Welcome to San Francisco, California!

Figure 1: CO₂ emissions from international shipping under IMO’s initial GHG strategy (blue and green) vs. BAU (black), with cumulative emissions 2015 through 2075.
Goal:
Discuss technology pathways and barriers to zero-emission international shipping to help identify related research, development, and demonstration needs.
Output:

A workshop summary document that can inform ongoing discussions at the International Maritime Organization on funding for zero- and low-carbon technologies for international shipping.
### Day 1 Agenda (1/2)

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00-9:30</td>
<td>Registration, coffee/tea and a light breakfast</td>
</tr>
<tr>
<td>9:30-9:45</td>
<td>Review of agenda and workshop goals (Dan Rutherford, ICCT)</td>
</tr>
<tr>
<td>9:45-10:00</td>
<td>Setting the stage: A proposal to establish a Board to accelerate RDD&amp;D of ZEVs for international shipping (Bryan Wood-Thomas, WSC)</td>
</tr>
<tr>
<td>10:00-11:00</td>
<td>Hydrogen, fuel cells, and batteries</td>
</tr>
<tr>
<td></td>
<td>• Hydrogen co-combustion in ICE (Roy Campe, CMB)</td>
</tr>
<tr>
<td></td>
<td>• Electric and H₂ fuel cell ships in China (Guiyang Ling, Commission Office of Shanghai Port)</td>
</tr>
<tr>
<td>11:00-11:15</td>
<td>Coffee/Tea Break</td>
</tr>
<tr>
<td>11:15-11:45</td>
<td>Wind-assist: opportunities for existing and new ships</td>
</tr>
<tr>
<td></td>
<td>• Wind-assist technologies (Jay Gardner, Wind+Wing)</td>
</tr>
<tr>
<td>11:45-12:00</td>
<td>Group photo</td>
</tr>
<tr>
<td>12:00-1:00</td>
<td>Lunch (provided)</td>
</tr>
</tbody>
</table>
# Day 1 Agenda (2/2)

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00-2:00</td>
<td><strong>ZEV concepts</strong></td>
</tr>
<tr>
<td></td>
<td>• Zero fuel ship concept (Madadh MacLaine, ZESTAs)</td>
</tr>
<tr>
<td></td>
<td>• The Zero-V: Feasibility of an LH₂ research vessel (Lennie Klebanoff, Sandia)</td>
</tr>
<tr>
<td>2:00-3:00</td>
<td><strong>Longer-term low/zero emission energy sources for the shipping sector</strong></td>
</tr>
<tr>
<td></td>
<td>• Green ammonia (Tim Scarbrough, Ricardo)</td>
</tr>
<tr>
<td></td>
<td>• Utilization of H₂ and ammonia as marine fuel (Yoichi Niki, NMRI)</td>
</tr>
<tr>
<td>3:00-3:20</td>
<td><strong>Coffee/tea break</strong></td>
</tr>
<tr>
<td>3:20-4:30</td>
<td><strong>Potential ZEV pathways for international shipping</strong></td>
</tr>
<tr>
<td></td>
<td>• Scaling batteries and fuel cells to larger ships (Joe Pratt, Golden Gate ZEM)</td>
</tr>
<tr>
<td></td>
<td>• ZEV Roadmap to 2050 (Shinichi Hanayama, Class NK)</td>
</tr>
<tr>
<td>4:30-5:00</td>
<td><strong>Day 1 Closing remarks</strong> (Dan Rutherford, ICCT)</td>
</tr>
<tr>
<td>5:00</td>
<td><strong>Adjourn for the day</strong></td>
</tr>
<tr>
<td>6:00</td>
<td><strong>Group Dinner</strong> (complimentary)</td>
</tr>
<tr>
<td></td>
<td>Top of the Mark (19th floor)</td>
</tr>
</tbody>
</table>
# Day 2 Agenda (1/2)

