksi hidrogen?

Pengembangan **peralatan, metode + material** yang inovatif dan kreatif

# Mengapa $H_2$?


Why hydrogen?
A versatile, zero-emission, efficient energy carrier
Infinite supply
Easily transported in large volumes
Produces clean power and/or heat at the point of use
Biomass
Batteries
H₂
Can be produced with no carbon footprint from multiple sources
High energy density
Can be stored in large quantities and for long periods

# Aplikasi Nilai Tambah

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# Bagaimana $H_2$ memberdayakan transisi energi?

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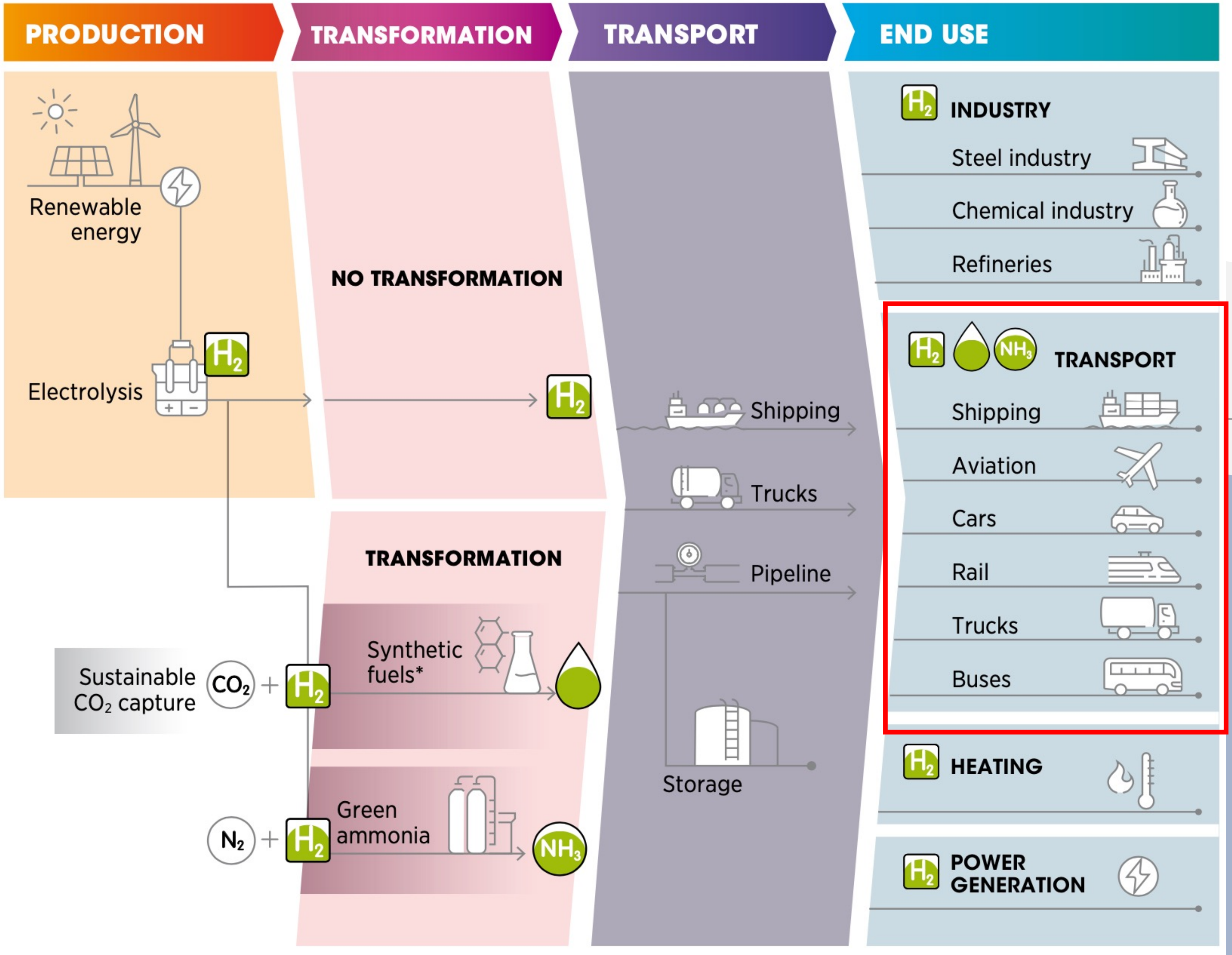


Source: IRENA.

# Berapa Besar Energi yang Diperlukan?

Kelayakan ekonomi elektrolisis air dapat diuji dengan ketersediaan energi yang bersifat ekses (**renewable**)