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00-9:30</td>
<td>Coffee/tea and a light breakfast</td>
</tr>
<tr>
<td>9:30-10:00</td>
<td>Recap of Day 1 and brainstorming session on any technologies we haven’t discussed (Dan Rutherford, ICCT)</td>
</tr>
<tr>
<td>10:00-11:00</td>
<td>Panel Discussion: What are key barriers to deploying low/zero emissions fuels and technologies in international shipping? (B. Wood-Thomas, WSC; F. Abbasov T&amp;E; J. Bradshaw, ICS; K. Iwaki, MLIT; J. Motlow, GGZEM; Madadh MacLaine, ZESTAs; Bryan Comer, ICCT, moderator)</td>
</tr>
<tr>
<td>11:00-12:00</td>
<td>Breakout group discussion, part 1</td>
</tr>
<tr>
<td></td>
<td>Taking into account the key barriers, what advances are needed to deploy each 1) fuel and 2) propulsion technology (e.g., engines/fuel cells) in international shipping by 2030?</td>
</tr>
<tr>
<td>12:00-1:00</td>
<td>Lunch (provided)</td>
</tr>
</tbody>
</table>
Day 2 Agenda (2/2)

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
</table>
| 1:00-2:30 | **Breakout group discussion, part 2**  
What research, development, and demonstration activities could support these advances for 1) fuels and 2) propulsion technologies (e.g., engines/fuel cells)? |
| 2:30-2:50 | **Coffee/tea break** (facilitators collate breakout group responses) |
| 2:50-3:45 | **Review of collated breakout group discussions and additional comments from the full group**  
(Bryan Comer and Dan Rutherford, ICCT, Facilitators) |
| 3:45-4:00 | **Closing Remarks** (Dan Rutherford, ICCT) |
| 4:00 | **Adjourn** |
| 5:00 | **Happy Hour**  
Top of the Mark (19th floor) |
Logistics

- Restrooms: immediately outside of the room
- WiFi: for hotel guests, you will have access already; for others, please let someone from ICCT know if you need access and we can arrange for it.
- Evacuation routes: out and down the large staircase.
- Chatham House Rules
- Skoll Foundation Videography 2nd Day
Day 1 Closing Remarks

Dan Rutherford, PhD
Director, ICCT Marine & Aviation Programs

ICCT Technical Workshop on Zero Emission Vessel Technology
InterContinental Mark Hopkins Hotel
San Francisco, California, USA
9-10 July 2019
Key takeaways (1)

- **High level**
  - IMO has a target for complete decarbonization but shipping is not currently receiving enough investment to get to a low/zero C future.
  - Regional demonstration/deployment projects will be needed in addition to IMO policies.
  - Air quality, fuel costs, and potentially carbon pricing as drivers for ZEV technologies.
  - A systems approach with broad expertise is valuable to combine innovations into a viable prototype (e.g. diesel-FC-battery system trialed by NMRI).
  - IMO GHG strategy implies a new frame: decarbonization a given, so how do ZEV fuels/technologies compare to one another rather than to incumbent fossil fuel technologies?

- **Barriers to ZEV technologies**
  - Cost competitiveness—major TBD.
  - Reliability/availability.
  - Experience (including end user acceptability).
  - Energy storage volume for larger transoceanic vessels.

- **Determinants for appropriate technologies** include engine power, energy demand, range, duty cycle (“small and fast”) and retrofit capabilities.
Key takeaways (2)

- **Fuel observations**
  - “Electric propulsion is here to stay” and may be an important application for certain ship types – short sea shipping, ferries, tugs, etc.
  - E-fuels plus hydrogen as the “last fuel standing” for transoceanic shipping. Carrier could be H₂, ammonia, methanol, DME, even bio or syn-LNG but each have tradeoffs.
  - How to produce fuels does matter for GHGs: Fossil NG liquid hydrogen about 10% higher than diesel, renewably generated has about 90% reductions

- **Technology pathways**
  - ICE (H₂ or green ammonia), starting as dual fuel and maybe A/E, as a potential platform to scale up synthetics and address the chicken-and-egg problem
  - Green ammonia as a chemical already traded, generated, widely exported, more easily stored than H₂. Watch for N₂O.

- **Other partial zero emission technologies**
  - Wind assist as potential supportive technology: useful to facilitate secondary renewables with higher cost/lower energy density, futureproof vessels
  - Advanced ship design may be important for newbuild ships: anti-drag, anti-friction hulls; air cavity friction reduction, etc.
Co-benefits
- Instant torque, no noise, no vibration, no exhaust emissions, no spills, lower fuel weights, maintenance savings on transmissions, etc.
- Renewable fuel production as a new business opportunity for emerging economies
- Pop up market/instant scaling of LH$_2$ production through shipping applications.