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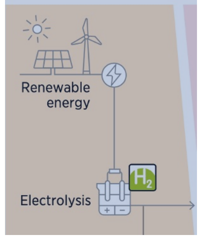
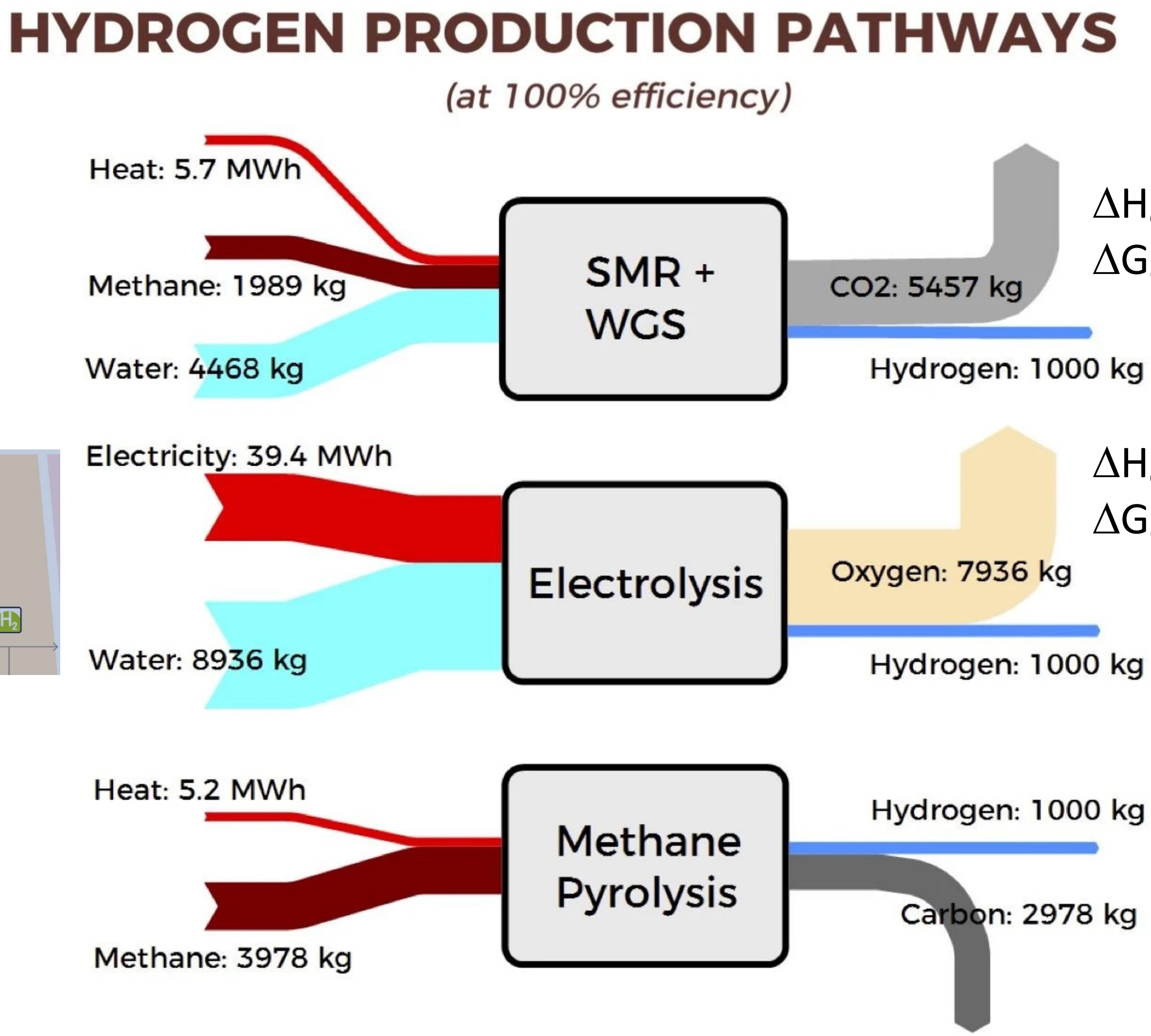



$\Delta H_o$ = +206 kJ/mol
$\Delta G_o$ = +141 kJ/mol

$\Delta H_o$ = +286 kJ/mol
$\Delta G_o$ = +237 kJ/mol

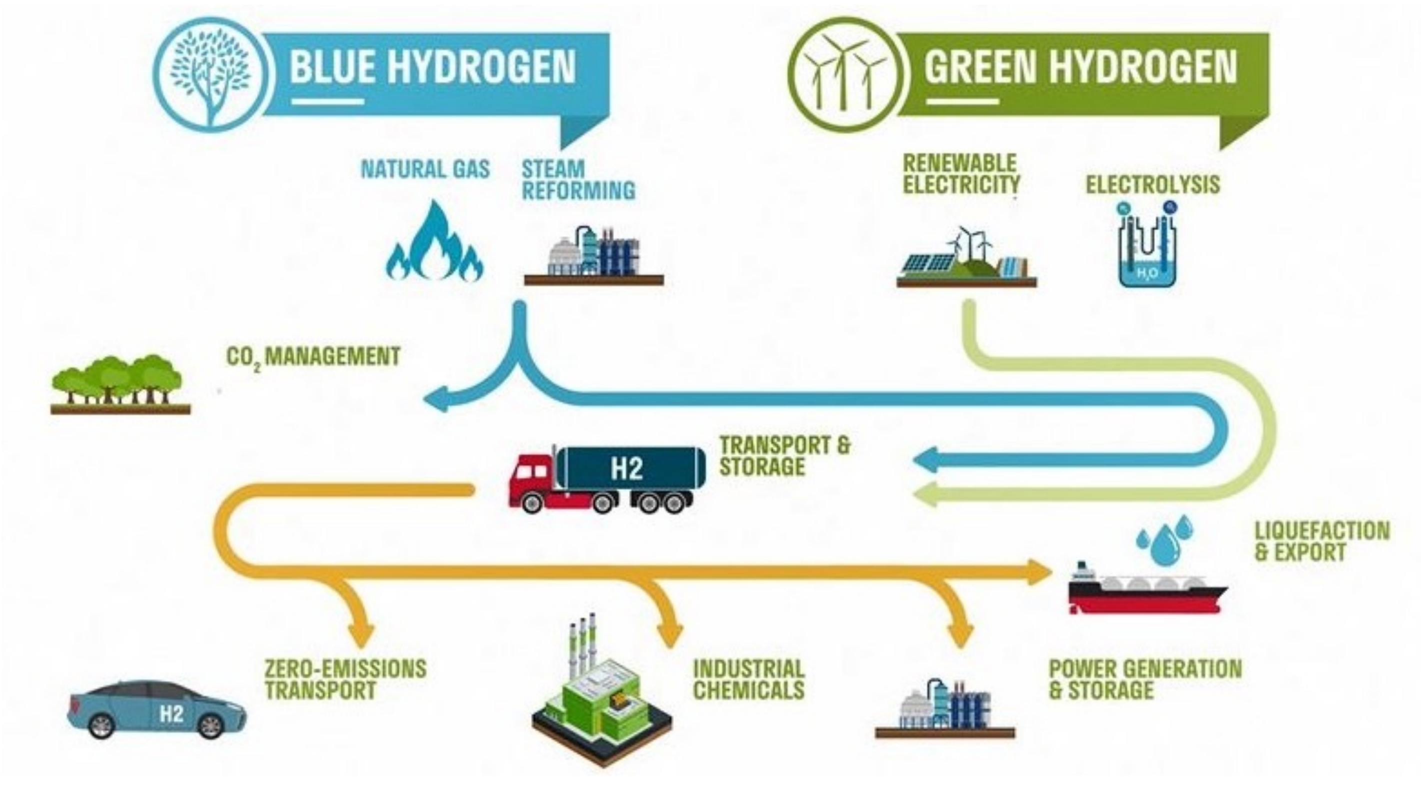
Kelayakan secara ekonomi, dampak lingkungan (termasuk sumber listrik yang digunakan), keselamatan proses

# Spektrum Warna $H_2$

| Color | GREY HYDROGEN | BLUE HYDROGEN | TURQUOISE HYDROGEN* | GREEN HYDROGEN |
|---|---|---|---|---|
| Process | SMR or gasification | SMR or gasification with carbon capture (85-95%) | Pyrolysis | Electrolysis |
| Source | Methane or coal | Methane or coal | Methane | Renewable electricity |

# Spektrum Warna $H_2$

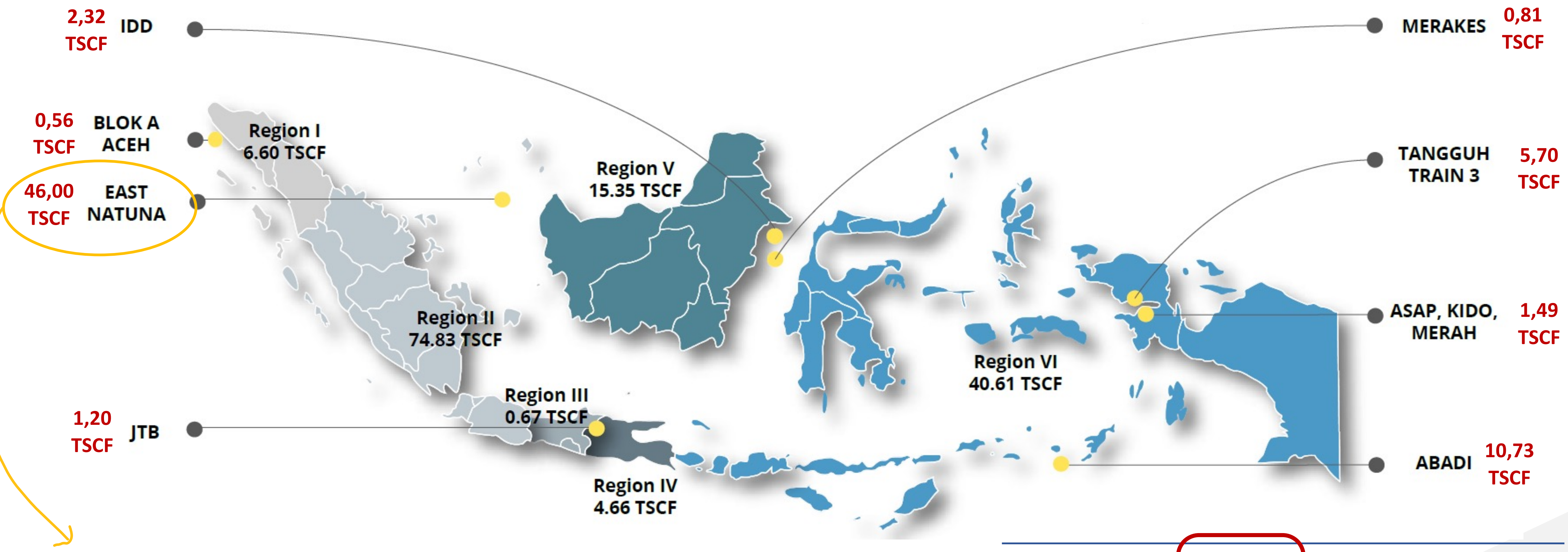

- Saat ini mayoritas $H_2$ dihasilkan dari gas alam ($CO_2$ lebih kecil) atau batubara ($CO_2$ lebih besar): **grey and blue hydrogen**



# Cadangan Gas Alam di Indonesia: Grey dan Blue $H_2$



(Sumber: Ditjen Migas dan SKK Migas, 2018)

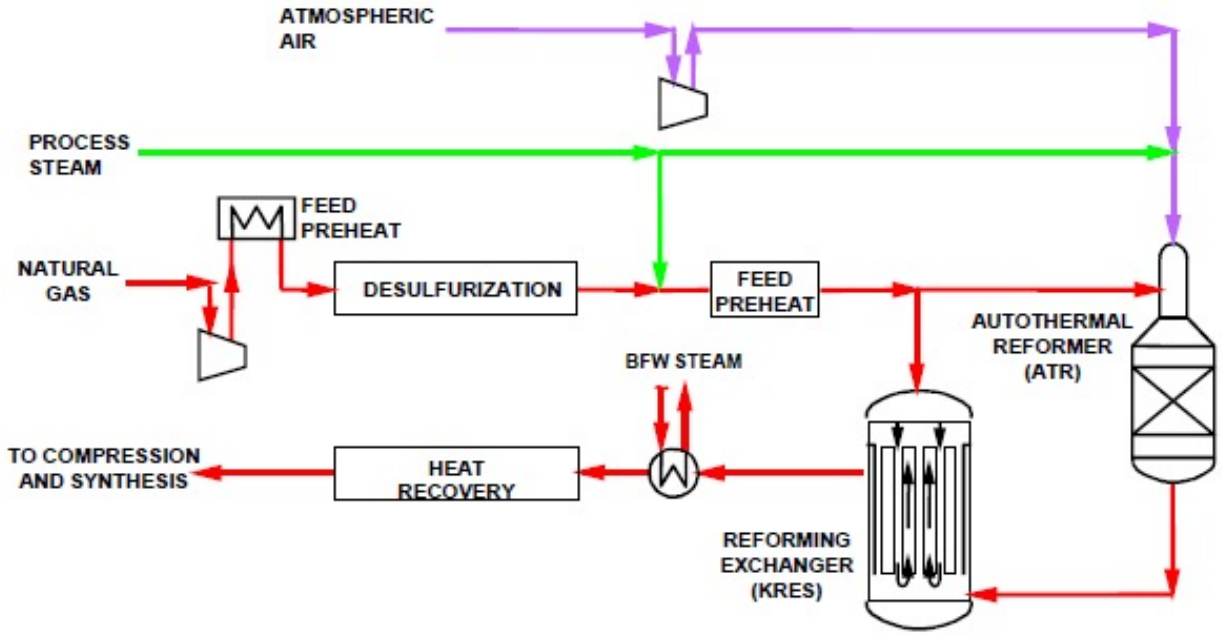



**Kepulauan Natuna** → cadangan **gas bumi terbesar di Indonesia (46 TSCF)**.
Komposisi $CO_2$ sangat tinggi sehingga pemanfaatannya masih terhambat.