Other ideas
- Idea of “innovation gaps” that need to be bridged to make the shipping energy transition.
- Cargo of today may not be the cargo of tomorrow
- AQ and efficiency targets imply their own 2030 technology solutions that may impact roadmaps for 2050 climate solutions
- Vessel displacement as a proxy metric to determine appropriate fuels
- Hybrid oil pumps!
Logistics for tonight and tomorrow

- **Dinner Tonight**
  - Top of the Mark Restaurant (19th Floor)
  - 6:00 p.m. sharp for food, drinks from 5:30 if you like
  - Free for workshop participants

- **Tomorrow**
  - 9:00 a.m. Coffee/tea light breakfast
  - 9:30 a.m. start time → any missing technologies?
  - Videography
  - Discussion-focused
  - Adjourn by 4:00 p.m. followed by Happy Hour at the Top of the Mark
Recap of Day 1

Dan Rutherford, PhD
Director, ICCT Marine & Aviation Programs

ICCT Technical Workshop on Zero Emission Vessel Technology
InterContinental Mark Hopkins Hotel
San Francisco, California, USA
9-10 July 2019
Key takeaways (1)

- **High level**
  - IMO has a target for complete decarbonization but shipping is not currently receiving enough investment to get to a low/zero C future.
  - Regional demonstration/deployment projects will be needed in addition to IMO policies.
  - Air quality, fuel costs, and potentially carbon pricing as drivers for ZEV technologies.
  - A systems approach with broad expertise is valuable to combine innovations into a viable prototype (e.g. diesel-FC-battery system trialed by NMRI).
  - IMO GHG strategy implies a new frame: decarbonization a given, so how do ZEV fuels/technologies compare to one another rather than to incumbent fossil fuel technologies?

- **Barriers to ZEV technologies**
  - Cost competitiveness—major TBD.
  - Reliability/availability.
  - Experience (including end user acceptability).
  - Energy storage volume for larger transoceanic vessels.

- **Determinants for appropriate technologies** include engine power, energy demand, range, duty cycle (“small and fast”) and retrofit capabilities.
Fuel observations
- “Electric propulsion is here to stay” and may be an important application for certain ship types – short sea shipping, ferries, tugs, etc.
- E-fuels plus hydrogen as the “last fuel standing” for transoceanic shipping. Carrier could be H₂, ammonia, methanol, DME, even bio or syn-LNG but each have tradeoffs.
- How to produce fuels does matter for GHGs: Fossil NG liquid hydrogen about 10% higher than diesel, renewably generated has about 90% reductions

Technology pathways
- ICE (H₂ or green ammonia), starting as dual fuel and maybe A/E, as a potential platform to scale up synthetics and address the chicken-and-egg problem
- Green ammonia as a chemical already traded, generated, widely exported, more easily stored than H₂. Watch for N₂O.

Other partial zero emission technologies
- Wind assist as potential supportive technology: useful to facilitate secondary renewables with higher cost/lower energy density, futureproof vessels
- Advanced ship design may be important for newbuild ships: anti-drag, anti-friction hulls; air cavity friction reduction, etc.
Key takeaways (3)

- **Co-benefits**
  - Instant torque, no noise, no vibration, no exhaust emissions, no spills, lower fuel weights, maintenance savings on transmissions, etc.
  - Renewable fuel production as a new business opportunity for emerging economies
  - Pop up market/instant scaling of LH$_2$ production through shipping applications.

- **Other ideas**
  - Idea of “innovation gaps” that need to be bridged to make the shipping energy transition.
  - Cargo of today may not be the cargo of tomorrow
  - AQ and efficiency targets imply their own 2030 technology solutions that may impact roadmaps for 2050 climate solutions
  - Vessel displacement as a proxy metric to determine appropriate fuels
  - Hybrid oil pumps!
# Technologies we’ve discussed