| Komponen | Natuna Timur | Bontang | JTB |
|---|---|---|---|
| $CH_4$ | 28-%v | 90% | - |
| **$CO_2$** | **71-%v** | **5%** | **34%** |
| $C_{2+}$, $H_2S$ | 1-%v | 5% | - |

# Periodisasi Teknologi Reformasi

- Teknologi **steam reforming** gas alam ($CO_2$ < 10%, separated)
  - Konvensional > 50 tahun
  - Termodifikasi **Kellogg Reforming Exchanger System** (less energy, less pollution) ± 30 tahun
- Teknologi **dry** reforming gas alam ($CO_2$ > 70%, separated)
  - Natuna dan Aceh
  - *Linde Pilot Dry Reformer* di Pullach, Munich, Jerman
  - ITB: Katalis berbasis **Ni** memiliki konversi $CH_4$ per massa pusat aktif mencapai **2,5 kali lipat lebih tinggi dibandingkan katalis *steam reforming* komersial**
  - **ITB: Tri-Reforming (SMR, DRM, PO)**



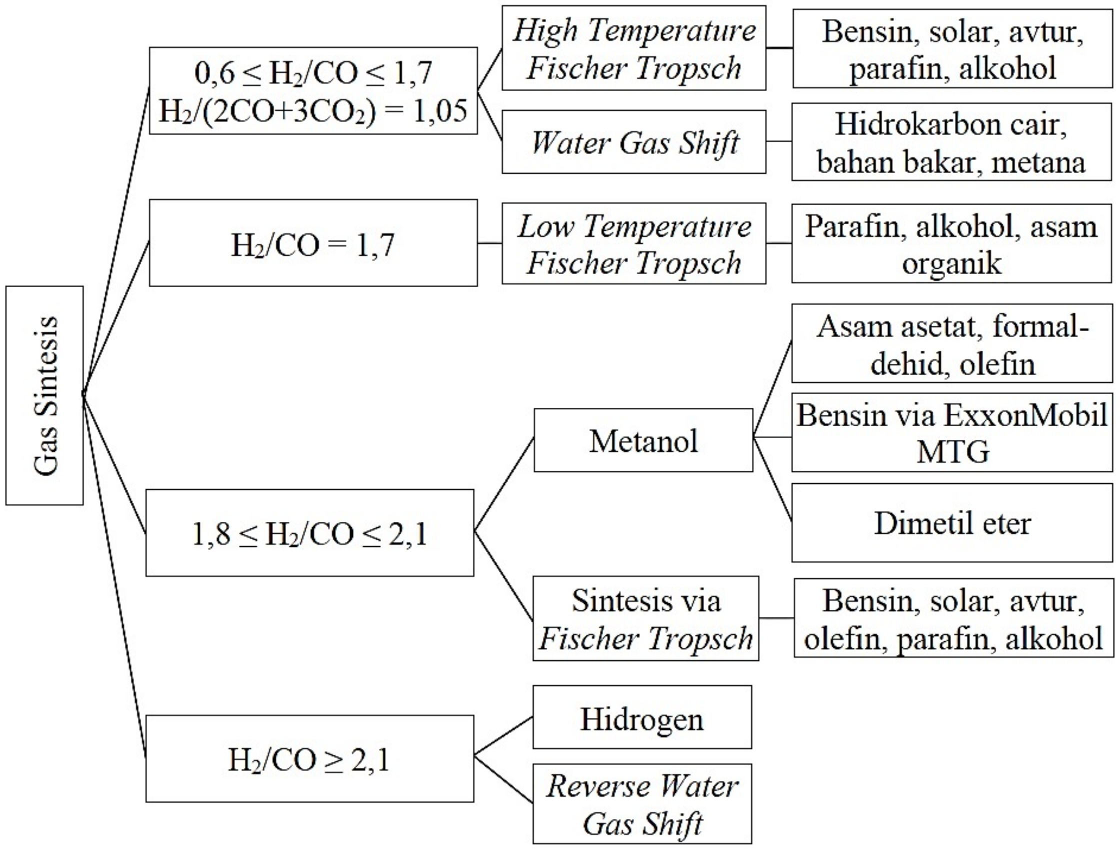

Kellogg Braun & Root (KBR)

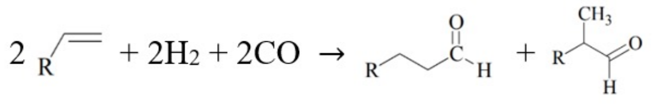
# Jenis Reformasi Metana: Grey Hydrogen

| Tipe reformasi metana | *Dry reforming* | *Steam reforming* | *Partial oxidation* |
|---|---|---|---|
| **Kondisi operasi** | 1 atm, 650-850°C<br>$CH_4$ : $CO_2$ = 1 : 1 | 3-5 atm, 700-1.000°C<br>$CH_4$ : $H_2O$= 1:1 | 100 atm, 950-1.100°C<br>$CH_4$ : $O_2$ = 2 : 1 |
| **Rasio $H_2$/CO** | 1 : 1 | 3 : 1 | 2 : 1 |
| **Keuntungan** | – Utilisasi 2 gas rumah kaca<br>– Produksi sumber energi bersih dan bahan kimia lain | – Konsentrasi produk $H_2$ lebih tinggi<br>– Efisiensi operasi tinggi | – Tingkat toleran ter-hadap sulfur tinggi<br>– Waktu kontak (reaksi) singkat |
| **Kerugian** | – Harga katalis logam mulia yang tinggi<br>– Katalis tersintering pada temperatur tinggi | – Memerlukan volume yang besar untuk emisi gas dari pembangkit uap<br>– Biaya tambahan dari alat eksternal untuk penukar panas | – Biaya tinggi untuk kebutuhan $O_2$ murni<br>– Kemungkinan ledakan dari campuran $CH_4/O_2$<br>– Kemungkinan terjadinya hotspot pada katalis |
| **Pabrik** | *Linde Pilot Dry Reformer* di Pullach dekat Munich | – *Topsoe Package $H_2$ Plants*, USA<br>– *Air Liquid Steam $CH_4$ Reformer*, Jerman | *Pearl GTL, Ras Laffan Industrial City*, Ad-Dahirah, Qatar |

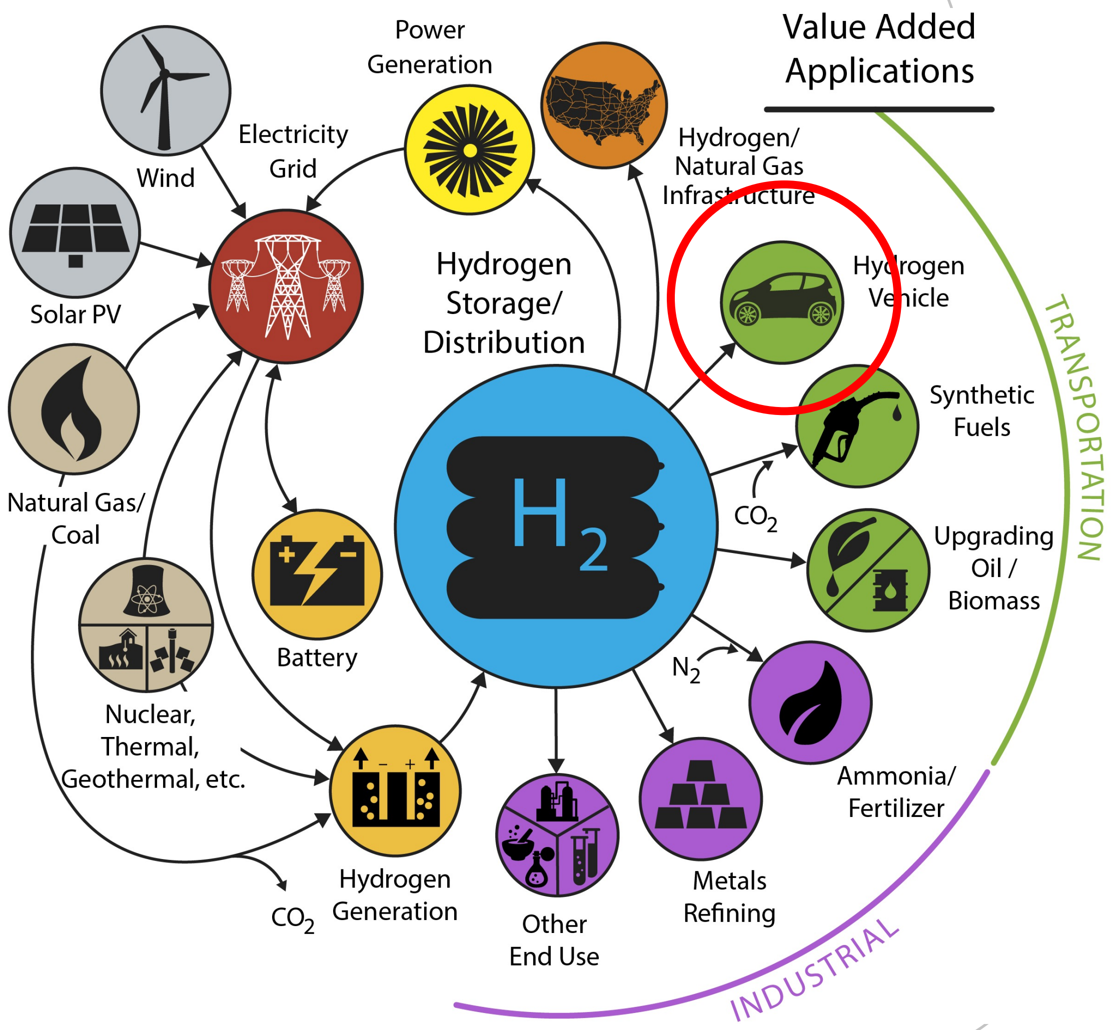
(Sumber: Abdulrasheed dkk., 2019)

## Rute konversi gas sintesis




| No. | Reaksi dengan rasio bahan baku $H_2$/CO = 1 | Produk |
|---|---|---|
| 1 | $3H_2 + 3CO \rightarrow CH_3OCH_3 + CO_2$ | Dimetil eter |
| 2 | $2H_2 + 2CO \rightarrow CH_3COOH$ | Asam asetat |
| 3 |  | Aldehid dan alkohol via sintesis oxo-alkohol |

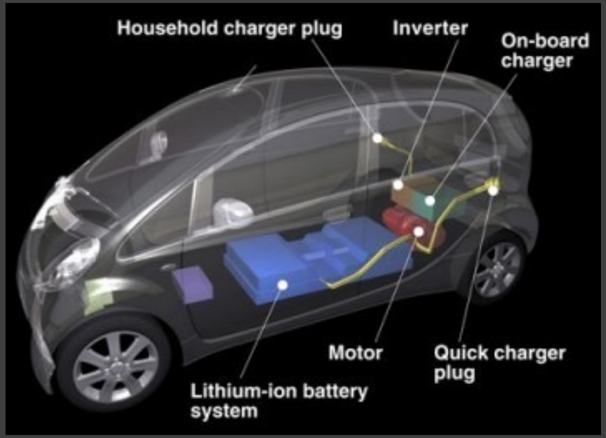
(Sumber: Balasubramanian dkk., 2018)




# Battery dan $H_2$ untuk Transportasi

## Ragam lintasan:

- Crude → BBM (base case)
- Natural gas → Listrik → **Battery**
- Wind → Listrik → **Battery**
- Natural gas (SMR, DRM) → **Hidrogen**
- Natural gas → Listrik → Elektrolisis → **Hidrogen**
- Solar PV → Listrik → Elektrolisis → **Hidrogen**