<table>
<thead>
<tr>
<th>Propulsion Tech [energy converter]</th>
<th>Fuel (Energy carrier)</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure batteries/motor</td>
<td>Electricity/batteries</td>
<td>Advanced hull design</td>
</tr>
<tr>
<td>Fuel Cells</td>
<td>Hydrogen, including LH₂</td>
<td>Energy recovery</td>
</tr>
<tr>
<td>ICE/gas turbine (diesel + Otto)</td>
<td>Ammonia</td>
<td>On-board CC + Storage</td>
</tr>
<tr>
<td>Wind Power/Assist</td>
<td>Methanol, including e-</td>
<td>Reforming</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Bio and synthetic LNG</td>
<td>Hybrid electronics/systems</td>
</tr>
<tr>
<td>Capacitor*</td>
<td>LNG</td>
<td>Advanced systems integration</td>
</tr>
<tr>
<td></td>
<td>DME</td>
<td>Solar</td>
</tr>
<tr>
<td></td>
<td>Biofuel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nuclear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Synthetic MGO</td>
<td></td>
</tr>
</tbody>
</table>
Panel Discussion

Moderated by: Bryan Comer, PhD
Senior Researcher, ICCT Marine Program

ICCT Technical Workshop on Zero Emission Vessel Technology
InterContinental Mark Hopkins Hotel
San Francisco, California, USA
9-10 July 2019
Panelists

- Bryan Wood-Thomas, Vice President of Environmental Policy, World Shipping Council
- Madadh MacLaine, Secretary General of Zero Emission Ship Technology Association
- Faig Abbasov, Shipping Manager, Transport & Environment
- John Bradshaw, Technical Director, International Chamber of Shipping
- Kohei Iwaki, Director of Environmental Policy, Maritime Bureau of Japan’s Ministry of Land, Infrastructure, Transportation, and Tourism
- John Motlow, Vice President of Marketing & Strategy, Golden Gate Zero Emission Marine
What are key barriers to deploying low/zero emissions fuels and technologies in international shipping?
Breakout Group Discussions

Moderated by:

Dan Rutherford, PhD, Director, ICCT Marine & Aviation Programs and
Bryan Comer, PhD, Senior Researcher, ICCT Marine Program

ICCT Technical Workshop on Zero Emission Vessel Technology
InterContinental Mark Hopkins Hotel
San Francisco, California, USA
9-10 July 2019
Part 1, focused on “advances”

Guiding question:

- Taking into account the key barriers, what **advances** are needed to deploy each 1) fuel and 2) propulsion technology (e.g., engines/fuel cells) in international shipping by 2030?
Part 2, focused on “activities”

- Guiding question:
  - What research, development, and demonstration activities could support these advances for 1) fuels and 2) propulsion technologies (e.g., engines/fuel cells)?
Closing Remarks

Dan Rutherford, PhD
Director, ICCT Marine & Aviation Programs

ICCT Technical Workshop on Zero Emission Vessel Technology
InterContinental Mark Hopkins Hotel
San Francisco, California, USA
9-10 July 2019
## Technologies we’ve discussed

<table>
<thead>
<tr>
<th>Propulsion Tech (energy converter)</th>
<th>Fuel (Energy carrier)</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure batteries/motor</td>
<td>Electricity/batteries</td>
<td>Advanced hull design</td>
</tr>
<tr>
<td>Fuel Cells</td>
<td>Hydrogen, including LH$_2$</td>
<td>Energy recovery</td>
</tr>
<tr>
<td>ICE/gas turbine (diesel + Otto)</td>
<td>Ammonia</td>
<td>On-board CC + Storage</td>
</tr>
<tr>
<td>Wind Power/Assist</td>
<td>Methanol, including e-</td>
<td>Reformating</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Bio and synthetic LNG</td>
<td>Hybrid electronics/systems</td>
</tr>
<tr>
<td>Capacitor*</td>
<td>LNG</td>
<td>Advanced systems integration</td>
</tr>
<tr>
<td></td>
<td>DME</td>
<td>Solar</td>
</tr>
<tr>
<td></td>
<td>Biofuel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nuclear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Synthetic MGO</td>
<td></td>
</tr>
</tbody>
</table>
ICCT will create a workshop webpage on its website to host all of the workshop materials, including the agenda, presentations, and a workshop summary document.

Workshop summary document will be circulated to participants for comment before publication.

Expect an email from the ICCT with the workshop summary document for review in the next several weeks.
Logistics for tonight

- Happy Hour
  - Top of the Mark Restaurant (19th Floor)
  - First round on us from 5 p.m.
Thank you!

Thanks to:

The presenters
The panelists
Jessica and Bryan
The InterContinental Mark Hopkins and its Staff
The Heising-Simons and Skoll Foundations
And most of all, you, the participants!

Questions/Comments:

bryan.comer@theicct.org or dan@theicct.org