# Electric Vehicle with X - System

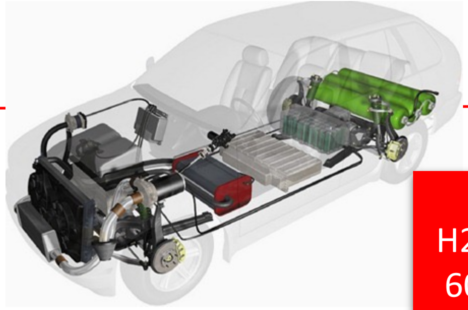
- **X = Battery system:**
  - Long charging time (3-5 h)
    - Tesla (super charging 120 kW, 20-75 min, specific station)
  - Limited distance (150-200 km)
  - Not practical, not flexible
- **X = Hydrogen** (liquified, > 600 atm)
  - High energy/cost
  - Safety issue/explosion

**Bagaimana dengan:**

- **X = Methanol** (liquid, atmosferik)
  - Microprocessor

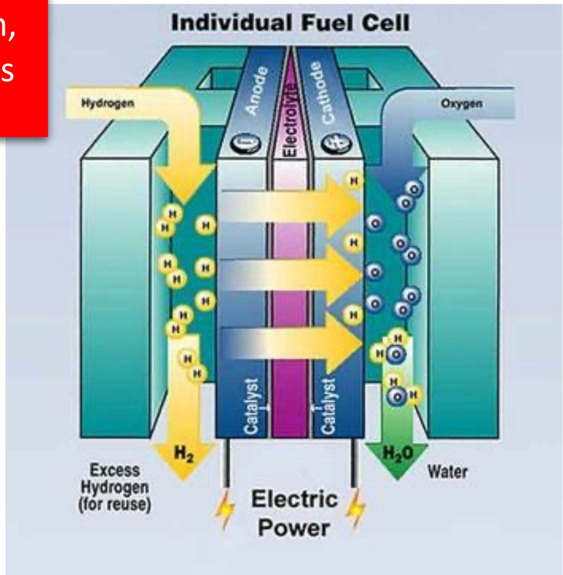
# Concept of Technology Development

Renewable Source



Clean Energy

H2 bottle, 600 atm, 50% loss




Raw Material → Methanol (L) → $H_2$, CO, $CO_2$, $N_2$ → $H_2$ (high purity) → Fuel Cell

(separation)

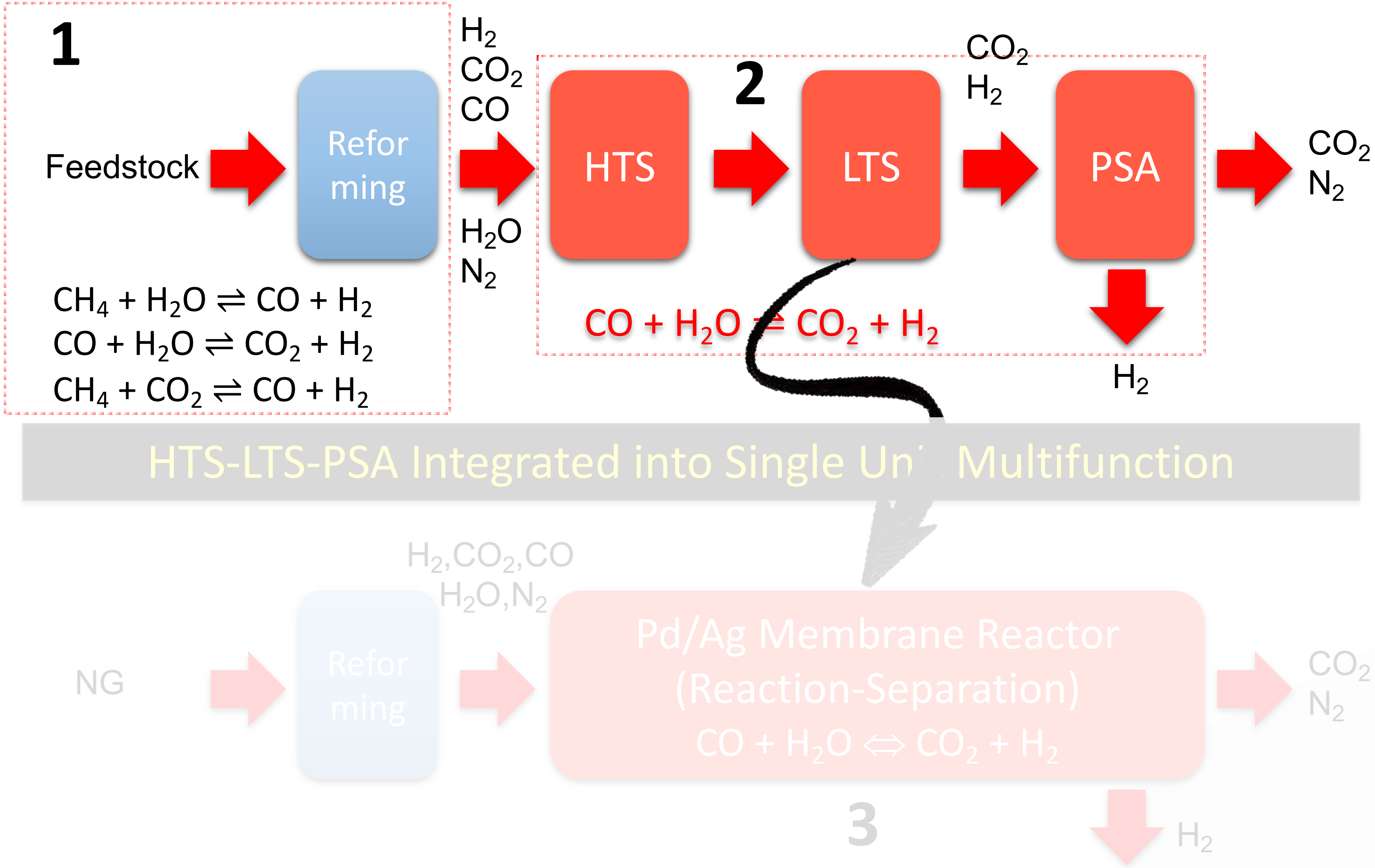
Natural gas
Coal
Biomass
$H_2O$ & CCS

CO, $CO_2$, $N_2$

The development of an automotive industry that uses the fuel cell has opened a new way for utilization of hydrogen and is becoming a key process driven by spectacular advances in fuel cell technology, better know as process intensification.

# Process Intensification via Integration

1. $CH_4:CO_2$ = 50:50
   - $CH_4:CO_2$ = 30:70
2. Catalyst:
   - Core-shell
   - Ni/MCM-41
   - $NiO/CeZrO_2$
3. Dynamic system






Feedstocks:
- Natural gas
- Methanol

HTS = High Temperature Shift
LTS = Low Temperature Shift
PSA = Pressure Swing Adsorption

# Macroreactor vs Microreactor

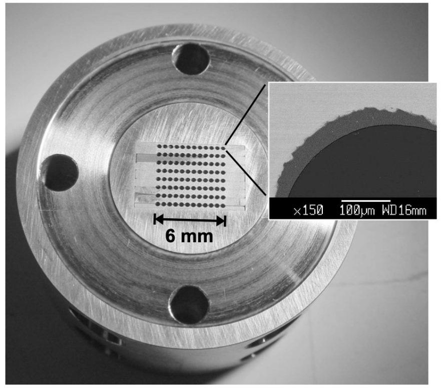



Figure 1.1: Example of a microreactor containing 96 microchannels with a diameter of 400 µm and a length of 1.5 cm. The inlay shows a detail of a single microchannel coated with a 35 µm thick catalyst layer.

Negligible mass and heat transfer limitations
Fast reaction

# Application of process intensification

## PI EXAMPLE **FINEPHARM SECTOR** – MICRO REACTOR

**Traditional technology**

Stirred Tank Reactor: the reactants are mixed in a large vessel, and the heat is removed through the jacket or a heat transfer coil (1)

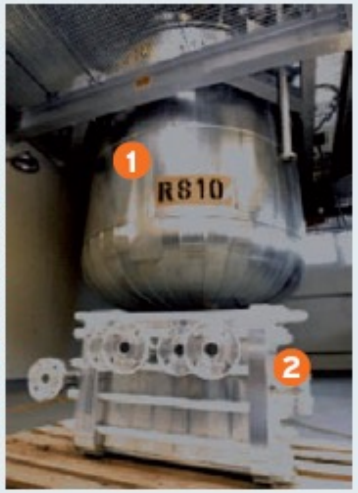
**PI technology**

Micro Reactor: the reactants are mixed, and the heat is removed through thousands of micro channels, fabricated by micromachining (2) or lithography

**Benefits**

- Equipment content 3 liters versus 10 $m^3$
- 20% higher selectivity
  20% higher material yield
- Process more reliable because continuous instead of batch
- Same capacity (1700 kg/h)

*Photo coourtesy of DSM an Borshungszentrum Karlsruhe*

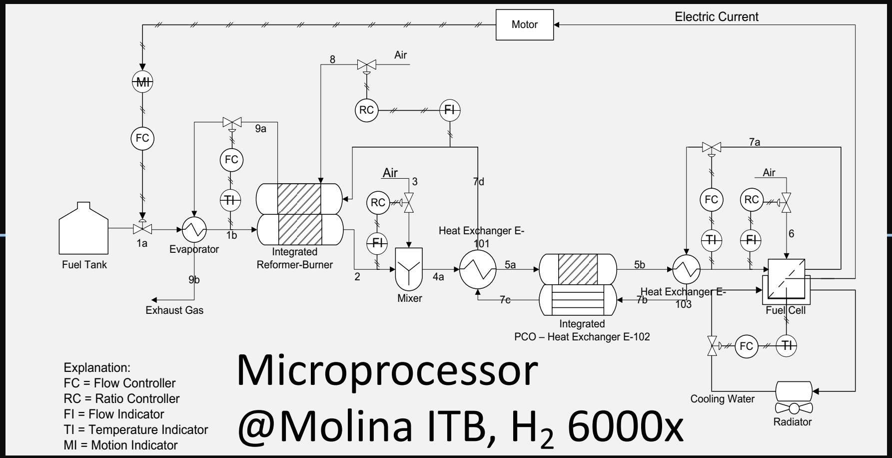


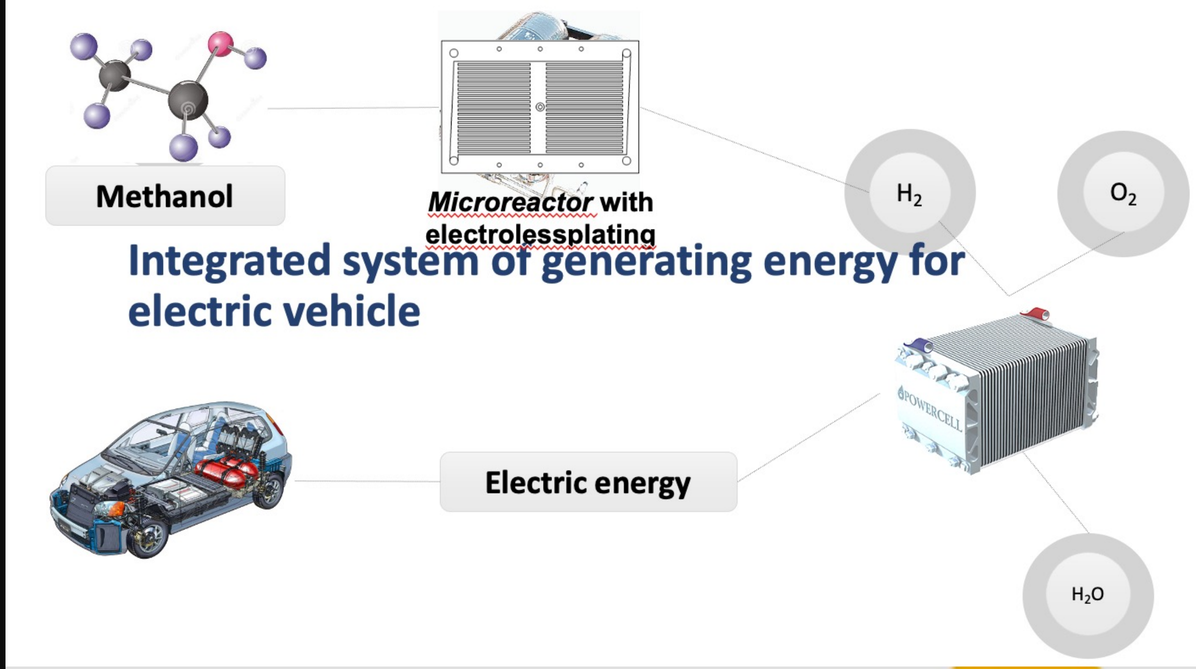


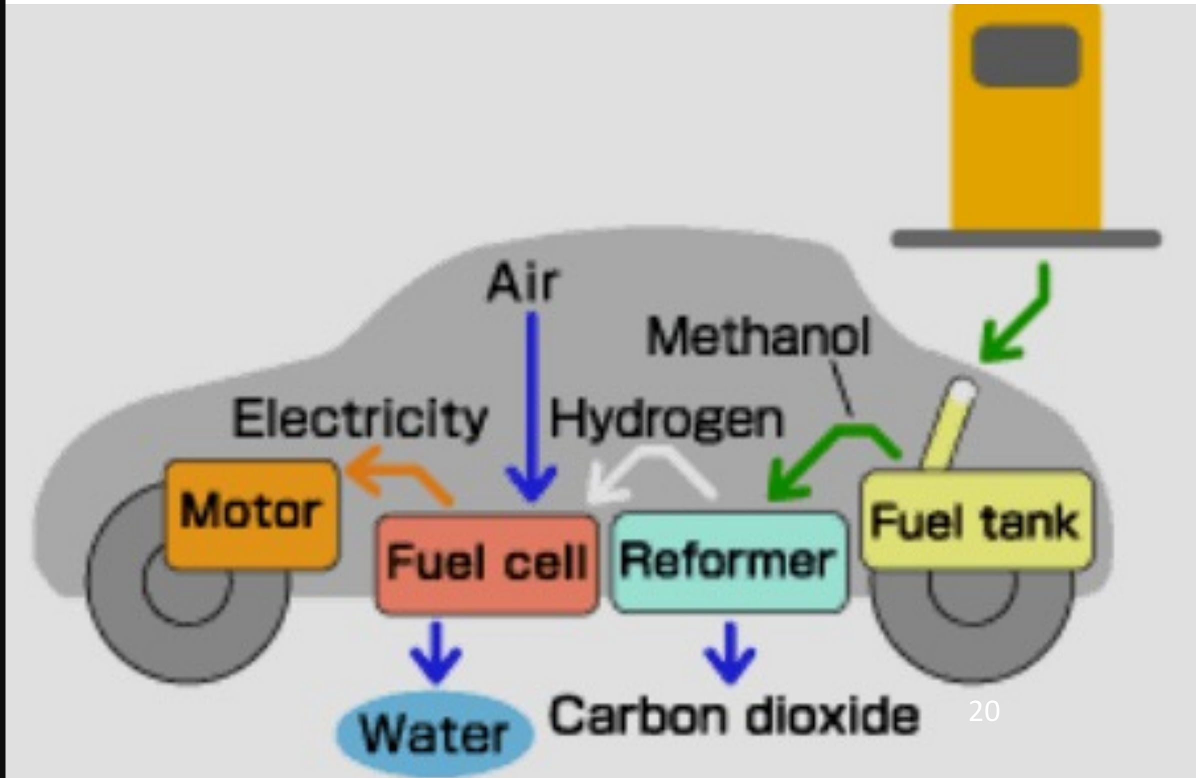
**10 $m^3$** vs **0,003 $m^3$** → same capacity

# Principle of Methanol Conversion to $H_2$

- **Advantages**:
  - Atmospheric fuel tank
  - No waiting time to refueling
  - Long trip distance
- **Disadvantages**:
  - $CO_2$ production (exc from biomass)



# Sistem Penyedia Energi

**Energy Management System** (TF)

**Fuel Processor + Fuel Cell**

(TK)

**Battery**

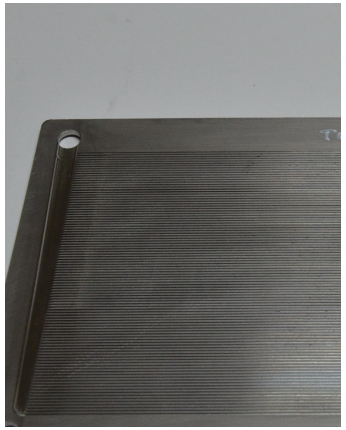
(KI+FI)

**Ultracapacitor**

(EL)

Main Energy Supplier

Energy Storage



Microreactor for $H_2$ production

# Konsep Peta Jalan Produksi $H_2$

FS & Demonstration → $H_2$ refueling & Infrastructure → Enhancement → Cost Reduction → Competitive

Now | 2040 | 2050 | 2090

**Grey s.d. 2040**
- Natural gas, coal
- Polluting
- 10 kg $CO_2$ / 1 kg $H_2$
- Termurah

? GW

**Blue**
- Natural gas, coal
- Polluting
- $CO_2$ capture
- Belum terbukti, mahal

? GW

**Green**
- Menggunakan RE
- Belum ekonomis
- Potensi besar untuk dekarbonisasi + metanasi

? GW

**Turquoise**
- Menggunakan $CH_4$
- Masih baru, sedikit riset
- Alternatif karbon rendah

? GW

**Pink**
- Menggunakan energi nuklir

? GW

Metanasi via green $H_2$
Fotokatalitik

Steps
1 - R & D Programs
2 – Vision Document
3 - Roadmap
4 - Strategy
5 – Action Plan

# Penutup: Peran Intensifikasi Proses

| Pengembangan kreatif dan inovatif **Peralatan Proses** | Pengembangan kreatif dan inovatif **Metode Proses** | Pengembangan kreatif dan inovatif **Material** |
|---|---|---|
| • Microreactor: produktivitas **$H_2$** sangat tinggi<br>• Reforming exchanger (integrasi reaktor dan penukar panas): less energy and pollution for **$H_2$** production | • Tri-Reforming: optimasi produksi **$H_2$**<br>• Utilisasi ekses energi/renewable energy: optimasi produksi **$H_2$** | • Nanocatalyst: konversi gas alam menjadi **$H_2$**<br>• Thin Pd-based membrane wall: untuk pemisahan **$H_2$** |

# Terima Kasih